ASME BPE-2024

(Revision of ASME BPE-2022)

Bioprocessing Equipment

AN INTERNATIONAL STANDARD

The American Society of Mechanical Engineers

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The American Society of Mechanical Engineers
Two Park Avenue • New York, NY • 10016 USA

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The next edition of this International Standard is scheduled for publication in 2026. This International Standard will become effective 6 months after the Date of Issuance.

This international code or standard was developed under procedures accredited as meeting the criteria for American National Standards and it is an American National Standard. The standards committee that approved the code or standard was balanced to ensure that individuals from competent and concerned interests had an opportunity to participate. The proposed code or standard was made available for public review and comment, which provided an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

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The endnotes and preamble in this document (if any) are part of this American National Standard.

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ASME Single Certification Mark

The American Society of Mechanical Engineers
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FOREWORD

At the 1988 American Society of Mechanical Engineers (ASME) Winter Annual Meeting (WAM), many individuals expressed interest in developing standards for the design of equipment and components for use in the biopharmaceutical industry. As a result of this interest, the ASME Council on Codes and Standards (CCS) was petitioned to approve this as a project. The initial scope was approved by the CCS on June 20, 1989, with a directive to the Board on Pressure Technology to initiate this project with the following initial scope:

> This standard is intended for design, materials, construction, inspection, and testing of vessels, piping, and related accessories such as pumps, valves, and fittings for use in the biopharmaceutical industry. The rules provide for the adoption of other ASME and related national standards, and when so referenced become part of the standard.

(a) At the 1989 WAM, an ad hoc committee was formed to assess the need to develop further the scope and action plan. The committee met in 1990 and there was consensus concerning the need to develop standards that would meet the requirements of operational bioprocessing, including

(1) the need for equipment designs that are both cleanable and sterilizable
(2) the need for special emphasis on the quality of weld surfaces once the required strength is present
(3) the need for standardized definitions that can be used by materials suppliers, designers/fabricators, and users
(4) the need to integrate existing standards covering vessels, piping, appurtenances, and other equipment necessary for the biopharmaceutical industry without infringing on the scopes of those standards

(b) The BPE Main Committee was structured with six functioning subcommittees and an executive committee comprising the main committee chair and the subcommittee chairs. The initial subcommittees were

(1) General Requirements
(2) Design Relating to Sterility and Cleanability of Equipment
(3) Dimensions and Tolerances
(4) Material Joining
(5) Surface Finishes
(6) Seals

(c) Throughout the development of the Standard, close liaison was made with the European Committee for Standardization (CEN), the American Society for Testing and Materials (ASTM), and the 3-A Dairy Standards. The purpose was to develop an ASME standard that would be distinctive, germane, and not in conflict with other industry standards. Wherever possible, the Committee strove to reference existing standards that are applicable to biopharmaceutical equipment design and fabrication.

(d) This Standard represents the work of the BPE Standards Committee, and this edition includes the following:

Chapter 1, Introduction, Scope, and General Requirements
- Part GR, General Requirements

Chapter 2, Certification
- Part CR, Certification Requirements

Chapter 3, Materials
- Part MM, Metallic Materials
- Part PM, Polymeric and Other Nonmetallic Materials

Chapter 4, Design for Multiuse
- Part SD, Systems Design for Multiuse

Chapter 5, Process Components for Multiuse
- Part DT, Dimensions and Tolerances for Process Components
- Part PI, Process Instrumentation for Multiuse
- Part MC, Components for Multiuse

Chapter 6, Fabrication, Assembly, and Erection for Multiuse
Part MJ, Materials Joining for Multiuse
Part SF, Process Contact Surface Finishes for Multiuse
Chapter 7, Design for Single-Use
Part SU, Systems Design for Single-Use
Chapter 8, Process Components for Single-Use
Part SC, Components for Single-Use
Chapter 9, Fabrication, Assembly, and Erection for Single-Use
Part SJ, Joining Methods for Single-Use
Part SI, Single-Use Process Instrumentation

The first edition of this Standard was approved as an American National Standard on May 20, 1997. This edition was approved by the American National Standards Institute (ANSI) on April 5, 2024.

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In addition, the committee may post errata on the committee web page. Errata become effective on the date posted. Users can register on the committee web page to receive e-mail notifications of posted errata.

This Standard is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number, the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

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(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Standard

(4) to permit the use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Standard.

(c) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:

(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Standard and the paragraph, figure, or table number

(4) the editions of the Standard to which the proposed case applies

(d) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Approved cases are posted on the committee web page.

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ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

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Committee Meetings. The BPE Standards Committee regularly holds meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the committee. Information on future committee meetings can be found on the committee web page at https://go.asme.org/BPEcommittee.

ASME BPE-2024
SUMMARY OF CHANGES

Following approval by the ASME BPE Committee and ASME, and after public review, ASME BPE-2024 was approved by the American National Standards Institute on April 5, 2024.

ASME BPE-2024 includes the following changes identified by a margin note, **(24)**.

Page	*Location*	*Change*
1	GR-1	Revised
1	GR-2	Revised
2	GR-4	Cross-references to GR-8 updated to GR-11
2	GR-4.2.1	Subparagraph (c) revised
6	GR-4.3.2	Title revised
6	GR-5.2	Revised in its entirety
7	GR-5.3	Revised in its entirety
8	GR-5.4	Former GR-5.5 redesignated
8	GR-5.5	Added
8	GR-6	Added
9	GR-7	Added
9	GR-8	Added
9	GR-9	Former GR-6 redesignated
9	GR-10	Former GR-7 redesignated and updated
11	GR-11	Former GR-8 redesignated and revised
20	GR-12	Former GR-9 redesignated
21	Table CR-1-1	Revised
22	CR-2.1	(1) Subparagraphs (b) and (d) revised (2) Subparagraph (e) added
22	CR-2.2.3	Revised
23	CR-2.3.2	Subparagraph (b) revised
25	Table MM-2.1-1	S32750 added
27	Table MM-2.1-3	J93404 added
28	MM-4.2	Updated
29	MM-4.3	Updated
29	MM-4.4	Updated
29	MM-4.5	Updated
30	MM-4.6	Updated
30	MM-5.2.1.1	Subparagraph (a) revised
31	Table MM-5.2.1.1-1	References in notes updated
31	MM-5.2.1.3	Second paragraph revised
32	Table MM-5.2.5-1	Note (3) revised
35	Table MM-5.3-2	Revised

Page	*Location*	*Change*
36	Table MM-5.3-3	S32750 added
38	Table MM-5.3-5	Revised
40	Table MM-5.4-1	S32750 added
40	MM-8.2	Last paragraph added
40	MM-9.1	Revised
40	MM-9.1.1	Revised
41	MM-9.1.2	Revised
42	Part PM	PM-4.3 revised and redesignated as MC-5
42	PM-2.1	Revised
48	PM-4.2	Revised
48	PM-4.2.1	Revised in its entirety
48	PM-4.2.2	Revised
49	PM-4.2.4.1	Revised in its entirety
49	PM-4.2.4.2	Revised
49	PM-4.2.5	Revised in its entirety
50	SD-1	First paragraph revised
50	SD-2	Revised
50	SD-2.2	First paragraph revised
50	SD-2.3	Subparagraph (b) revised in its entirety
51	SD-2.4	Revised
52	SD-2.4.2	Subparagraphs (a)(1) and (a)(2) revised
53	SD-2.4.3.4	In subpara. (a), last sentence added
53	SD-2.4.4.2	First paragraph and subparas. (d), (g), (j), and (m) revised
54	SD-2.5	First sentence revised
54	SD-2.6	Deleted
54	SD-3.1.1	Subparagraph (c) revised
56	SD-3.1.2.2	Last paragraph revised
59	Figure SD-3.1.2.2-1	Revised in its entirety
66	SD-3.4	(1) Title revised (2) In SD-3.4.1, first paragraph and subpara. (c) revised (3) In SD-3.4.2, subpara. (c) added and subsequent subparagraphs redesignated (4) In SD-3.4.6, subpara. (a) revised
68	Figure SD-3.4.2-2	Note (2) revised
96	SD-3.13	Subparagraphs (a) and (d) revised
99	SD-3.19	Added
105	SD-5.1.4	(1) Redesignated in its entirety (2) Figures SD-5.1.4.4-1 through SD-5.1.4.4-4 and SD-5.1.4.7-1 through SD-5.1.4.7-3 redesignated as Figures SD-5.1.4.1.3-1 through SD-5.1.4.1.3-4 and SD-5.1.4.2.1-1 through SD-5.1.4.2.1-3, respectively
119	SD-5.3.5.5	Revised in its entirety
121	SD-5.5.2	Added
122	SD-5.5.4	Added
122	SD-5.5.5	Revised in its entirety
123	SD-5.5.6	Added

Page	*Location*	*Change*
123	SD-5.5.7	Added
134	SD-6.2.4.7	Revised
135	SD-6.3.3.3	Revised
137	SD-6.3.4.2	Revised in its entirety
140	SD-6.3.5.1	Revised in its entirety
140	SD-6.3.5.2.1	Subparagraph (c) revised
140	SD-6.3.5.2.2	(1) Subparagraphs (b) and (d) revised (2) Subparagraph (c) deleted and subsequent subparagraphs redesignated
141	SD-6.3.5.3	Added
141	SD-6.3.5.4	Added
141	SD-6.3.6	Revised in its entirety
141	SD-6.3.7	Revised in its entirety
153	SD-7.1	Last paragraph revised
155	DT-2	Revised
155	DT-4	Cross-reference to GR-6 updated to GR-9
156	DT-7.2	Revised
158	Table DT-2-1	General Notes revised
170	Table DT-4.1.2-6	Editorially reformatted
171	Table DT-4.1.2-7	Editorially reformatted
172	Table DT-4.1.2-8	Editorially reformatted
173	Table DT-4.1.2-9	Editorially reformatted
175	Table DT-4.1.2-13	Revised
180	Table DT-4.1.5-1	Revised in its entirety
191	Table DT-7.2-1	Added
204	PI-5	(1) Revised in its entirety (2) Figures PI-5.1.2.1-1 and PI-5.1.3.3-1 redesignated as Figures PI-5.1.5-1 and PI-5.1.1.1-1, respectively
217	PI-8.4	Added
221	MC-2.2.2	Revised
222	Figure MC-2.2.2-1	Revised
222	Figure MC-2.2.2-2	Title revised
231	Figure MC-2.3.1.9-1	Revised in its entirety
234	MC-2.3.2.4	(1) Revised in its entirety (2) Titles of Figures MC-2.3.2.4-1 through MC-2.3.2.4-16 revised (3) Figures MC-2.3.2.4-1 and MC-2.3.2.4-2 revised (4) Figure MC-2.3.2.4-8 redesignated as Figure MC-2.3.2.4-13 and Figures MC-2.3.2.4-9 through MC-2.3.2.4-13 redesignated as Figures MC-2.3.2.4-8 through MC-2.3.2.4-12, respectively
245	MC-4.1	Last paragraph added
245	MC-4.2	Second paragraph and subpara. (b) revised
247	MC-5	Former PM-4.3 redesignated and revised
250	MJ-3.1	Third paragraph added
251	Figure MJ-3.1-1	Added
250	MJ-3.4	Revised
254	MJ-5.4	Revised

Page	Location	Change
267	Figure MJ-8.4-4	Captions for illustrations (b) and (c) and General Note revised
276	SF-2.5	Revised in its entirety
276	SF-2.6	First paragraph revised
276	SF-2.7	Updated
276	SF-2.8	In penultimate paragraph, cross-reference updated
279	SU-3	Revised in its entirety
281	SU-9	Revised in its entirety
281	SU-10	(1) Subparagraphs (a) and (b) revised (2) Subparagraph (c) added
282	SU-12	Added
284	SC-3.1.1	Added
284	SC-3.2.1	Added
284	SC-3.2.2	Added
284	SC-4	Revised
284	SC-5	Added
291	Part SI	Added
293	Mandatory Appendix III	Deleted
296	Nonmandatory Appendix A	Title revised
311	Table E-3.2-1	Revised
311	E-4	E-4.2 deleted
312	E-5.1	Last two paragraphs revised
320	Table F-1-1	(1) First column heading revised (2) ASTM A1084 and ISO 3651-2 added
322	Table F-3-1	S32750 added
324	Nonmandatory Appendix H	Revised in its entirety
341	Nonmandatory Appendix L	L-1 and L-2 updated
346	Nonmandatory Appendix N	Title and subparas. (a), (f), (i), and (j) revised
347	O-1.1	Former PM-2.1.1 redesignated
347	O-1.2	Former PM-2.1.2 redesignated
348	Table O-1.1-1	Former Table PM-2.1.1-1 redesignated
348	Table O-1.2-1	Former Table PM-2.1.2-1 redesignated
349	Table O-1.3-1	Former Table PM-2.1.3-1 redesignated
348	O-1.3	Former PM-2.1.3 redesignated
348	O-1.4	Former O-1.1 redesignated
350	P-1	Updated
367	Z-1	Revised
368	Z-3.4	Subparagraph (c) added
368	Z-3.5	(1) Second paragraph added by errata (2) Last two paragraphs revised by errata
369	Z-3.8	Subparagraph (b)(2)(-e) revised
369	Z-3.9	Subparagraph (a) revised
370	Z-3.10	Subparagraph (b) editorially revised
371	Nonmandatory Appendix AA	Revised in its entirety
377	Nonmandatory Appendix BB	Deleted

Page	*Location*	*Change*
393	Nonmandatory Appendix FF	(1) Revised in its entirety (2) Table FF-1 revised and redesignated as Table FF-1-1 (3) Table FF-2 revised and redesignated as Table FF-1-2
401	Nonmandatory Appendix HH	Added
404	Nonmandatory Appendix JJ	Added
405	Table JJ-1	Former Table PM-4.2.1-1 redesignated
406	Index	Updated

CHAPTER 1
INTRODUCTION, SCOPE, AND GENERAL REQUIREMENTS

PART GR
GENERAL REQUIREMENTS

GR-1 INTRODUCTION (24)

The ASME Bioprocessing Equipment (BPE) Standard was developed to aid in the design and construction of new fluid processing equipment used in the manufacture of pharmaceuticals and biopharmaceuticals, where a defined level of purity and bioburden control is required.

The General Requirements Part states the scope of the ASME BPE Standard and provides requirements, references, and definitions that apply throughout the Standard.

When operating under pressure conditions, systems shall be constructed in accordance with the ASME Boiler and Pressure Vessel Code (BPVC), Section VIII, and/or ASME B31.3 Process Piping Code or applicable local, national, or international codes or standards. The owner/user may stipulate additional or alternative specifications and requirements.

This Standard shall govern the design and construction of piping systems for hygienic service. For process piping systems designed and constructed in accordance with ASME B31.3, it is the owner's responsibility to select a fluid service category for each fluid service. Should any fluid service meet the definition of high-purity fluid service (ASME B31.3, Chapter X) it is recommended that such fluid service be selected and the requirements of this Standard and ASME B31.3, Chapter X be met.

When an application is covered by laws or regulations issued by an enforcement authority (e.g., municipal, provincial, state, or federal), the final construction requirements shall conform to those laws.

Items or requirements that are not specifically addressed in this Standard are not prohibited. Engineering judgments must be consistent with the fundamental principles of this Standard. Such judgments shall not be used to override mandatory regulations or specific prohibitions of this Standard.

New editions of the ASME BPE Standard may be used beginning with the date of issuance and become effective 6 months after the date of issuance.

GR-2 SCOPE OF THE ASME BPE STANDARD (24)

The ASME BPE Standard provides requirements for components, equipment, and systems when there is contact with the product, raw materials, or product intermediates during clinical or commercial manufacturing of molecules intended for human or animal medicinal applications. It also applies to supporting systems that could directly or indirectly affect the clinical or commercial process [e.g., water-for-injection (WFI), clean steam, filtration, and intermediate product storage].

The Standard is intended for clinical and commercial manufacturing of pharmaceutical and biopharmaceutical products used for human and animal medicinal applications. However, some of the principles, practices, and guidance may be used for research and development, scale-up operations, or other products where the control and reduction of microbial, particulate, and endotoxin or pyrogen contamination is considered important.

This Standard provides requirements for components, equipment, and systems designed for multiuse processes that are subject to cleaning [e.g., clean-in-place (CIP), clean-out-of-place (COP)], sanitization and/or sterilization [e.g., steam-in-place (SIP)], and other operations used in the manufacturing of pharmaceuticals and biopharmaceuticals. This Standard also provides requirements for single-use systems and components that are discarded after use in one manufacturing campaign.

This Standard may be used, in whole or in part, for other applications in which bioburden risk is a concern.

This Standard applies to

(a) new system (and component) design and fabrication

(b) definition of system boundaries

(c) specific metallic, polymeric, and elastomeric (e.g., seals and gaskets) materials of construction

(d) component dimensions and tolerances

(e) surface finishes

(f) materials joining

(g) examinations, inspections, and testing

(h) certification

This Standard is intended to apply to new fabrication and construction. If the provisions of this Standard are optionally applied by an owner/user to existing, in-service equipment, other considerations may be necessary. For installations between new construction and an existing, in-service system, such as a retrofit, modification, or repair, this Standard applies to the new construction. The system boundaries and requirements shall be specified by the owner/user.

The owner/user determines which requirements of the Standard are applicable to individual components, equipment, or systems based on intended service. However, for a component, equipment, or system to be BPE-conforming, adherence to all applicable requirements of this Standard is mandatory.

GR-3 MANUFACTURER'S QUALITY ASSURANCE PROGRAM

The manufacturer shall implement a quality assurance program describing the systems, methods, and procedures used to control materials, drawings, specifications, fabrication, assembly techniques, and examination/inspection used in the manufacturing of bioprocessing equipment.

Nonmandatory Appendix Z provides guidance on quality assurance programs. This is only required for organizations that are ASME BPE Certificate Holders or applicants (see Part CR). However, it may be used by any organization that implements this Standard.

(24) GR-4 EXAMINATION, INSPECTION, AND TESTING

The examination, inspection, and testing requirements are specified in each Part of this Standard. If an inspection or examination plan is required, it shall be developed and agreed to by the owner/user, contractor, inspection contractor, and/or engineer ensuring that the systems and components meet this Standard.

As it relates to pressure vessels, vessels not rated for pressure service, process piping and tubing, and process contact equipment, this Standard uses the terms "examination," "inspection," and "testing" and other forms of these terms in a manner consistent with the uses in ASME BPVC, Section VIII, and ASME B31.3. References for examination, inspection, and testing per this Standard are listed in Nonmandatory Appendix CC. These requirements are in addition to the requirements of ASME BPVC, Section VIII, and ASME B31.3. This Standard also uses the common language meaning of these terms. Be aware of the differences between the usage as defined in GR-11 versus common usage.

GR-4.1 Inspector/Examiner

Inspector and examiner in this Standard shall be defined for the following:

(a) Pressure Vessels. Authorized Inspector, as defined in ASME BPVC, Section VIII.

(b) Piping, Tubing, and Non-Code Vessels. Owner's Inspector, as defined in ASME B31.3, paras. 340.4(a) and 340.4(b). Quality Inspector's Delegate, as defined in GR-11, meets the additional requirements listed in GR-4.2.

(c) Piping and Tubing. Examiner, defined as a person who performs quality control examinations for a manufacturer as an employee of the manufacturer as defined in ASME B31.3, para. 341.1.

When local regulations require that pressure equipment be designed and constructed in accordance with standards other than ASME codes and standards, the inspector in this Standard is defined as one who is acceptable to the relevant regulatory authority.

GR-4.2 Quality Inspector's Delegate

Quality Inspector's Delegate qualifications shall be in accordance with the requirements listed herein. The employer of the Quality Inspector's Delegate shall have documented training and qualification programs to ensure the qualifications and capabilities of personnel are met.

The capabilities requirements are listed in Table GR-4.2-1. It is required that a capability listed for a lower level of qualification is also required for subsequent higher levels of qualification.

GR-4.2.1 Levels of Qualification. There are four levels (24)
of qualification for Quality Inspector's Delegate. Examination personnel qualifications are not covered in this section but shall be in accordance with ASME B31.3, para. 342.

(a) Trainee. An individual who is not yet certified to any level shall be considered a trainee. Trainees shall work under the direction of a certified Quality Inspector's Delegate and shall not independently conduct any tests or write a report of test results.

(b) Quality Inspector's Delegate 1 (QID-1). This individual shall be qualified to properly perform specific calibrations, specific inspections, and specific evaluations for acceptance or rejection according to written instructions. A QID-1 may perform tests and inspections according to the capabilities' requirements under the supervision of, at a minimum, a QID-2.

(c) Quality Inspector's Delegate 2 (QID-2). This individual shall be qualified to set up and calibrate equipment and to interpret and evaluate results with respect to applicable codes, standards, and specifications. The QID-2 shall be thoroughly familiar with the scope and limitations of the inspection being performed and shall exercise assigned responsibility for on-the-job training and guidance of trainees and QID-1 personnel. A QID-2 may perform tests and inspections according to the capabilities' requirements.

Table GR-4.2-1
Quality Inspector's Delegate Capabilities

Capability	Trainee	QID-1	QID-2	QID-3
Materials				
(a) Identify materials				
(1) Fitting type	X	...	...	...
(2) Tube/pipe	X	...	...	...
(3) Filler materials	...	X	...	...
(4) Elastomers	...	X	...	...
(5) Process components	...	X	...	...
(b) Verify material marking to standard	X	...	...	...
(c) Measure material dimensions	X	...	...	...
(d) Measure material surface finish	X	...	...	...
(e) Verify material documentation				
(1) Material Test Reports (MTRs)	...	X	...	...
(2) Certificates of Conformance	...	X	...	...
(3) Instrument calibration records	...	X	...	...
(4) Elastomers	...	X	...	...
(f) Evaluate to acceptance criteria	...	X	...	...
(g) Verify material conformance to specification	...	X	...	...
(h) Verify material storage/handling conformance	...	...	X	...
Equipment Use				
(a) Mirrors/magnifiers	X	...	...	...
(b) Measuring devices		...	...	...
(1) Steel rule	X	...	...	...
(2) Calipers (dial, digital)	X	...	...	...
(3) Fillet gauge	...	X	...	...
(4) Radius gauge	...	X	...	...
(5) Temperature-sensitive crayon (tempilstick)	...	X	...	...
(6) Slope level	...	X	...	...
(7) Undercut gauge	...	X	...	...
(c) Borescope/fiberscope	...	X	...	...
(d) Profilometer	X	...	...	...
(e) Positive material identification (PMI)	...	...	X	...
(f) Calibration records (inspection equipment)	...	X	...	...
Knowledge and Skills				
Understand inspection fundamentals				
(a) Effective oral and written communication	...	X	...	...
(b) Quality procedures				
(1) Prepare documentation control requirements	...	...	...	X
(2) Develop inspection procedures	...	...	...	X
(c) Review of specifications	...	...	X	...
(d) Codes and Standards (training)				
(1) ASME BPE	GR/DT/SF	MJ/SD 3.12	X	...
(2) ASME B31.3	...	...	Chapter VI	X
(3) ASME BPVC, Section IX	...	...	X	...
(e) Interpret welding symbols and drawings				
(1) Detail drawings (mechanical)	...	...	X	...
(2) P&ID	...	...	X	...
(3) Single line isometric drawings (weld maps)	...	X	...	...

Table GR-4.2-1
Quality Inspector's Delegate Capabilities (Cont'd)

Capability	Trainee	QID-1	QID-2	QID-3
Knowledge and Skills (Cont'd)				
(4) Isometric drawings (slope maps)	...	X	...	...
(5) General/fabrication arrangement drawings (details)	...	...	X	...
(6) Interpret welding symbols	...	...	X	...
(f) Prepare documents/reports in accordance with GR-5.3				
(1) Material examination log	...	X	...	...
(2) Nonconformance reports	...	X	...	...
(3) Visual weld inspection	...	X	...	...
(4) Slope verification (isometric)	...	X	...	...
(5) Pressure test	...	...	X	...
(g) Turnover package				
(1) Assemble	...	...	X	...
(2) Review	...	...	...	X
(h) Basic understanding of NDT/NDE				
(1) PT	...	...	X	...
(2) UT	...	...	X	...
(3) RT	...	...	X	...
(4) Eddy current	...	...	X	...
(5) Pressure/leak testing	...	...	X	...
Inspection				
(a) Perform visual inspection (other than weld inspection)	...	X	...	...
(b) Perform weld inspection	...	X	...	...
(c) Evaluate weld inspection results	...	...	X	...
(d) Perform slope verification	...	X	...	...
(e) Witness pressure tests	...	...	X	...
(f) Verify inspection conformance	...	...	X	...
(g) Review inspection reports	...	...	X	...
(h) Verify nonconformance disposition	...	...	X	...
(i) Perform installation verification				
(1) Installation per P&ID	...	...	X	...
(2) Check for cold spring	...	...	X	...
(3) Hanger verification	...	X	...	...
(4) Component installation per manufacturer's recommendations	...	...	X	...
Vessel Inspection (additional to above)				
(a) Verify surface finish	...	...	X	...
(b) Verify drainability	...	...	X	...
(c) Cleanability (CIP/riboflavin/sprayball testing)	...	...	...	X
(d) Verify dimensions and orientation	...	...	...	X
(e) Conformance with ASME BPVC (U-1)	...	...	...	X
(f) Documentation review	...	...	X	...
Welding Procedure Qualification				
Verify Welding Procedure Specification/Procedure Qualification Record (WPS/PQR) conformance	...	...	...	X
Welder and/or Welding Operator Performance Qualification				
Verify welder and/or welding operator performance qualification conformance	...	...	X	...

Table GR-4.2-1
Quality Inspector's Delegate Capabilities (Cont'd)

Capability	Trainee	QID-1	QID-2	QID-3
Project Planning				
(a) Review contract requirements	...	...	...	X
(b) Prepare weld inspection criteria	...	...	...	X
(c) Review specifications	...	...	...	X
(d) Prepare purchase specifications	...	...	...	X
(e) Develop inspection plan	...	...	...	X
Training				
(a) Provide on-the-job training for Quality Inspectors	...	...	X	...
(b) Maintain records of training	...	...	X	...
Audit				
(a) Perform vendor audits	...	...	...	X
(b) Perform fabricator audits	...	...	...	X
(c) Prepare audit and surveillance plan	...	...	...	X

(d) Quality Inspector's Delegate 3 (QID-3). This individual shall be capable of establishing techniques and procedures; interpreting codes, standards, specifications, and procedures; and designating the particular inspection methods, techniques, and procedures to be used. The QID-3 shall have sufficient practical background in applicable materials, fabrication, and product technology to establish techniques and to assist in establishing acceptance criteria when none are otherwise available. The QID-3 shall be capable of training personnel. A QID-3 may perform tests and inspections according to the capabilities' requirements.

GR-4.2.2 Qualification Requirements. The qualification requirements listed herein shall be met prior to consideration for examination/certification.

(a) Trainee

(1) be a high school graduate or hold a state or military approved high school equivalency diploma

(2) receive a minimum of 8 hr of relevant documented training (total 8 hr), including as a minimum the requirements shown in Table GR-4.2-1

(b) QID-1. To be considered as a QID-1, personnel shall meet the following:

(1) be a trainee for a minimum of 6 months of documented relevant industry experience. Alternate methods for meeting the work experience requirement are at least one of the following:

(-a) prior or current certification as a QID-1

(-b) completion with a passing grade of at least 2 yr of engineering or science study in a university, college, or technical school

(-c) possess an AWS CWI certificate[1] or ACCP Level II VT certificate[2] or international equivalent

(-d) 2 yr of documented relevant experience in inspection, examination, or testing activities

(2) receive a minimum of 16 additional hr of relevant documented training (minimum total = 24 hr), including as a minimum the requirements shown in Table GR-4.2-1

(3) pass a written test and practical performance examination, including as a minimum the requirements shown in Table GR-4.2-1 for this level

(c) QID-2. To be considered as a QID-2, personnel shall meet the following:

(1) be a QID-1 for a minimum of 6 months of documented relevant industry experience. Alternate methods for meeting the work experience requirement are at least one of the following:

(-a) prior or current certification as a QID-2

(-b) completion with a passing grade of at least 4 yr of engineering or science study in a university, college, or technical school

(-c) possess an AWS CWI certificate[1] or ACCP Level II VT certificate[2] or international equivalent

(-d) 2 yr of documented relevant experience in inspection, examination, or testing activities of high-purity/hygienic systems

(2) receive a minimum of 16 additional hr of relevant documented training (minimum total = 40 hr), including as a minimum the requirements shown in Table GR-4.2-1

[1] Certifications from the American Welding Society (AWS). CAWI is a Certified Associate Welding Inspector, and CWI is a Certified Welding Inspector.

[2] Certifications from the American Society of Nondestructive Testing (ASNT). ACCP is the ASNT Central Certification Program.

(3) pass a written test and practical performance examination, including as a minimum the requirements shown in Table GR-4.2-1 for this level

(d) *QID-3.* To be considered as a QID-3, personnel shall meet the following:

(1) be a QID-2 for a minimum of 24 months of documented relevant industry experience. Alternate methods for meeting the work experience requirement are at least one of the following:

(-a) prior or current certification as a QID-3

(-b) 3 yr of documented relevant experience in inspection, examination, or testing activities of high-purity/hygienic systems

(2) receive a minimum of 40 additional hr of relevant documented training (minimum total = 80 hr), including as a minimum the requirements shown in Table GR-4.2-1

(3) pass a written test and practical performance examination, including as a minimum the requirements shown in Table GR-4.2-1 for this level

GR-4.2.3 Certification. The employer is responsible for training, testing, and certification of employees. The employer shall establish a written practice in accordance with the guidelines of ASNT SNT-TC-1A including

(a) the requirements listed in Table GR-4.2-1

(b) training programs

(c) certification testing requirements

(d) eye examinations as follows:

(1) *Near Vision Acuity.* The individual shall have natural or corrected near distance acuity in at least one eye such that the individual is capable of reading a minimum of a Jaeger Number 2 or equivalent type and size letter at a distance designated on the chart but no less than 12 in. (305 mm). This test shall be administered initially and at least annually thereafter.

(2) *Color Contrast.* The individual shall demonstrate the capability of distinguishing and differentiating contrast among colors. This test shall be administered initially and, thereafter, at intervals not exceeding 3 yr.

These examinations shall be administered by an ophthalmologist, optometrist, medical doctor, registered nurse or nurse practitioner, certified physician assistant, or other ophthalmic medical personnel, and the documentation shall include the state or province (or applicable jurisdictional) license number.

(e) certification documentation

The owner/user is responsible for verifying the requirements of this section are met.

GR-4.2.4 Recertification. A QID-1, QID-2, or QID-3 whose employment has been terminated may be recertified to their former level of qualification by a new or former employer based on examination, provided all of the following requirements are met:

(a) The employee has proof of prior certification.

(b) The employee was working in the capacity to which certified within 6 months of termination.

(c) The employee is being recertified within 6 months of termination.

If the employee does not meet the listed requirements, additional training as deemed appropriate by the owner's Inspector shall be required.

GR-4.3 Responsibilities

The responsibilities of inspection personnel are defined in GR-4.3.1 and GR-4.3.2.

GR-4.3.1 Pressure Vessels. The responsibilities of the owner's Inspector shall be the same as the inspector in ASME BPVC, Section VIII.

GR-4.3.2 Piping and Tubing. The responsibilities of the owner/user's Inspector shall be in accordance with ASME B31.3, para. 340.2. (24)

GR-4.4 Access for Inspectors

Manufacturers of bioprocessing equipment and components shall allow free access to owner/user and authorized inspection personnel at all times while work on the equipment or components is being performed. The notification of an impending inspection should be mutually agreed to by the manufacturer and the inspector. Access may be limited to the area of the manufacturer's facility where assembly, fabrication, welding, and testing of the specific equipment or components are being performed. Inspectors shall have the right to audit any examination, to inspect components using any examination method specified in the Design Specification (including Purchase Order), and to review all certifications and records necessary to satisfy the requirements of GR-5. The manufacturer shall provide the Inspector with work progress updates.

GR-5 DOCUMENTATION

GR-5.1 General

Documentation requirements shall be agreed to at the beginning of a design project and shall be made available upon request or submitted at the agreed-upon time to support the requirements of this Standard, as agreed to by the owner/user and manufacturer/contractor.

GR-5.2 General List of Documents (24)

GR-5.2.1 Turnover Package Documentation for Multiuse Systems. Documentation required for current Good Manufacturing Practices (cGMP)-validated distribution systems, including the vessels, tubing systems on modules, super skids, skids, and the shop or field fabrication of tubing, includes the following:

(a) *Materials Documentation*

(1) Material Test Reports (MTRs)

(2) Certificates of Conformance

(3) Material Examination Logs

(4) Identification of the filler metal or consumable insert used

(b) *Welding, Inspection, and Examination Qualification Documentation* (not required for standard fittings, valves, and components unless specifically required by the owner/user)

(1) Welding Procedure Specifications/Parameters (WPS/P)

(2) Procedure Qualification Records (PQRs)

(3) Welder Performance Qualifications (WPQs)

(4) Welding Operator Performance Qualifications (WOPQs)

(5) Examiner qualifications

(6) documentation of approval of (1) through (5) by the owner/user's representative prior to welding

(7) Inspector qualifications

(8) documentation of the approval of (7) by the owner/user prior to welding

(c) *Weld Documentation* (not required for standard fittings, valves, and components unless specifically required by the owner/user)

(1) weld maps

(2) weld logs

(3) weld examination and inspection logs

(4) coupon logs

(d) *Testing and Examination Documentation* (as applicable)

(1) passivation reports

(2) spray device coverage testing

(3) pressure testing

(4) final slope check documentation

(5) calibration verification documentation

(6) purge gas certifications

(7) signature logs

(8) number of welds — both manual and automatic

(9) number of welds inspected expressed as a percentage (%)

(10) heat numbers of components that must be identified, documented, and fully traceable to the installed system

(11) surface finish Certificates of Conformance

(12) nondestructive examination (NDE) reports

(e) *System/Equipment*

(1) standard operating and maintenance procedures and manuals

(2) installation procedures

(3) piping and instrumentation diagrams

(4) detail mechanical drawings and layouts

(5) technical specification sheets of components and instrumentation

(6) original equipment manufacturer's data

(7) manufacturer's data and test reports

(8) any documentation that is specifically needed for the owner/user's qualification of a system

GR-5.2.2 Technical Support Information. Documentation to support the design, operation, and maintenance of equipment may include, but is not limited to, the following:

(a) material handling procedures

(b) mechanical and electropolishing procedures

(c) shop passivation procedures

GR-5.3 Document Requirements for Metallic Materials (24)

MTRs for metallic process components shall be verified to be in conformance to the applicable specification. In addition, the following documentation shall be provided to the owner/user or their designee.

GR-5.3.1 MTRs/Certificates of Conformance. The combination of documents, including Certificates of Conformance and MTRs, for all valves and fittings having process contact surfaces shall include the following information, as a minimum:

(a) ASME BPE Standard, including year

(b) material type

(c) heat number or code traceable to the original heat

(d) chemical composition

(e) AWS classification of filler metal, if used

(f) alloy designation and material specification of insert, if used

(g) postweld heat treatment documentation, if applicable

(h) mechanical properties are not required, but if included must be accurate to the raw material specification

MTRs for other components made to a material specification shall contain the minimum information specified by the material specification incorporated by reference. MTRs for tubing shall also state the year edition of the ASME BPE Standard.

GR-5.3.2 Electropolishing. The electropolishing service provider shall provide documentation for each type of component or process equipment (e.g., vessel, filter housing), including, but not limited to, the following information:

(a) service provider company name

(b) description of component or components or process equipment

(c) identification of component or components or process equipment

(d) identification of the qualified electropolishing procedure used

(e) final surface finish report (R_a if required by the owner/user)

GR-5.3.3 Passivation. The passivation service provider shall provide documentation for each type of component, type of process equipment (e.g., vessel, filter housing), or process system, including, but not limited to, the following information:

(*a*) service provider company name
(*b*) description of component or components, process equipment, or process system
(*c*) identification of component or components, process equipment, or process system
(*d*) identification of the qualified passivation procedure used

GR-5.3.4 Weld and Examination/Inspection Log. The results of the welding, examination, and inspection shall be recorded on a Weld and Examination/Inspection Log. The information required to be on the Weld Log may be in any format, written or tabular, to fit the needs of the manufacturer/supplier, installing contractor, inspection contractor, and owner/user as long as all required information is included or referenced. Form WEL-1 (see Nonmandatory Appendix B) has been provided as a guide for the Weld and Examination/Inspection Log. This form includes the required data plus some other information that is not required. The minimum requirements are as follows:

(*a*) isometric drawing number (including revision number)
(*b*) weld number
(*c*) date welded
(*d*) welder and/or welding operator identification
(*e*) size
(*f*) examination
(*1*) date
(*2*) type of examination
(*3*) acceptance/rejection
(*4*) initials
(*g*) inspection
(*1*) date
(*2*) type of examination
(*3*) acceptance/rejection
(*4*) initials
(*h*) identification of blind welds
(*i*) identification of manual welds
(*j*) basis of rejection

In addition, heat numbers (or other identification system for material traceability) and slope shall be recorded on the Weld and Examination/Inspection Log, an isometric drawing, or other owner/user-approved document.

(24) GR-5.4 Records Retention

GR-5.4.1 Vessel Documentation. For all bioprocessing ASME BPVC-stamped vessels, National Board registration is recommended to maintain vessel data on file. Manufacturing documentation shall be maintained throughout the design and manufacture for each component, assembly, part, or unit.

All documentation shall be retained by the owner/user. As agreed to by the owner/user and manufacturer, documentation from the manufacturer will be retained for the agreed-upon duration of time but not less than 3 yr after manufacture.

GR-5.4.2 Welding Documentation

(*a*) *Piping and Tubing.* Records and retention of records associated with piping and tubing shall be in accordance with ASME B31.3.
(*b*) *Pressure Vessels and Tanks.* Records and retention of records for code vessels shall be in accordance with ASME BPVC, Section VIII.

GR-5.5 Document Requirements for Polymeric and Other Nonmetallic Materials (24)

The manufacturer of polymeric and other nonmetallic components shall issue a Certificate of Conformance that the components meet requirements as shown in Table PM-2.2.1-1. In addition, the following documentation shall be provided to the owner/user or their designee.

GR-5.5.1 Seal Documentation. Seal manufacturers shall provide, upon owner/user request, documentation (test report) of the USP <88> Biological Reactivity Test in Vivo, Class VI and the USP <87> Biological Reactivity Test in Vitro testing on final manufactured seals. A Certificate of Conformance shall be issued by the seal manufacturer to certify conformance to this Standard when required by the owner/user. The Certificate of Conformance shall contain the information listed in Table PM-2.2.1-1. Additional agreements may be required.

GR-5.5.2 Sealed Unions. The seal manufacturer shall provide, upon request of the owner/user, a certificate of design conformance that the sealed union meets the intrusion requirements of MC-4.2.

GR-6 PRODUCT IDENTIFICATION AND PACKAGING (24)

Manufacturers shall use a combination of marking, labeling, and primary packaging for identification and protection of components, equipment, and assemblies.

GR-6.1 Marking and Labeling

Marking and labeling shall provide traceability for process contact components, equipment, and assemblies. Specific marking and labeling requirements are addressed in the applicable Parts of this Standard.

GR-6.2 Packaging

Components or single-use assemblies shall be packaged by the manufacturer to protect against damage and contamination that may result from routine shipping and subsequent handling and storage to maintain the as-manufactured condition. Additional packaging that may be necessary for shipping and subsequent handling and storage is not addressed in this Standard except when

necessary to maintain sterility or integrity. Specific packaging requirements are addressed in the applicable Parts of this Standard.

(24) GR-7 PROCESS COMPATIBILITY

GR-7.1 Materials

Process contact surfaces of components shall not be reactive, additive, or absorptive so as to alter the safety, identity, strength, quality, or purity of the product given the following requirements:

(a) Materials shall be capable of withstanding process, cleaning, and sanitization conditions (e.g., temperature, pressure) and shall be chemically compatible with those conditions.

(b) For a metallic material to be acceptable for hygienic service, it shall meet the requirements in Part MM. For a polymeric or other nonmetallic material to be acceptable for hygienic service, it shall meet the requirements in Part PM.

GR-7.2 Animal-Derived Ingredients

Process contact surfaces of components, equipment, and systems shall be constructed from and processed with materials that are free from animal-derived ingredients/products (ADI/ADP) or shall be manufactured with materials that meet the conditions of the Committee for Medicinal Products for Human Use (CHMP, formerly known as CPMP) Note for Guidance (EMEA/410/01 rev 3).

(24) GR-8 CONTAMINATION CONTROL

GR-8.1 Closed Systems

Components, equipment, and systems of closed processes shall be designed to mitigate the risk of contamination within the process zone, including the risk of ingress of contaminants during bioprocessing. Functionally closing a system is a two-step process:

(a) removal of latent viable and nonviable contaminants within the process zone prior to process or product contact (e.g., CIP, SIP, ionizing irradiation)

(b) prevention of ingress of viable and nonviable particulates during product contact

GR-8.2 Open Systems

Components, equipment, and systems of open processes shall be designed to mitigate the risk of bioburden proliferation within the process zone.

GR-9 U.S. CUSTOMARY AND SI UNITS (24)

This Standard uses standard units listed in Mandatory Appendix II. Nonmandatory Appendix U has been provided as a guide for U.S. Customary and SI unit conversion.

GR-10 REFERENCES (24)

Material specifications for metallic materials are listed by product form in Part MM and for polymeric materials in Part PM. Testing standards for polymeric materials are listed in the appropriate appendices. For this Standard, the most recent approved version of the following referenced standards shall apply:

3-A Sanitary Standards. 3-A Sanitary Standards.

ANSI/FCI Standard 70-2. Control Valve Seat Leakage. Fluid Controls Institute.

ASME B31.3. Process Piping. The American Society of Mechanical Engineers.

ASME B46.1. Surface Texture (Surface Roughness, Waviness, and Lay). The American Society of Mechanical Engineers.

ASME Boiler and Pressure Vessel Code, Section V. Nondestructive Examination. The American Society of Mechanical Engineers.

ASME Boiler and Pressure Vessel Code, Section VIII. Rules for Construction of Pressure Vessels. The American Society of Mechanical Engineers.

ASME Boiler and Pressure Vessel Code, Section IX. Welding, Brazing, and Fusing Qualifications. The American Society of Mechanical Engineers.

ASME CA-1. Conformity Assessment Requirements. The American Society of Mechanical Engineers.

ASME MFC-22. Measurement of Liquid by Turbine Flowmeters. The American Society of Mechanical Engineers.

ASME NM 3.3. Nonmetallic Materials, Part 3 — Properties. The American Society of Mechanical Engineers.

ASME PTC 19.3 TW. Thermowells. The American Society of Mechanical Engineers.

ASME PVHO-1. Safety Standard for Pressure Vessels for Human Occupancy. The American Society of Mechanical Engineers.

ASQ/ANSI Z1.4. Sampling Procedures and Tables for Inspection by Attributes. American Society for Quality.

ASTM A262. Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels. American Society for Testing and Materials.

ASTM A380. Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems. American Society for Testing and Materials.

ASTM A923. Standard Test Methods for Detecting Detrimental Intermetallic Phase in Duplex Austenitic/Ferritic Stainless Steels. American Society for Testing and Materials.

ASTM A967. Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts. American Society for Testing and Materials.
ASTM A1015. Standard Guide for Videoborescoping of Tubular Products for Sanitary Applications. American Society for Testing and Materials.
ASTM A1084. Standard Test Method for Detecting Detrimental Phases in Lean Duplex Austenitic/Ferritic Stainless Steels. American Society for Testing and Materials.
ASTM B912. Standard Specification for Passivation of Stainless Steels Using Electropolishing. American Society for Testing and Materials.
ASTM D395. Standard Test Methods for Rubber Property — Compression Set. American Society for Testing and Materials.
ASTM D412. Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers — Tension. American Society for Testing and Materials.
ASTM D471. Standard Test Method for Rubber Property — Effect of Liquids. American Society for Testing and Materials.
ASTM D624. Standard Test Method for Tear Strength of Conventional Vulcanized Rubber and Thermoplastic Elastomers. American Society for Testing and Materials.
ASTM D1599. Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings. American Society for Testing and Materials.
ASTM D2240. Standard Test Method for Rubber Property — Durometer Hardness. American Society for Testing and Materials.
ASTM D2657. Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings. American Society for Testing and Materials.
ASTM D4991. Standard Test Method for Leakage Testing of Empty Rigid Containers by Vacuum Method. American Society for Testing and Materials.
ASTM E112. Test Methods for Determining Average Grain Size. American Society for Testing and Materials.
ASTM E220. Standard Test Method for Calibration of Thermocouples by Comparison Techniques. American Society for Testing and Materials.
ASTM E230/E230M. Standard Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples. American Society for Testing and Materials.
ASTM E499. Standard Practice for Leaks Using the Mass Spectrometer Leak Detector in the Detector Probe Mode. American Society for Testing and Materials.
ASTM E515. Standard Practice for Leaks Using Bubble Emission Techniques. American Society for Testing and Materials.
ASTM E644. Standard Test Methods for Testing Industrial Resistance Thermometers. American Society for Testing and Materials.
ASTM E1003. Standard Practice for Hydrostatic Leak Testing. American Society for Testing and Materials.
ASTM E1137/E1137M. Standard Specification for Industrial Platinum Resistance Thermometers. American Society for Testing and Materials.
ASTM E2500. Standard Guide for Specification, Design, and Verification of Pharmaceutical and Biopharmaceutical Manufacturing Systems and Equipment. American Society for Testing and Materials.
ASTM E3244. Standard Practice for Integrity Assurance and Testing of Single-Use Systems. American Society for Testing and Materials.
ASTM E3251. Standard Test Method for Microbial Ingress Testing on Single-Use Systems. American Society for Testing and Materials.
ASTM E3336. Standard Test Method for Physical Integrity Testing of Single-Use Systems. American Society for Testing and Materials.
ASTM G28. Standard Test Methods for Detecting Susceptibility to Intergranular Corrosion in Wrought, Nickel-Rich, Chromium-Bearing Alloys. American Society for Testing and Materials.
ASTM G48. Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution. American Society for Testing and Materials.
AWS A3.0M/A3.0. Standard Welding Terms and Definitions. American Welding Society.
AWS B2.4. Specification for Welding Procedure and Performance Qualification for Thermoplastics. American Welding Society.
AWS D18.2. Guide to Weld Discoloration Levels on Inside of Austenitic Stainless Steel Tube. American Welding Society.
AWS G1.10M. Guide for the Evaluation of Hot Gas, Hot Gas Extrusion, and Heated Tool Butt Thermoplastic Welds. American Welding Society.
AWS QC1. Standard for AWS Certification of Welding Inspectors. American Welding Society.
DVS 2202-1. Imperfections in Thermoplastic Welding Joints; Features, Descriptions, Evaluation. DVS-Verlag GmbH.
EN 12266-1. Industrial valves — Testing of metallic valves. European Committee for Standardization.
European Hygienic Engineering & Design Group (EHEDG). Document No. 18 — Passivation of Stainless Steel. European Committee for Standardization.
FDA, 21 CFR, Part 177.1520. Olefin Polymers. U.S. Food and Drug Administration.
FDA, 21 CFR, Part 177.2510. Polyvinylidene Fluoride Resins. U.S. Food and Drug Administration.
FDA, 21 CFR, Part 177.2600. Rubber Articles Intended for Repeated Use. U.S. Food and Drug Administration.
FDA, 21 CFR, Parts 210 and 211. Current Good Manufacturing Practices. U.S. Food and Drug Administration.

GMP: Current Good Manufacturing Practices, Title 21 of the Food and Drug Administration. U.S. Food and Drug Administration.
IEC 60751. Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors. International Electrotechnical Commission.
IEST-RP-CC001.6. Contamination Control Division Recommended Practice 001.6, HEPA and ULPA Filters. Institute of Environmental Sciences and Technology.
ISO 34-1. Rubber, vulcanized or thermoplastic — Determination of tear strength — Part 1: Trouser, angle and crescent test pieces. International Organization for Standardization.
ISO 34-2. Rubber, vulcanized or thermoplastic — Determination of tear strength — Part 2: Small (Delft) test pieces. International Organization for Standardization.
ISO 37. Rubber, vulcanized or thermoplastic — Determination of tensile stress–strain properties. International Organization for Standardization.
ISO 48. Rubber, vulcanized or thermoplastic — Determination of hardness (hardness between 10 IRHD and 100 IRHD). International Organization for Standardization.
ISO 815-1. Rubber, vulcanized or thermoplastic — Determination of compression set — Part 1: At ambient or elevated temperatures. International Organization for Standardization.
ISO 815-2. Rubber, vulcanized or thermoplastic — Determination of compression set — Part 2: At low temperatures. International Organization for Standardization.
ISO 1402. Rubber and plastics hoses and hose assemblies — Hydrostatic testing. International Organization for Standardization.
ISO 1817. Rubber, vulcanized — Determination of the effect of liquids. International Organization for Standardization.
ISO 2859-1. Sampling procedures for inspection by attributes. International Organization for Standardization.
ISO 3651-2. Determination of resistance to intergranular corrosion of stainless steels — Part 2: Ferritic, austenitic and ferritic-austenitic (duplex) stainless steels — Corrosion test in media containing sulfuric acid. International Organization for Standardization.
ISO 10648-2. Containment enclosures — Part 2: Classification according to leak tightness and associated checking methods. International Organization for Standardization.
ISO 10790. Measurement of fluid flow in closed conduits — Guidance to the selection, installation and use of Coriolis flowmeters (mass flow, density and volume flow measurements). International Organization for Standardization.
ISO 10993. Biological evaluation of medical devices. International Organization for Standardization.
ISO 11137. Sterilization of health care products — Radiation — Part 1: Requirements for development, validation, and routine control of a sterilization process for medical devices. International Organization for Standardization.
ISO 14644-1. Cleanrooms and associated controlled environments — Part 1: Classification of air cleanliness by particle concentration. International Organization for Standardization.
ISO 14644-7. Cleanrooms and associated controlled environments — Part 7: Separative devices (clean air hoods, gloveboxes, isolators and mini-environments). International Organization for Standardization.
ISPE Baseline® Pharmaceutical Engineering Guide for Water and Steam Systems — Volume 4. International Society for Pharmaceutical Engineering.
MSS-SP-67. Butterfly Valves. Manufacturers Standardization Society of the Valve and Fittings Industry, Inc.
MSS-SP-72. Ball Valves with Flange or Butt-Welding Ends for General Service. Manufacturers Standardization Society of the Valve and Fittings Industry, Inc.
MSS-SP-88. Diaphragm Valves. Manufacturers Standardization Society of the Valve and Fittings Industry, Inc.
MSS-SP-110. Ball Valves Threaded, Socket-Welding, Solder Joint, Grooved and Flared Ends. Manufacturers Standardization Society of the Valve and Fittings Industry, Inc.
NIH (BL-1/BL-4). Biohazard Containment Guidelines. National Institutes of Health.
PFI Standard ES-50. Internal Oxidation for Piping Welds. Pipe Fabrication Institute.
Recommended Practice (RP) No. SNT-TC-1A. Personnel Qualification and Certification in Nondestructive Testing. American Society for Nondestructive Testing.
SEMI F60. Test Method for ESCA Evaluation of Surface Composition of Wetted Surfaces of Passivated 316L Stainless Steel Components. U.S. Pharmacopeia Convention.
SEMI F72. Test Method for Auger Electron Spectroscopy (AES) Evaluation of Oxide Layer of Wetted Surfaces of Passivated 316L Stainless Steel Components. U.S. Pharmacopeia Convention.
United States Pharmacopeia and National Formulary (USP-NF). U.S. Pharmacopeia Convention.

GR-11 TERMS AND DEFINITIONS (24)

animal-derived ingredients (ADI): products or ingredients derived from tissues or secretions of animals susceptible to transmissible spongiform encephalopathies (TSEs), primarily cattle's bovine spongiform encephalopathy (BSE).

animal-derived products (ADP): products made from animal-derived ingredients (ADI).

annealing, metallic: heating and cooling to produce softening.

annealing, polymeric: heating of a polymeric part to a temperature below its glass transition temperature to relieve internal stresses.

anomaly: a localized surface area that is out of specifications to the surrounding area, and is classified as abnormal.

arc gap: for orbital GTAW, the nominal distance, measured prior to welding, from the tip of the electrode to the surface of the weld joint or insert.

arc strike: a discontinuity consisting of any localized remelted metal, heat-affected metal, or change in the surface profile of any part of a weld or base metal resulting from an arc, generated by the passage of electrical current between the surface of the weld or base material and a current source, such as a welding electrode, magnetic particle prod, or electropolishing electrode.

aseptic: free of pathogenic (causing or capable of causing disease) microorganisms.

aseptic processing: operating in a manner that prevents contamination of the process.

audit: an ASME Certificate Holder's documented evaluation of a supplier performed to verify, by examination of objective evidence, that those selected elements of a previously approved quality management system have been developed, documented, and implemented in accordance with specified requirements. A surveillance is not an audit.

audit (as performed by ASME or their designee on ASME BPE Certificate Holders and Applicants): see ASME CA-1.

autogenous fillet weld: a fillet weld that is produced without the addition of filler metal. (See also *seal weld*.)

autogenous weld: a weld made by fusion of the base material without the addition of filler.

automatic welding: welding with equipment that performs the welding operation without adjustment of the controls by a welding operator. The equipment may or may not perform the loading and unloading of the work.

barrier fluid: a fluid used to separate environment from product such as water or condensate in a dual mechanical seal.

bioburden: the number of viable contaminating organisms per product unit.

biofilm: a film of microorganisms or cell components adhering to surfaces submerged in or subjected to fluid environments.

biologics: therapeutic or diagnostic products generated and purified from natural sources.

biopharmaceuticals: pharmaceuticals manufactured by biotechnology methods, with the products having biological sources, usually involving live organisms or their active components. Biopharmaceuticals generally include recombinant proteins, (monoclonal) antibodies, vaccines, blood/plasma-derived products, nonrecombinant culture-derived proteins, and cultured cells and tissues.

bioprocess: technique or operation used in the manufacture and/or purification of biopharmaceuticals or other biological materials, such as products derived from microbial fermentation (e.g., yeast, mold, bacteria), cell culture (e.g., insect, mammalian, plant), tissue culture, blood, or milk fractionation.

bioprocessing: see *bioprocess*.

bioprocessing equipment: equipment, systems, or facilities used in the creation of products utilizing living organisms.

blind weld: a weld joint whose internal surfaces are not accessible for either direct or remote visual examination.

blister (polymeric): a localized imperfection on a polymer surface, containing a pocket of fluid.

blistering (metallic): a localized delamination within the metal that has an appearance of chipped or flaked-off areas. Per SEMI F019-0304, section 4.2.1.

borescope: generic term for a group of optical instruments for visual examinations. This includes rigid borescopes and flexible borescopes (fiberscopes). Often a camera chip is mounted to the borescope. (See also *videsoscope*.)

break: a discontinuity in the face of a fitting.

buffing: a metal finishing process for smoothing the surface using a grease-suspended abrasive.

burr: excess material protruding from the edge typically resulting from operations such as cutting or facing.

butt joint: a joint between two members lying approximately in the same plane.

cartridge seal: a self-contained seal assembly.

cavitation: a condition of liquid flow where, after vaporization of the liquid, the subsequent collapse of vapor bubbles can produce surface damage.

Certificate: a Certificate of Authorization or Quality System Certificate issued by ASME.

Certificate Holder: an organization holding a Certificate of Authorization or a Quality System Certificate issued by the Society upon satisfactory completion of evaluation of its capability to conform to the requirements of this Standard.

Certificate of Authorization: a document issued by ASME that authorizes the application of the ASME Single Certification Mark with the BPE certification designator for a specified time and for a specified scope of activity.

certification: documented testimony by qualified authorities that a system qualification, calibration, validation, or revalidation has been performed appropriately and that the results are acceptable.

cGMPs: current Good Manufacturing Practices. Current design and operating practices developed by the pharmaceutical industry to meet FDA requirements as published in the Code of Federal Regulations, Chapter 1, Title 21, Parts 210 and 211.

chromatography: the purification of substances based on the chemical, physical, and biological properties of the molecules involved.

clean: a condition achieved by removal of dirt, residues, detergents, or other surface contaminants.

cleaning: operations by which dirt, residues, detergents, or other surface contaminants are removed to achieve predetermined surface attributes.

clean-in-place (CIP): cleaning of process contact surfaces of a system or component without disassembly beyond the removal of single-use components.

clean steam: see *pure steam*.

closed head: for orbital GTAW, a welding head that encapsulates the entire circumference of the tube/pipe during welding and that contains the shielding gas.

cloudiness: the appearance of a milky white hue across some portion of a surface resulting from the electropolish process.

cluster of pits: two or more pits, the closest distance between each being less than the diameter of any one pit.

cluster porosity: a localized porosity having a random geometric distribution.

compendial water: purported to conform to USP and/or any other acknowledged body of work related to the quality, manufacture, or distribution of high-purity water.

compliance: performing a function or operation in a recognized way to abide by a law or legislative requirement such as complying with the Code of Federal Regulations (CFR). Compliance is externally imposed. Noncompliance is the failure to adhere to an act or law or regulation.

compression set: permanent deformation of rubber after subscription in compression for a period of time, as typically determined by ASTM D395.

concavity: a condition in which the surface of a welded joint is depressed relative to the surface of the adjacent tube or pipe. Concavity is measured as a maximum distance from the outside or inside diameter surface of a welded joint along a line perpendicular to a line joining the weld toes. This is a nonstandard term for underfill of a root surface or weld face (see AWS A3.0).

conformance: see *conformity*.

conformity: the state of meeting, acting, or behaving in accordance with a specification, procedure, method, stated rule, or standard such as the ASME BPE Standard. Nonconformity is the state when a process or action or system does not conform to a stated quality requirement, specification requirement, procedure, or standard such as the ASME BPE Standard.

consumable insert: a ring of metal placed between the two members to be welded that provides filler for the joint, when performed with fusion welding equipment.

convexity: a condition in which the surface of a welded joint is extended relative to the surface of the adjacent tube or pipe. Convexity is measured as a maximum distance from the outside or inside diameter surface of a welded joint along a line perpendicular to a line joining the weld toes. This is a nonstandard term for root surface or weld face reinforcement (see AWS A3.0).

corrosion: a chemical or electrochemical interaction between a metal and its environment, which results in changes in the property of the metal. This may lead to impairment of the function of the metal, the environment, and/or the technical system involved.

cracks: fracture-type discontinuities characterized by a sharp tip and high ratio of length and width to opening displacement.

crater: a depression at the termination of a weld bead.

crater cracks: cracks that form in the crater, or end, of the weld bead.

creep: a time-dependent permanent deformation that occurs under stress levels below the yield stress.

Cr/Fe ratio: see *total Cr/Fe ratio*.

dead leg: a space where system design and operating conditions result in insufficient process fluid flow, presenting a risk for particulate, chemical, or biological contamination.

defects: discontinuities that by nature or accumulated effect (e.g., total crack length) render a part or product unable to meet requirements.

deionized water: a grade of purified water produced by the exchange of cations for hydrogen ions and anions for hydroxyl ions.

delamination: separation into constituent layers.

descaling: the removal of heavy, tightly adherent oxide films resulting from hot-forming, heat-treatment, welding, and other high-temperature operations such as in steam systems.

direct visual examination: a visual examination where there is an uninterrupted optical path from the observer's eye to the area to be examined. This can be either unaided or aided via mirrors, lenses, etc.

dirty: a relative term indicating the condition of being contaminated.

discoloration: any change in surface color from that of the base metal. Usually associated with oxidation occurring on the weld and heat-affected zone on the outside diameter and inside diameter of the weld joint as a result of heating

the metal during welding. Colors may range from pale bluish-gray to deep blue, and from pale straw color to a black crusty coating.

discontinuity: interruption of the typical structure of a material, such as a lack of homogeneity in the mechanical, metallurgical, or physical characteristics of the material or weldment. A discontinuity is not necessarily a defect. (See also *defects*.)

distribution system: centralized system for the delivery of fluids from point of generation or supply to point of use.

downslope: that part of an automatic orbital weld sequence during which the welding current is gradually reduced prior to extinguishing of the welding arc. The downslope portion of a welded joint is seen as a tapering of the end of the weld bead with a reduction of penetration from the beginning to the end of the downslope so that the final weld bead is small with minimal penetration.

drainable: a designed characteristic of a component, equipment, or system that enables the removal of water by means of gravity except for that which remains due to surface adherence. Drain paths that become blocked due to surface-adhered water are not considered drainable.

duplex stainless steel: a group of stainless steels whose chemical composition is designed to produce a room-temperature microstructure that is a mixture of austenite and ferrite.

durometer: measurement of hardness related to the resistance to penetration of an indenter point in to a material as typically determined by ASTM D2240.

dynamic seal: seal with a component that is in motion relative to a second surface.

dynamic spray device: a moving device designed to produce a nonstationary spray pattern.

elastomer: rubber or rubberlike material possessing elasticity. (See also *elastomeric material*.)

elastomeric material: a material that can be stretched or compressed repeatedly and, upon immediate release of stress, will return to its approximate original size.

electropolishing: a controlled electrochemical process utilizing acid electrolyte, direct current, anode, and cathode to smooth the surface by removal of metal.

end grain effect: a surface discontinuity of small diameter (or linear) cavities located perpendicular to the rolling direction of the material and appearing after electropolishing.

etching: the process of selectively removing material from a surface using a chemical and/or electrolytic process.

ethical pharmaceutical: a controlled substance for the diagnosis or treatment of disease.

examination: as it relates to pressure vessels, vessels not rated for pressure service, process piping, and process contact equipment, the quality control functions carried out by the manufacturer, fabricator, or erector.

excessive penetration: weld penetration whose extent is greater than that required. (See also *convexity*.)

expiration date: the date after which the shelf life has been exceeded.

extractables (polymeric): chemicals that can be removed from polymeric articles using appropriate solvents.

fermentation: the biochemical synthesis of organic compounds by microorganisms or cultivated cells.

fermentor: a vessel for carrying out fermentation. Also called *fermenter*.

finishing marks: any surface texture or pattern resulting from cutting, machining, forming, grinding, polishing, and/or other finishing methods.

fixture marks: an area on an electropolished component where the electrical connection was made for the processing of the component.

flash electropolish: an electrochemical process done for a very short duration of time with a low current density, which neither significantly alters the surface of the material nor meets the acceptance criteria as set forth in Nonmandatory Appendix H, Table H-4.3-1.

fluoropolymer: polymer material having a carbon chain either partially or completely bonded to fluorine atoms.

flushing: the flowing of water over the process contact surfaces of system components for the removal of particulates or water-soluble contaminants. Also called *rinsing*.

full penetration: a weld joint in which weld material extends all the way through the joint thickness.

fusion: the melting together of filler metal and base metal, or of base metal only, that results in coalescence.

fusion welding: welding in which the base metal is fused together either with or without the addition of filler material.

gasket: static seal made from deformable material compressed between two mating surfaces.

gas tungsten-arc welding (GTAW): an arc welding process that produces coalescence of metals by heating them with an arc between a tungsten (nonconsumable) electrode and the work. Shielding is obtained from a gas or gas mixture. (This process is sometimes referred to by the nonstandard term “TIG,” which means “tungsten inert gas.”) GTAW may be performed either with or without filler metal.

GMP facility: a facility designed, constructed, and operated in accordance with cGMP guidelines established by the FDA.

grain boundary: an interface separating two grains, where the orientation of the lattice structure changes from that of one grain to that of the other.

harvesting: the separation of cells from growth media. This can be accomplished by filtration, precipitation, or centrifugation.

haze: a localized diminished surface brightness, commonly produced by gassing or variations of the essential variables during electropolishing.

heat-affected zone: that portion of the base metal or polymer that has not been melted, but whose microstructure or mechanical properties have been altered by the heat of joining or cutting.

heat number: an alphanumeric identification of a stated tonnage of metal obtained from a continuous melting in a furnace.

High Efficiency Particulate Air (HEPA) filter: a type of air filter that removes 99.97% of particles 0.3 μ and larger in diameter.

higher alloy: a metal containing various alloying constituents formulated to provide enhanced corrosion resistance and possibly improved mechanical properties beyond those that are typically observed in 316L-type stainless steel.

holdup volume: the volume of liquid remaining in a vessel or piping system after it has been allowed to drain.

hydrotest: a pressure test of piping, pressure vessels, or pressure-containing parts, usually performed by pressurizing the internal volume with water at a specified pressure.

hygienic: of or pertaining to equipment and piping systems that by design, materials of construction, and operation provide for the maintenance of cleanliness so that products produced by these systems will not adversely affect human or animal health.

hygienic clamp joint: a tube outside diameter union consisting of two neutered ferrules having flat faces with a concentric groove and mating gasket that is secured with a clamp, providing a nonprotruding, recessless process contact surface.

hygienic joint: a tube outside diameter union providing a nonprotruding, recessless process contact surface.

inclusions: particles of foreign material in a metallic or polymer matrix.

incomplete fusion: a weld discontinuity in which fusion does not occur between weld metal and fusion faces or between adjoining weld beads. Also, in welding of tubing, when the weld fully penetrates the wall thickness but misses the joint, leaving some portion of the inner (inside diameter) weld joint with unfused edges. Also called *lack of fusion*.

incomplete penetration: a groove weld in which the weld metal does not extend completely through the joint thickness. Also called *lack of penetration*.

indication: evidence obtained from a nondestructive examination method.

inspection:

as it relates to pressure vessels: functions or actions carried out by an ASME-accredited Authorized Inspector; normally a regular employee of an ASME-accredited Authorized Inspection Agency (or equivalent for other applicable codes or standards) in accordance with ASME BPVC, Section VIII.

as it relates to process piping, tubing, and process contact surfaces: functions performed by the owner's Inspector to verify that all required examinations and testing have been completed and to evaluate the physical attributes of the piping to the extent necessary to be satisfied that it conforms to all applicable requirements.

integrity test (single-use): a test used to confirm the defined barrier properties of a single-use system, in accordance with ASTM E3336.

interrupted electropolish: a break in the continuity of the electropolished surface appearance, due to a change of electropolishing conditions at the overlapping boundaries, which may occur when surfaces are electropolished by zones. It may be visible as haze, cloudiness, or variance in luster across these overlapping boundaries.

ISO class 1–9: clean room classifications based on air particulate concentration as defined by the International Organization for Standardization in ISO 14644-1.

joint penetration: the depth that a weld extends from the lower of the two base metal surfaces being joined into a joint, exclusive of reinforcement.

lack of fusion after reflow: a discontinuity in autogenous welding of tubing where, after a reflow or second weld pass has been made, the original joint has still not been consumed, leaving the weld joint with unfused edges on the inner surface.

leachables (polymeric): typically a subset of extractables, these chemicals migrate from polymeric articles into the product or process fluid.

leak test (single-use): a test used to identify leaks not correlated to the defined barrier properties of a single-use system, in accordance with ASTM E3336.

looped header: a piping ring with multiple branches for inlet or outlet. The branches on the ring can be closed by valves, caps, or other means of flow isolation.

luster: the state or quality of shining by reflecting light. (See also *variance in luster*.)

machine welding: welding with equipment that performs the welding operation under the constant observation and control of a welding operator. The equipment may or may not perform the loading and unloading of the works.

manual welding: welding in which the entire welding operation is performed and controlled by hand.

material manufacturer: an organization responsible for the production of products meeting the requirements of the material specification(s).

Material Test Report (mill test report or *MTR):* a document in which the results of tests, examinations, repairs, or treatments required by the material specification to be reported are recorded. This document includes those of any supplementary requirements or other requirements stated in the order for the material. This document may be combined with a Certificate of Conformance as a single document.

material type: a commercial designation for a given alloy or chemical composition.

maximum allowable leakage limit (MALL) (single-use): the greatest leakage rate (or leak size) tolerable for a given single-use system to maintain its barrier properties under its use-case conditions (e.g., prevent any risk to product safety, product quality, or operator and environmental safety), in accordance with ASTM E3336.

maximum working pressure: the pressure at which the system is capable of operating for a sustained period of time.

maximum working temperature: the temperature at which the system is capable of operating for a sustained period of time. The maximum working temperature should relate to the maximum working pressure and the fluids involved.

meandering: alternating side-to-side deviation of a weld bead from the center of the joint. See Figure MJ-8.4-4, illustration (c).

mechanical polishing: a process by which abrasive media is applied to a surface until the specified surface roughness (R_a) is achieved.

mechanical seal: a device used for sealing fluids with rotating shafts. A mechanical seal is a prefabricated or packaged assembly that forms a running seal between flat surfaces.

micron (1 μ): one-millionth of a meter. Also called *micrometer* (1 μm).

misalignment: in welding, offset of the surfaces of two members to be joined or that have been joined. Also called *mismatch*.

miter: two or more straight sections of tube matched and joined in a plane bisecting the angle of junction so as to produce a change of direction.

molded seal: a seal that is manufactured by forming in a mating cavity.

mold flash: excess material that is greater than the designed geometry of a part that is formed in the molding process.

multiuse: a term describing process contact components, equipment, and systems that are designed to be cleaned, sanitized, or sterilized and used multiple times (also referred to as repeated use).

nick: a surface void anomaly caused by material removal or compression from the surface, whose bottom surface is usually irregular.

nominal outside diameter: a numerical identification of outside diameter to which tolerances apply.

nominal wall thickness: a numerical identification of wall thickness to which tolerances apply.

nonsliding seal: a seal that does not have transverse or rotational movement between the seal and mating surface or surfaces.

nonuniform mechanical polishing marks: a localized surface polishing pattern that is dissimilar to the surrounding area.

off angle: a measurement of face-to-face squareness.

off plane: a measurement of the offset between part centerlines or two planes.

open head: for orbital GTAW, a welding head that is open to the atmosphere external to the tube/pipe being welded and that does not enclose the shielding gas, which is still provided through the torch.

orange peel: large-featured, roughened type of surface visible to the unaided eye whose surface appearance pattern is like that of an orange peel.

orbital welding: automatic or machine welding of tubes or pipe with the electrode rotating (or orbiting) around the work. Orbital welding can be done with or without the addition of filler metal.

O-ring: ring seal of circular cross section.

outboard seal: a seal that is outside the product area in the outermost part of a mechanical seal assembly.

overlap: the protrusion of weld metal beyond the weld toes or weld root.

owner/user: the body on which final possession or use rests.

oxidation: a common form of electrochemical reaction that is the combining of oxygen with various elements and compounds.

oxide island: a concentration of nonmetallic impurities (often oxides or nitrides) that may form in the weld pool and solidify on the underbead or weld top surface.

packing: a type of shaft seal formed into coils, spirals, or rings that is compressed into the seal cavity.

particulates (single-use): small, solid, and mobile matter.

passivation: removal of exogenous iron or iron from the surface of stainless steels and higher alloys by means of a chemical dissolution, most typically by a treatment with an acid solution that will remove the surface contamination and enhance the formation of the passive layer.

passive layer: a chromium-enriched oxide layer on a stainless steel surface that improves the corrosion resistance of the base metal.

passivity: the state in which a stainless steel exhibits a very low corrosion rate; the loss (or minimizing) of chemical reactivity exhibited by certain metals and alloys under special environmental conditions.

PE: polyethylene, polymer material composed of carbon and hydrogen.

penetration: see *full penetration, incomplete penetration*, and *joint penetration*.

personal care products: products used for personal hygiene or cosmetic care.

PFA: perfluoroalkoxy, copolymer of tetrafluoroethylene and perfluorovinyl ether.

pharmaceutical: relating to the use and/or manufacture of medical drugs or compounds used to diagnose, treat, or prevent a medical condition.

pickling: a chemical process for cleaning and descaling stainless steel and other alloy parts, equipment, and systems.

pipe: pipe size is determined by diameter and schedule, series, or SDR. For bioprocessing equipment, pipe does not include tube.

pit: a small surface void resulting from a localized loss of base material.

pitch: to cause to be set at a particular angle or slope; degree of slope or elevation.

polymer: a molecule consisting of many smaller groups. Polymers can be synthesized either through chain reactions or by templating. Some examples of polymers are plastics, proteins, DNA, and dendrimers.

polymeric material: a natural or synthetic material whose molecules are linked in a chain.

polypropylene (PP): polymer material composed of carbon and hydrogen.

porosity: cavity-type discontinuities formed by gas entrapment during solidification.

pressure rating: pressure at which a system is designed to operate, allowing for applicable safety factors.

process component: a constituent part of equipment or a system that contacts the product or process fluid. Examples of process components include, but are not limited to, tube, fittings, gaskets, valves, and instruments.

process contact surface: a surface under design operating conditions that is in contact with, or has the potential to be in contact with, raw materials, in-process materials, APIs, clean utilities (e.g., WFI, CIP, pure steam, process gases), or components (e.g., stoppers) and where there is a potential for the surface to affect product safety, quality, identity, strength, or purity.

process equipment: an assembly of components that, when combined, provides the platform for one or more process operations including, but not limited to, storage, momentum transfer, heat transfer, mass transfer, and separation. Examples of process equipment include, but are not limited to, pumps, vessels, heat exchangers, chromatography columns, centrifuges, and filter housings.

process system: an assembly of components, equipment, and subsystems that, when integrated, provides a platform for one or more process operations to produce an output within predefined specifications. Examples of process systems include, but are not limited to, bioreactor, chromatography, CIP, and purified water systems.

process zone: area to which the product is potentially exposed during manufacturing (e.g., interior of bioreactor after SIP). The manufacturing suite environment is not in the process zone unless the system is open.

product contact surface: a process contact surface that is in contact with, or has the potential to be in contact with, a product where product is defined by the owner/user. Examples of product contact surfaces may include the interior surfaces of bioreactors, transfer tubing, chromatography columns, vessels, and recirculating segments of CIP systems.

profilometer: an instrument for the measurement of the degree of surface roughness.

progressive polishing: a mechanical grinding procedure where a coarse grit material is used first and the successive operations use a finer and finer grit until the desired surface roughness is achieved.

PTFE: polytetrafluoroethylene, homopolymer material of tetrafluoroethylene.

pure steam: also known as *clean steam*, steam that is produced by a steam generator that, when condensed, meets requirements for water-for-injection (WFI).

purified water (PW): a classification of water according to compendial standards.

PVDF: polyvinylidene fluoride, homopolymer, and/or copolymer material composed of carbon, hydrogen, and fluorine.

pyrogen: a fever-producing substance.

Quality Inspector's Delegate: a person who is delegated by an owner's Inspector to perform inspection functions as referenced in ASME B31.3, para. 340.4(c).

Quality System Certificate: a document issued by ASME that authorizes the use of an ASME Certificate number on Certificates of Conformance for a specified time and for a specified scope of activity.

R_a*:* log of the arithmetic mean of the surface profile.

R_a*max.:* the highest value of a series of R_a readings.

reflow: in autogenous welding, a second pass used to repair specific defects.

reinforcement: see *convexity*.

remote visual examination: a visual examination where there is an interrupted optical path from the observer's eye to the area to be examined. This covers the use of photography, video systems, videoscopes, and borescopes.

repeated use: see *multiuse*.

rouge: a general term used to describe a variety of discolorations in high-purity stainless steel biopharmaceutical systems. It is composed of metallic (primarily iron) oxides and/or hydroxides. Three types of rouge have been categorized.

Class I rouge: a rouge that is predominantly particulate in nature that tends to migrate downstream from its origination point and can deposit on process contact surfaces. It is generally orange to red-orange in color. These particles can be wiped off a surface and are evident on a wipe. Surface composition under the rouge remains unchanged.

Class II rouge: a localized form of active corrosion. It occurs in a spectrum of colors (orange, red, blue, purple, gray, black). It can be the result of chloride or other halide attack on the surface of the stainless steel.

Class III rouge: a surface oxidation condition occurring in high-temperature environments such as pure steam systems. The system's color transitions to gold, to blue, to various shades of black, as the layer thickens. This surface oxidation initiates as a stable layer and is rarely particulate in nature. It is an extremely stable form of magnetite (iron sesquioxide, Fe_3O_4).

sanitary: see *hygienic*.

schedule: dimensional standard for pipe as defined by ASTM.

scratch: an elongated mark or groove cut in the surface by mechanical means, not associated with the predominant surface texture pattern.

SDR: standard dimension ratio, a sizing system for polymer piping systems that relates wall thickness to pressure rating as defined by ISO.

seal chamber: see *stuffing box*.

seal face: surface point on which a seal is achieved.

seal point: location of process boundary created by components in contact (seal), having sufficient contact stress/load to create media or environmental isolation.

seal weld: a weld intended primarily to provide joint tightness against leakage in metallic piping for which strength or size requirements are optional. (See also *autogenous fillet weld*.)

seat leakage: a quantity of test fluid passing through an assembled valve in the closed position under the defined test conditions.

SEM: scanning electron microscope.

semi-automatic arc welding: arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.

service life: the life expectancy or number of cycles for which the unit will maintain its performance.

shelf life: the duration, under specified storage conditions, from the date of manufacture to the last date the product can be placed in service without having an unacceptable effect on performance.

shell leakage: a quantity of test fluid passing from the inside of a component externally to atmosphere under the defined test conditions.

significant change (polymeric): a change that may affect form, fit, or function.

single-use: a term describing process contact components, assemblies, and systems that are designed to be used once, and not to be cleaned or sterilized for reuse.

slag: a nonmetallic product resulting from the mutual dissolution of flux and nonmetallic impurities in some welding and brazing operations.

sliding seal: a seal that has transverse or rotational movement between the seal and mating surface(s).

slope: an incline or deviation from the horizontal. A tube or pipe installed in the horizontal plane is said to slope if one end is positioned higher than the other.

sparger: a device used to agitate, oxygenate, or aerate a liquid by means of compressed air or gas.

spatter: the metal particles expelled during welding that do not form part of a weld.

special process: a process, the results of which are highly dependent on the control of the process or the skill of the operators, or both, and in which the specified quality cannot be readily determined by inspection or test of the product.

spot electropolishing: a localized electrochemical process that is capable of producing the correct Cr to Fe ratios on the surface of a material and meeting the requirements of Nonmandatory Appendix H, Table H-4.3-1.

spray device: device for the directed distribution (delivery) of liquids to defined process contact surfaces of equipment. (See also *dynamic spray device* and *static spray device*.)

square cut: a tube end cut perpendicular to the tangent plane.

squareness: face-to-face perpendicularity.

static seal: a stationary sealing device.

static spray device: a stationary device designed to produce a fixed directional spray pattern.

steam-in-place (SIP): the use of steam to sanitize or sterilize a piece of equipment without the use of an autoclave.

stem seal: a seal element that is used on a shaft.

sterile: free from living organisms.

sterility: the absence of all life forms.

strainer: a component that mechanically separates and retains suspended solid particulates from a process fluid. (See also *strainer body* and *strainer element*.)

strainer body: the subcomponent of a strainer that holds or houses the strainer element. A strainer body can be part of the process piping in which the strainer is installed (e.g., gasket strainer).

strainer element: the subcomponent of a strainer with openings (e.g., perforations, slots). This subcomponent provides the straining of suspended solid particulates.

stringer: a linear discontinuity containing an elongated nonmetallic inclusion or secondary phase.

stuffing box: in shaft seals, the casing containing the sealing material; seal chamber for shaft seals. (See also *packing*.)

superaustenitic stainless steel: a subgroup of austenitic stainless steels having elevated levels of nickel, chromium, and molybdenum compared with standard austenitic stainless steels (e.g., UNS S31603) and that may have other additions (e.g., nitrogen and/or copper) to increase strength and resistance to pitting corrosion and stress corrosion cracking in the presence of chlorides.

super duplex stainless steel: those duplex stainless steels whose chemical composition is designed to result in a pitting resistance equivalent number (PREN) of at least 40.

surface finish: all surfaces as defined by Part SF of the current ASME BPE Standard and/or the owner/user or manufacturer and expressed in R_a inches or meters.

surface inclusion: particles of foreign material in a metallic matrix. The particles are usually compounds such as oxides, sulfides, or silicates, but may be a substance foreign to and essentially insoluble in the matrix.

surface residual: a foreign substance that adheres to a surface by chemical reaction, adhesion, adsorption, or ionic bonding (e.g., corrosion, rouging, and staining).

surveillance: the act of an ASME Certificate Holder's monitoring or observing a supplier's in-process production activities at the location of work to verify whether an item conforms to specified requirements.

survey: an ASME Certificate Holder's documented evaluation of a supplier's ability to supply items to meet specified requirements as verified by a determination of the adequacy of the organization's quality management system for the items to be procured and by review of the implementation of that quality management system at the location of work.

survey (as performed by ASME or their designee on ASME BPE Certificate Holders and Applicants): see ASME CA-1.

swing elbow: a movable elbow used to connect and reconfigure flow paths.

system volume: total volume of liquid in the system, including equipment, piping, valving, and instrumentation.

tack weld: a weld made to hold members or consumable inserts in proper alignment until the final welds are made.

testing:

as it relates to pressure vessels: a function of the manufacturer or fabricator, as witnessed by the examiner or ASME Authorized Inspector and verified or witnessed by the owner's Inspector or the Quality Inspector's Delegate including written documentation in accordance with ASME BPVC, Section VIII (or equivalent for other applicable codes or standards).

as it relates to process contact equipment: a function of the manufacturer, fabricator, or erector, as witnessed by the examiner and may be verified or witnessed by the owner's Inspector or the Quality Inspector's Delegate including written documentation in accordance with ASME BPE.

as it relates to process piping: a function of the manufacturer, fabricator, or erector, as witnessed by the examiner or Inspector and verified or witnessed by the owner's Inspector or the Quality Inspector's Delegate including written documentation in accordance with ASME B31.3.

as it relates to vessels not rated for pressure service: a function of the manufacturer, fabricator, or erector, as witnessed by the examiner and verified or witnessed by the owner's Inspector or the Quality Inspector's Delegate including written documentation.

thermoplastic: long-chain polymers that are usually not connected by crosslinks. Once formed, these materials can be reshaped.

thermoset: long-chain polymers that are usually connected by crosslinks. Once formed, these materials cannot be reshaped.

total Cr/Fe ratio: the ratio calculated from the peak areas of all species, elemental and oxides, of each element from the high-resolution data of the as-received surface (see SEMI F60).

transfer panel: a panel to which process and/or utilities are piped that mechanically precludes erroneous cross-connections.

tube: tube is sized by its nominal outside diameter. For bioprocessing equipment, tube does not include pipe.

tungsten inclusions: tungsten particles transferred into the weld deposit. Tungsten inclusions may be invisible to the unaided eye, but are readily identified in a radiograph.

Ultra-Low Particulate Air (ULPA) filter: a type of air filter that removes 99.999% of particles 0.1 μ and larger in diameter.

unacceptable leakage: leakage level above which the system performance is considered unacceptable by the system user and applicable regulating body.

undercut: a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

underfill: a depression on the weld face or root surface extending below the adjacent surface of the base metal. (See also *concavity*.)

uniformly scattered porosity: porosity that is distributed in a weldment in a uniform pattern.

user: see *owner/user*.

validation: establishing documented evidence that the system does what it purports to do.

variance in luster: the appearance of a different shine or reflectivity resulting from the examination or inspection technique or from the preconditioning or conditioning of the electropolished surface.

videoscope: a type of borescope with a camera chip mounted to the instrument for taking photos or videos of the area of examination.

waviness: undulations or rippling of the surfaces.

welding operator: one who operates machine or automatic welding equipment.

weld joint design: the shape, dimensions, and configuration of the weld joint.

weld whitening: a difference in appearance of grain structure between weld metal and base metal after electropolishing.

WFI: water-for-injection, a classification of water according to compendial standards.

GR-12 NOMENCLATURE (24)

Dimensional and mathematical symbols used in this Standard are listed in Mandatory Appendix IV with definitions for each symbol given in addition to their point-of-use location or locations within the Standard. Uppercase and lowercase English letters are listed alphabetically, followed by Greek letters.

CHAPTER 2
CERTIFICATION

PART CR
CERTIFICATION REQUIREMENTS

CR-1 PURPOSE AND SCOPE

Part CR establishes the requirements for an organization manufacturing components in accordance with the ASME BPE Standard to certify the components under an ASME Certificate of Authorization or an ASME Quality System Certificate. The type of certificate issued is based on the type of components manufactured, as identified in Table CR-1-1.

Application of the ASME Single Certification Mark with the "BPE" certification designator (see Figure CR-1-1) to components or documentation that fulfills the requirements of the ASME BPE Standard is granted by ASME under a Certificate of Authorization.

An ASME Quality System Certificate is issued to a manufacturer to identify the acceptance of its Quality Management System (QMS) by ASME. That manufacturer may then issue a Certificate of Conformance, bearing its Certificate number, with components that fulfill the requirements of the ASME BPE Standard.

Both programs are voluntary certification programs; however, organizations seeking to apply the ASME Single Certification Mark or issue the Certificate of Conformance shall conform with the requirements of Part CR.

In Part CR, the term "components" shall be limited to those listed in Table CR-1-1.

CR-2 GENERAL

(a) To obtain, maintain, and renew an ASME Certificate, applicants and Certificate Holders shall conform with the conformity assessment requirements addressed in ASME CA-1. An ASME BPE Certificate Holder shall have a QMS in conformance with Nonmandatory Appendix Z. The essential controls of the QMS ensuring the components' conformance with the ASME BPE Standard shall be documented in a QMS Manual. Decisions to issue, renew, suspend, withhold, or withdraw an ASME Certificate are made by ASME based upon surveys, audits, and investigations conducted by an ASME team. A list of ASME BPE Certificate Holders can be found on the ASME website.

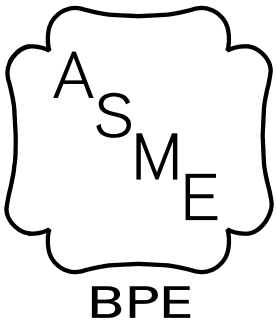
(b) ASME surveys are conducted by an ASME team to evaluate the capability of an organization to manufacture components in conformance with the requirements of its QMS and the ASME BPE Standard. Surveys are conducted as part of the ASME decision process for the issuance or renewal of an ASME Certificate. ASME Certificates are issued and renewed with an expiration date by which time the Certificate Holders shall have their QMS Manual and its implementation surveyed by ASME. During the term of the ASME Certificate, Certificate Holders are subject to a planned audit program by

(24) **Table CR-1-1**
Types of ASME BPE Certificates

Component	Certificate of Authorization	Quality System Certificate
Metallic fittings	X	...
Metallic tubing	X	...
Metallic valves	X	[Note (1)]
Polymeric seals	...	X

NOTE: (1) Valve Certificate Holders may issue a Certificate of Conformance for polymeric seals they manufacture within the scope of their authorization.

Figure CR-1-1
The ASME Single Certification Mark With the BPE Certification Designator



ASME. Additional audits may be conducted based upon the results of past surveys and audits or complaints.

(c) Certificate Holders who manufacture components under a Certificate of Authorization shall provide designated oversight of their activities and the proper utilization of the ASME Single Certification Mark. This shall be performed by a Certified Individual (CI). The CI shall be an employee of the Certificate Holder and shall be qualified and certified by the Certificate Holder. The Certificate Holder's qualification and certification program for the CI shall be subject to evaluation at the time of the ASME survey.

(d) Certificate Holders who manufacture components under a Quality System Certificate are not required to use a CI to provide designated oversight of their activities.

(24) **CR-2.1 ASME BPE Certificate Holders**

(a) An ASME BPE Certificate Holder shall have a QMS that has been reviewed and accepted by ASME and shall have demonstrated their capability to fulfill the requirements of the ASME BPE Standard for the scope of work identified on the ASME Certificate.

(b) ASME BPE Certificate Holders shall be issued a Certificate number to be used to attest to the validity of their certification statements on documentation, Certificates of Conformance, or both.

(c) Written references indicating that an organization is an ASME BPE Certificate Holder shall not be valid without reference to the Certificate number.

(d) ASME BPE Certificate Holders shall be authorized, under a valid Certificate of Authorization, to mark components, documentation traceable to the components, or both, with the ASME Single Certification Mark with the BPE certification designator and their Certificate number.

(e) When an ASME BPE Certificate Holder supplies documentation for a manufactured component that includes material supplied by another organization, it is not mandatory for the Certificate Holder to add their ASME Single Certification Mark with BPE certification designator to the documentation received from the original organization. However, if the Certificate Holder chooses to add their ASME Single Certification Mark with BPE certification designator in addition to that on the existing documentation from the original organization, the additional markings shall be clearly identified and traceable to the Certificate Holder.

CR-2.2 ASME BPE Certificate Holder's Responsibilities

CR-2.2.1 All Certificate Holders shall be responsible for

(a) obtaining an ASME BPE Certificate issued by ASME in accordance with Table CR-1-1

(b) conformance to the latest edition of ASME CA-1 as applicable to the ASME BPE Certification Program

(c) conformance to all requirements of the ASME BPE Standard, as applicable, for the scope of work identified on the ASME BPE Certificate

(d) establishing and maintaining an effective QMS under Part CR

(e) documenting the QMS as follows:

(1) The QMS Manual shall provide a detailed description of the items and services that are being provided under the company's ASME BPE Certificate and address the essential controls for each element identified in Nonmandatory Appendix Z.

(2) The Certificate Holder shall prepare procedures, work instructions, forms, and other implementing documents specified by the QMS.

(f) filing a controlled copy of the QMS Manual with ASME

(g) qualifying and approving suppliers of subcontracted work

CR-2.2.2 Organizations manufacturing components under an ASME BPE Certificate of Authorization are also responsible for the following:

(a) ensuring that the BPE certification designator is used in conjunction with the ASME Single Certification Mark. The BPE certification designator shall be the responsibility of the Certificate Holder. The BPE certification designator shall consist of the uppercase letters "BPE" and shall be of a design having similar proportions to that shown in Figure CR-1-1. The BPE certification designator shall be legible and located immediately beneath the ASME Single Certification Mark.

(b) establishing and defining competency requirements for the qualification and certification of a CI.

(c) establishing and defining the duties for the CI.

(d) providing authorization for the CI to perform duties that protect the integrity of the ASME Single Certification Mark with the BPE certification designator.

(e) providing authorization for the CI to notify ASME when the ASME Single Certification Mark with the BPE certification designator is being inappropriately controlled or misused.

CR-2.2.3 All Certificate Holders shall be responsible (24) for proper use of ASME markings, i.e., the ASME Single Certification Mark, "ASME," or the ASME Certificate number. These markings shall certify conformance with the ASME BPE Standard and shall clearly indicate by stampings, labels, nameplates, documentation, or Certificates of Conformance that the component is certified by the name of the Certificate Holder as it appears on the ASME BPE Certificate.

CR-2.3 Certified Individual Requirements Under a Certificate of Authorization

Certificate Holders performing work under a Certificate of Authorization shall have a CI providing designated oversight of the proper utilization of the ASME Single Certification Mark with the BPE certification designator.

CR-2.3.1 Competency Requirements. The Certificate Holder shall establish and define the competency requirements for an individual to qualify and be certified as a CI.

(a) At a minimum, the competency requirements shall require the individual to

(1) be an employee of the Certificate Holder with authorization to ensure the ASME Single Certification Mark with the BPE certification designator is not misused and to contact ASME on matters concerning the integrity of the Mark

(2) have knowledge of the applicable requirements of the ASME BPE Standard for the application of the ASME Single Certification Mark with the BPE certification designator

(3) have knowledge of the Certificate Holder's QMS

(4) have training commensurate with the scope, complexity, or special nature of the activities to which oversight is to be provided

(b) The individual meeting the established competency requirements under the Certificate Holder's qualification and certification program shall be certified by the Certificate Holder to be able to perform the duties of a CI.

(c) The Certificate Holder shall maintain a record of the qualifications and training of the CI.

CR-2.3.2 Duties of the Certified Individual. The duties of the CI shall include, but are not limited to (24)

(a) verifying that each component to which the ASME Single Certification Mark with the BPE certification designator is applied conforms with both the QMS on file with ASME and the applicable requirements of the ASME BPE Standard. Verification activities include, but are not limited to, ensuring the component is manufactured in accordance with

(1) the scope of the ASME Certificate of Authorization

(2) a valid and current ASME Certificate of Authorization

(3) the QMS Manual on file with ASME

(b) certifying the appropriate documentation, Certificate of Conformance, or both prior to release of the BPE component. This certification shall attest to the component being in conformance with the ASME BPE Standard and shall be by signature or other means as described in the organization's QMS.

(c) terminating the application of the ASME Single Certification Mark with the BPE certification designator on components that do not conform with the QMS or the ASME BPE Standard.

(d) notifying ASME when the QMS, or any portion thereof, is not being effectively implemented.

(e) being present during ASME surveys, audits, and investigations.

CHAPTER 3
MATERIALS

PART MM
METALLIC MATERIALS

MM-1 PURPOSE AND SCOPE

The purpose of this Part is to identify metallic materials considered acceptable for use in hygienic service. It identifies material specifications, grades and alloys, appropriate filler metals, and other attributes necessary for this service. It also specifies the data that must be submitted to the MM Subcommittee for any new or unlisted alloy that is proposed for inclusion in Part MM.

MM-2 ALLOY DESIGNATIONS

MM-2.1 General

This Part identifies those metallic materials that have demonstrated the ability to meet welding and surface finish criteria as set forth in other Parts of this Standard. It is the responsibility of the owner/user to ensure that any metallic materials selected for use from those listed in Tables MM-2.1-1 through MM-2.1-4 are appropriate for the intended application.

The guidelines and criteria listed in this Part indicate a general acceptability for use and do not address the specifics of fabrication or requirements of any given service.

MM-3 USES OF SPECIFICATIONS

MM-3.1 General

The specifications listed in MM-4.2 through MM-4.6 may contain references to codes, standards, or specifications not listed in this Part. Such unlisted codes, standards, or specifications are to be used only in the context of the listed documents in which they are referenced. Where specifications listed in MM-4.2 through MM-4.6 contain design rules that are in conflict with this Standard, the design rules of this Standard shall govern.

MM-3.2 Listed Specifications

Materials manufactured to specifications listed in the appropriate sections of MM-4.2 through MM-4.6 may be used for applications governed by this Standard, provided they meet all requirements of those specifications.

Austenitic stainless steel tube shall be capable of passing the weld decay test in ASTM A249/A249M, Supplement S7 and either the intergranular corrosion test in ASTM A270/A270M, Supplement S1 or ISO 3651-2 Method B.

Materials used in applications governed by this Standard shall conform to a specification listed in MM-4.2 through MM-4.6, except as provided in MM-3.3.

MM-3.3 Unlisted Specifications

Alloys in specifications not listed in MM-4.2 through MM-4.6 may be used for applications governed by this Standard provided they conform to a published specification covering composition, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control, and otherwise meet the chemical composition requirements of one of the specifications listed in MM-4.2 through MM-4.6. Alloys not listed in Tables MM-2.1-1 through MM-2.1-4 may be used for applications governed by this Standard provided the following requirements are met:

(a) The applicable requirements of MM-9 are met.

(b) The specific written permission of the owner/user is obtained.

Materials listed in MM-5.2.5 are exempt from the requirements of MM-3.3.

MM-3.4 Unknown Materials

Materials of unknown origin or specification shall not be used in hygienic service.

Table MM-2.1-1
Wrought Stainless Steels: Nominal Compositions (wt. %)

(24)

UNS Number [Note (1)]	EN Designation	JIS Designation	C	Mn	N	Cr	Ni	Mo	Cu
Austenitic Stainless Steels									
S30400	...	...	0.07	2.00	0.10	18.0–20.0	8.0–11.0	...	...
...	1.4301	...	0.07	2.00	0.10	17.5–19.5	8.0–10.5	...	...
...	...	SUS304	0.08	2.00	...	18.0–20.0	8.0–10.5	...	...
S30403	...	...	0.030	2.00	0.10	18.0–20.0	8.0–12.0	...	...
...	1.4307	...	0.030	2.00	0.10	17.5–19.5	8.0–10.5	...	...
...	1.4306	...	0.030	2.00	0.10	18.0–20.0	10.0–13.0	...	...
...	...	SUS304L	0.030	2.00	...	18.0–20.0	9.0–13.0	...	...
S31600	...	...	0.08	2.00	0.10	16.0–18.0	10.0–14.0	2.00–3.00	...
...	1.4401	...	0.07	2.00	0.10	16.5–18.5	10.0–13.0	2.00–2.50	...
...	...	SUS316	0.08	2.00	...	16.0–18.0	10.0–14.0	2.00–3.00	...
S31603	...	...	0.030	2.00	0.10	16.0–18.0	10.0–14.0	2.00–3.00	...
...	1.4404	...	0.030	2.00	0.10	16.5–18.5	10.0–14.5	2.00–2.50	...
...	1.4435	...	0.030	2.00	0.10	17.0–19.0	12.5–15.0	2.50–3.00	...
...	...	SUS316L	0.030	2.00	...	16.0–18.0	12.0–15.0	2.0–3.0	...
Superaustenitic Stainless Steels									
N08904	...	...	0.020	2.00	0.10	19.0–23.0	23.0–28.0	4.0–5.0	1.0–2.0
...	1.4539	...	0.020	2.00	0.15	19.0–21.0	24.0–26.0	4.0–5.0	1.20–2.00
N08367	...	...	0.030	2.00	0.18–0.25	20.0–22.0	23.5–25.5	6.0–7.0	0.75
S31254	...	...	0.020	1.00	0.18–0.25	19.5–20.5	17.5–18.5	6.0–6.5	0.50–1.00
...	1.4547	...	0.020	1.00	0.18–0.25	19.5–20.5	17.5–18.5	6.0–7.0	0.50–1.00
N08926	...	...	0.020	2.00	0.15–0.25	19.0–21.0	24.0–26.0	6.0–7.0	0.5–1.5
...	1.4529	...	0.020	1.00	0.15–0.25	19.0–21.0	24.0–26.0	6.0–7.0	0.50–1.50
Duplex Stainless Steels									
S32101	...	...	0.040	4.00–6.00	0.20–0.25	21.0–22.0	1.35–1.70	0.10–0.80	0.10–0.80
...	1.4162	...	0.04	4.0–6.0	0.20–0.25	21.0–22.0	1.35–1.70	0.10–0.80	0.10–0.80
S32205	...	...	0.030	2.00	0.14–0.20	22.0–23.0	4.5–6.5	3.0–3.5	...
...	1.4462	...	0.030	2.00	0.10–0.22	21.0–23.0	4.5–6.5	2.50–3.5	...
S32750	...	...	0.030	1.20	0.24–0.32	24.0–26.0	6.0–8.0	3.0–5.0	0.50
...	1.4410	...	0.030	2.00	0.24–0.35	24.0–26.0	6.0–8.0	3.0–4.5	...

GENERAL NOTES:

(a) Maximum, unless range or minimum is indicated.

(b) Values listed in this Table are primary elements only and are not complete chemical compositions as listed in specific product type material specifications. Alloy composition is typically at the low end of the ranges indicated above. Refer to appropriate product type material specification for complete material composition requirements.

(c) Alloys listed between horizontal lines are not equivalent, but comparable.

NOTE: (1) For cross-referencing of the UNS numbers listed above to common alloy names, refer to SAE Metals and Alloys in the Unified Numbering System, latest edition.

Table MM-2.1-2
Wrought Nickel Alloys: Nominal Compositions (wt. %)

UNS Number [Note (1)]	EN Designation	JIS Designation	C	Cr	Ni	Mo	Cu	Other
N06625	...	...	0.10	20.0–23.0	58.0 min.	8.0–10.0	...	Fe: 5.0 max. (Nb + Ta): 3.15–4.15
...	2.4856	...	0.03–0.10	20.0–23.0	58.0 min.	8.0–10.0	0.5	Fe: 5.0 max. (Nb + Ta): 3.15–4.15 Ti: 0.40 max.
...	...	NCF625	0.10	20.0–23.0	58.0 min.	8.0–10.0	...	Fe: 5.00 max. (Nb + Ta): 3.15–4.15 Ti: 0.40 max.
N10276	...	...	0.01	14.5–16.5	Balance	15.0–17.0	...	W: 3.0–4.5 Fe: 4.0–7.0 Co: 2.5 max. Mn: 1.0 max.
...	2.4819	...	0.01	14.5–16.5	Balance	15.0–17.0	0.5	W: 3.0–4.5 Fe: 4.0–7.0 Co: 2.5 max. Mn: 1.0 max.
...	...	NW0276	0.010	14.5–16.5	Balance	15.0–17.0	...	W: 3.00–4.50 Fe: 4.00–7.00 Co: 2.50 max. Mn: 1.00 max.
N06022	...	...	0.015	20.0–22.5	Balance	12.5–14.5	...	W: 2.5–3.5 Fe: 2.0–6.0 Co: 2.5 max. Mn: 0.50 max.
...	2.4602	...	0.01	20.0–22.5	Balance	12.5–14.5	...	W: 2.5–3.5 Fe: 2.0–6.0 Co: 2.5 max. Mn: 0.50 max.
...	...	NW6022	0.015	20.0–22.5	Balance	12.5–14.5	...	W: 2.50–3.50 Fe: 2.00–6.00 Co: 2.50 max. Mn: 0.50 max.

GENERAL NOTES:
(a) Maximum, unless range or minimum is indicated.
(b) Values listed in this Table are primary elements only and are not complete chemical compositions as listed in specific product type material specifications. Alloy composition is typically at the low end of the ranges indicated above. Refer to appropriate product type material specification for complete material composition requirements.
(c) Alloys listed between horizontal lines are not equivalent, but comparable.

NOTE: (1) For cross-referencing of the UNS numbers listed above to common alloy names, refer to SAE Metals and Alloys in the Unified Numbering System, latest edition.

Table MM-2.1-3
Stainless Steel and Nickel Alloy Cast Designations

(24)

				Approximate Wrought Equivalent		
UNS Designation	ACI Designation	EN Designation	JIS Designation	UNS Designation	EN Designation	JIS Designation
Austenitic Stainless Steels						
J92600	CF8	...	...	S30400	...	...
...	...	1.4308	...	...	1.4301	...
...	...	...	SCS 13A	...	...	SUS304
J92500	CF3	...	...	S30403	...	...
...	...	1.4309	...	...	1.4307	...
...	...	...	...	...	1.4306	...
...	...	...	SCS 19A	...	...	SUS304L
J92900	CF8M	...	...	S31600	...	...
...	...	1.4408	...	...	1.4401	...
...	...	...	SCS 14A	...	...	SUS316
J92800	CF3M	...	...	S31603	...	...
...	...	1.4409	...	...	1.4404	...
...	...	...	...	...	1.4435	...
...	...	...	SCS 16A	...	...	SUS316L
Superaustenitic Stainless Steels						
J94651	CN3MN	...	...	N08367	...	...
J93254	CK3MCuN	...	...	S31254	...	...
...	...	1.4557	...	...	1.4547	...
Duplex Stainless Steels						
J92205	CD3MN	...	...	S32205	...	...
...	...	1.4470	...	...	1.4462	...
J93404	CE3MN	...	...	S32750	...	...
...	...	1.4469	...	...	1.4410	...
...	...	1.4463	...	...	...	...
...	...	1.4417	...	...	...	...
Nickel-Based Alloys						
N26625	CW6MC	...	...	N06625	...	...
...	...	...	...	...	2.4856	...
N30002	CW12MW	...	...	N10276	...	...
...	...	...	...	...	2.4819	...
N26455	CW2M	...	...	N10276	...	...
...	...	...	...	...	2.4610	...
...	...	...	...	...	2.4819	...
N30107	CW6M	...	...	N10276	...	...
...	...	...	...	...	2.4819	...
N26002	CX2MW	...	...	N06022	...	...
...	...	...	...	...	2.4602	...

GENERAL NOTE: Alloys listed between horizontal lines are not equivalent, but comparable.

Table MM-2.1-4
Wrought Copper: Nominal Compositions (wt. %)
(Cleaned for Oxygen Service)

UNS Number	EN Designation	Cu + Ag	P	O
C10200	...	99.95	...	0.00010 max.
C12000	...	99.90	0.008–0.012	...
C12200	...	99.90	0.015–0.040	...
...	CW024A	99.90	0.015–0.040	...

GENERAL NOTES:
(a) Minimum, unless range or maximum is indicated.
(b) Copper grades listed between horizontal lines are not equivalent, but comparable.

MM-3.5 Reclaimed Materials

Reclaimed process components, equipment, or both may be used with owner/user authorization, provided they are properly identified as conforming to a published specification listed in MM-4.2 through MM-4.6 or to a published specification not listed in those paragraphs and otherwise meeting the minimum requirements of MM-9. When reclaiming superaustenitic or duplex stainless steel components, refer specifically to MM-5.2.1.2 or MM-5.2.1.3, respectively.

MM-4 REFERENCED SPECIFICATIONS

MM-4.1 General

Standards and specifications adopted by reference in this Standard are listed by product form in this section. It is not considered practical to identify the specific edition of each standard and specification in the following lists; therefore, the most current edition is implied. Sources for procuring any of the listed material specifications are found in Nonmandatory Appendix Y.

Material manufactured in accordance with earlier editions of the referenced standards that in all other respects conforms to this Standard will be considered to be in conformance with this Standard.

ASME BPVC has adopted many of the listed ASTM material specifications. Materials furnished to the latest edition of these ASME specifications are also considered to be in conformance with this Standard.

When preparing an MTR, a material manufacturer may transcribe data produced by other organizations, provided he accepts responsibility for the accuracy and authenticity of the data.

(24) **MM-4.2 Tubing, Piping, and Hollow Bar**

Tubing, piping, and hollow bar manufactured in accordance with the following specifications may be used:

ASTM A213/A213M. Standard Specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes. American Society for Testing and Materials.

ASTM A249/A249M. Standard Specification for Welded Austenitic Steel Boiler, Superheater, Heat-Exchanger, and Condenser Tubes. American Society for Testing and Materials.

ASTM A269/A269M. Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service. American Society for Testing and Materials.

ASTM A270/A270M. Standard Specification for Seamless and Welded Austenitic and Ferritic/Austenitic Stainless Steel Sanitary Tubing. American Society for Testing and Materials.

ASTM A312/A312M. Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes. American Society for Testing and Materials.

ASTM A511/A511M. Standard Specification for Seamless Stainless Steel Mechanical Tubing and Hollow Bar. American Society for Testing and Materials.

ASTM A789/A789M. Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service. American Society for Testing and Materials.

ASTM A790/A790M. Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Pipe. American Society for Testing and Materials.

ASTM B444. Standard Specification for Nickel-Chromium-Molybdenum-Columbium Alloys (UNS N06625 and UNS N06852) and Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219) Pipe and Tube. American Society for Testing and Materials.

ASTM B619/B619M. Standard Specification for Welded Nickel and Nickel-Cobalt Alloy Pipe. American Society for Testing and Materials.

ASTM B622. Standard Specification for Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube. American Society for Testing and Materials.

ASTM B626. Standard Specification for Welded Nickel and Nickel-Cobalt Alloy Tube. American Society for Testing and Materials.

ASTM B675. Standard Specification for UNS N08367 Welded Pipe. American Society for Testing and Materials.

ASTM B676. Standard Specification for UNS N08367 Welded Tube. American Society for Testing and Materials.

ASTM B690. Standard Specification for Iron-Nickel-Chromium-Molybdenum Alloy (UNS N08367) Seamless Pipe and Tube. American Society for Testing and Materials.

ASTM B704. Standard Specification for Welded Nickel Alloy Tubes. American Society for Testing and Materials.

ASTM B819. Standard Specification for Seamless Copper Tube for Medical Gas Systems. American Society for Testing and Materials.
DIN 17744. Wrought nickel alloys with molybdenum and chromium — Chemical composition. Deutsches Institut für Normung.
DIN 17751. Tubes of wrought nickel alloys — Properties. Deutsches Institut für Normung.
EN 10216-5. Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 5: Stainless steel tubes. European Committee for Standardization.
EN 10217-7. Welded steel tubes for pressure purposes — Technical delivery conditions — Part 7: Stainless steel tubes. European Committee for Standardization.
EN 10312. Welded stainless steel tubes for the conveyance of water and other aqueous liquids — Technical delivery conditions. European Committee for Standardization.
EN 13348. Copper and copper alloys — Seamless, round copper tubes for medical gases or vacuum. European Committee for Standardization.
JIS G 3447. Stainless steel sanitary pipes. Japanese Industrial Standards.
JIS G 3459. Stainless steel pipes. Japanese Industrial Standards.
JIS G 4903. Seamless nickel-chromium-iron alloy pipes. Japanese Industrial Standards.

(24) MM-4.3 Castings

Castings manufactured in accordance with the following specifications may be used:

ASTM A351/A351M. Standard Specification for Castings, Austenitic, for Pressure-Containing Parts. American Society for Testing and Materials.
ASTM A494/A494M. Standard Specification for Castings, Nickel and Nickel Alloy. American Society for Testing and Materials.
ASTM A743/A743M. Standard Specification for Castings, Iron-Chromium, Iron-Chromium-Nickel, Corrosion Resistant, for General Application. American Society for Testing and Materials.
ASTM A744/A744M. Standard Specification for Castings, Iron-Chromium-Nickel, Corrosion Resistant, for Severe Service. American Society for Testing and Materials.
ASTM A890/A890M. Standard Specification for Castings, Iron-Chromium-Nickel-Molybdenum Corrosion-Resistant, Duplex (Austenitic/Ferritic) for General Application. American Society for Testing and Materials.
ASTM A995/A995M. Standard Specification for Castings, Austenitic-Ferritic (Duplex) Stainless Steel, for Pressure-Containing Parts. American Society for Testing and Materials.
EN 10213. Steel castings for pressure purposes. European Committee for Standardization.
EN 10283. Corrosion resistant steel castings. European Committee for Standardization.
JIS G 5121. Corrosion-resistant cast steels for general applications. Japanese Industrial Standards.

MM-4.4 Forgings (24)

Forgings manufactured in accordance with the following specifications may be used:

ASTM A182/A182M. Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service. American Society for Testing and Materials.
ASTM A1049/A1049M. Standard Specification for Stainless Steel Forgings, Ferritic/Austenitic (Duplex), for Pressure Vessels and Related Components. American Society for Testing and Materials.
ASTM B462. Standard Specification for Forged or Rolled Nickel Alloy Pipe Flanges, Forged Fittings, and Valves and Parts for Corrosive High-Temperature Service. American Society for Testing and Materials.
ASTM B564. Standard Specification for Nickel Alloy Forgings. American Society for Testing and Materials.
EN 10222-5. Steel forgings for pressure purposes — Part 5: Martensitic, austenitic, and austenitic-ferritic stainless steels. European Committee for Standardization.
EN 10250-4. Open die steel forgings for general engineering purposes — Part 4: Stainless steels. European Committee for Standardization.
JIS G 3214. Stainless steel forgings for pressure vessels. Japanese Industrial Standards.
JIS G 4319. Stainless steel blooms and billets or forgings. Japanese Industrial Standards.

MM-4.5 Plate, Sheet, and Strip (24)

Plate, sheet, and strip manufactured in accordance with the following specifications may be used:

ASTM A240/A240M. Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications. American Society for Testing and Materials.
ASTM A666. Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar. American Society for Testing and Materials.
ASTM B443. Standard Specification for Nickel-Chromium-Molybdenum-Columbium Alloy and Nickel-Chromium-Molybdenum-Silicon Alloy Plate, Sheet, and Strip. American Society for Testing and Materials.
ASTM B575. Standard Specification for Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, Low-Carbon Nickel-Chromium-Molybdenum-Tantalum, and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Plate,

Sheet, and Strip. American Society for Testing and Materials.
ASTM B688. Standard Specification for Chromium-Nickel-Molybdenum-Iron (UNS N08367) Plate, Sheet, and Strip. American Society for Testing and Materials.
DIN 17744. Wrought nickel alloys with molybdenum and chromium — Chemical composition. Deutsches Institut für Normung.
DIN 17750. Strip and sheet of nickel and wrought nickel alloys — Properties. Deutsches Institut für Normung.
EN 10028-1. Flat products made of steels for pressure purposes — Part 1: General requirements. European Committee for Standardization.
EN 10028-7. Flat products made of steels for pressure purposes — Part 7: Stainless steels. European Committee for Standardization.
EN 10088-2. Stainless steels — Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes. European Committee for Standardization.
EN 10095. Heat resistant steels and nickel alloys. European Committee for Standardization.
JIS G 4304. Hot-rolled stainless steel plate, sheet and strip. Japanese Industrial Standards.
JIS G 4305. Cold-rolled stainless steel plate, sheet and strip. Japanese Industrial Standards.
JIS G 4312. Heat-resisting steel plate, sheet and strip. Japanese Industrial Standards.
JIS G 4902. Corrosion-resisting and heat-resisting superalloy plates and sheets. Japanese Industrial Standards.

(24) MM-4.6 Shapes, Rods, and Bars

Shapes, rods, and bars manufactured in accordance with the following specifications may be used:

ASTM A276/A276M. Standard Specification for Stainless Steel Bars and Shapes. American Society for Testing and Materials.
ASTM A479/A479M. Standard Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels. American Society for Testing and Materials.
ASTM B574. Standard Specification for Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Molybdenum-Chromium-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Rod. American Society for Testing and Materials.
ASTM B649. Standard Specification for Ni-Fe-Cr-Mo-Cu-N Low-Carbon (UNS N08925, UNS N08031, UNS N08034, UNS N08354, and UNS N08926), and Cr-Ni-Fe-N Low-Carbon Alloy (UNS R20033) Bar and Wire, and Ni-Cr-Fe-Mo-N Alloy (UNS N08936) Wire. American Society for Testing and Materials.
ASTM B691. Standard Specification for Iron-Nickel-Chromium-Molybdenum Alloy (UNS N08367) Rod, Bar, and Wire. American Society for Testing and Materials.
DIN 17744. Wrought nickel alloys with molybdenum and chromium — Chemical composition. Deutsches Institut für Normung.
DIN 17752. Wrought nickel and nickel alloy rods and bars — Requirements and testing. Deutsches Institut für Normung.
EN 10088-3. Stainless steels — Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes. European Committee for Standardization.
EN 10095. Heat resistant steels and nickel alloys. European Committee for Standardization.
EN 10272. Stainless steel bars for pressure purposes. European Committee for Standardization.
JIS G 4303. Stainless steel bars. Japanese Industrial Standards.
JIS G 4308. Stainless steel wire rods. Japanese Industrial Standards.
JIS G 4311. Heat-resisting steel bars and wire rods. Japanese Industrial Standards.
JIS G 4901. Corrosion-resisting and heat-resisting superalloy bars. Japanese Industrial Standards.
JIS H 4553. Nickel and nickel alloy bars. Japanese Industrial Standards.
JIS H 4554. Nickel and nickel alloy wire and drawing stock. Japanese Industrial Standards.

MM-5 BASE METALS AND FILLER MATERIALS

MM-5.1 General

This section provides requirements and recommendations for the base metals listed in Tables MM-2.1-1 through MM-2.1-4. The use of base metals other than those listed in this section is permitted with the owner/user's written approval (see MM-3.3).

This section also recommends filler metals and consumable inserts for welding these alloys in order to produce weldments whose weld metal has corrosion resistance consistent with that of the base metal. Details necessary for welding are provided in Part MJ.

MM-5.2 Base Metals

MM-5.2.1 Stainless Steels

MM-5.2.1.1 Austenitic Stainless Steels (24)

(a) Weld Ends. Weld ends of process components and process equipment with nominal dimensions depicted in Table DT-4-1 that are to be autogenously welded shall have a sulfur content between 0.005 wt. % and 0.017 wt. % [see also MJ-2.1.1(a)]. This requirement applies to the austenitic stainless steels listed in

(24) **Table MM-5.2.1.1-1**
Predicted Ferrite Number (FN) Ranges for Various Austenitic Stainless Steel Product Forms and Welds

Product Form	Expected FN
Wrought product forms with sulfur levels less than 0.005%	0.5 to 4
Wrought product forms with a sulfur range of 0.005% to 0.017%	1.0 to 6
GMAW/GTAW using ER316L [Note (1)]	4 to 12 [Note (2)]
SMAW using E316L [Notes (3), (4)]	4 to 10 [Note (5)]
CF8M and CF3M castings	5 to 15

GENERAL NOTE: FN ranges determined from Kotecki, D. J., and Siewart, T. A. (1992). "WRC-1992 Constitution Diagram for Stainless Steel Weld Metals: A Modification of the WRC-1988 Diagram." Welding Journal, 71(5), pp. 171-s–178-s.

NOTES:
(1) SFA 5.9/5.9M. Specification for Bare Stainless Steel Welding Electrodes and Rods. The American Society of Mechanical Engineers.
(2) Nitrogen pickup or weld metal dilution could result in a 3 FN to 4 FN loss in the as-deposited weld metal.
(3) SFA 5.4/5.4M. Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding. The American Society of Mechanical Engineers.
(4) Electrodes with a restricted FN usually require a special order, with the exception of 2 FN maximum product for cryogenic temperatures.
(5) FN in the as-deposited weld is influenced by welding technique and is lowered by nitrogen pickup or weld metal dilution.

Tables MM-2.1-1 and MM-2.1-3. This requirement does not apply to materials used in the manufacture of process components and process equipment, only to the weld ends of process components and process equipment in their final form.

(b) Delta Ferrite. If specific delta ferrite levels in austenitic stainless steels are deemed necessary to maintain certain properties, the owner/user shall specify required delta ferrite ranges separately for the base metal, for welds in the solution-annealed condition, and for welds left in the as-welded condition. As a general rule, materials with low Cr-to-Ni ratios show lower delta ferrite levels in the base metal and subsequent to welding. See Table MM-5.2.1.1-1 for predicted ferrite number ranges for various austenitic stainless steel product forms. These are not acceptance criteria. The listed ferrite numbers refer to as-solidified austenitic stainless steels and therefore indicate predicted delta ferrite levels of the respective autogenous welds, welds with filler metal, or castings. Additional information regarding delta ferrite can be found in Nonmandatory Appendix G.

MM-5.2.1.2 Superaustenitic Stainless Steels. The superaustenitic stainless steels in Tables MM-2.1-1 and MM-2.1-3 are prone to the precipitation of undesirable secondary intermetallic phases such as sigma and chi. This precipitation typically occurs in the range of 1,000°F to 1,900°F (540°C to 1 040°C). This is a concern during welding and other thermomechanical processes, including solution annealing. It is, therefore, desirable to keep exposure time within this temperature range to a minimum.

Exposure time to undesirable temperatures reached during high-temperature service, heat treatment, or joining should be minimized. The material manufacturer should be consulted for specific instructions regarding heat treatment.

MM-5.2.1.3 Duplex Stainless Steels. The corrosion (24) resistance and mechanical properties of duplex stainless steels listed in Tables MM-2.1-1 and MM-2.1-3 are based on having roughly equal amounts of ferrite and austenite in the microstructure at room temperature while also avoiding undesirable secondary phases.

The UNS S32101 grade listed in Table MM-2.1-1 may be prone to the precipitation of undesirable nitrides and carbides. This precipitation typically occurs in the range of 1,200°F to 1,570°F (650°C to 850°C) and is time-dependent. Similarly, the duplex stainless steels, UNS S32205 and UNS S32750, may be prone to the precipitation of undesirable secondary intermetallic phases such as sigma and chi. This precipitation occurs continually in the range of 1,200°F to 1,830°F (650°C to 1 000°C). Exposure time to undesirable temperatures reached during high-temperature service, heat treatment, or joining should be minimized. The material manufacturer should be consulted for specific instructions regarding heat treatment.

MM-5.2.2 Nickel Alloys. The nickel alloys listed in Tables MM-2.1-2 and MM-2.1-3 may be prone to precipitation of secondary phases such as mu and P. Such secondary precipitation typically occurs when the material is subjected to temperatures in the range of 1,500°F to 1,800°F (820°C to 980°C) and can create a detrimental effect on the material's corrosion resistance. Exposure time to undesirable temperatures reached during high-temperature service, heat treatment, or joining should be minimized.

MM-5.2.3 Castings. When cast alloys discussed in this section solidify, microsegregation of chromium and molybdenum occurs. Segregation reduces corrosion resistance and is corrected in castings by a full solution anneal as specified by the material specification or as recommended by the material manufacturer. All cast materials shall be supplied in the solution-annealed condition, and the solution-anneal procedure shall meet the time and temperature requirements of the product specification. Any weld repair by the casting manufacturer shall

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Table MM-5.2.5-1
Materials for OEM Equipment

UNS Number	EN Designation	Common Name
...	...	Platinum (coating)
...	...	Gold (coating)
...	...	Silver (coating)
R50250	...	Ti — Grade 1
...	3.7025	...
R50400	...	Ti — Grade 2
...	3.7026	...
R56400	...	Ti — Grade 5
...	3.7164	...
R52400	...	Ti — Grade 7
R56320	...	Ti — Grade 9
R53400	...	Ti — Grade 12
N06200	...	Hastelloy C-2000 [Note (1)]
N06600	...	Inconel 600 [Note (2)]
N07718	...	Inconel 718 [Note (2)]
...	2.4668	...
S17400	...	17-4 PH [Note (3)]
...	1.4542	...

GENERAL NOTE: Alloys listed between horizontal lines are not equivalent, but comparable.

NOTES:
(1) Hastelloy C-2000 is a registered trademark of Haynes International, Inc.
(2) Inconel is a registered trademark of Special Metals Corp.
(3) 17-4 PH is a registered trademark of Cleveland-Cliffs Steel Corp.

meet the requirements of the specification or shall be as specified by the owner/user.

MM-5.2.4 Copper Alloys. In applications allowed in Part SD or approved by the owner/user, copper tubing, as listed in Table MM-2.1-4, may be used for process gas distribution systems.

MM-5.2.5 Special Alloys. When specified by the owner/user, alloys listed in Table MM-5.2.5-1 may be used for process contact surfaces in unique applications, such as original equipment manufacturer (OEM) process instrumentation, pump internals, etc.

MM-5.2.6 Unlisted Alloys. Alloys not listed in Part MM and having corrosion resistance less than that typical of 304L-type stainless steel may be used for process contact surfaces in unique applications such as OEM instrumentation when the owner/user has determined that the proposed material is suitable for the intended service.

MM-5.3 Filler Materials

Filler material shall conform to a published specification. Tables MM-5.3-1 through MM-5.3-4 list the recommended filler metals for welding the listed austenitic, superaustenitic, and duplex stainless steels and nickel alloys.

Table MM-5.3-5 lists the recommended materials from which consumable inserts may be made for use in welding the listed superaustenitic and duplex stainless steels.

Filler materials other than those listed in Tables MM-5.3-1 through MM-5.3-5 may be used with the prior approval of the owner/user provided that

(a) they produce weld metal having corrosion resistance equal to or greater than that of the base metal

(b) the welding procedure is qualified in accordance with Part MJ

Proprietary filler materials may be used with the prior agreement of the owner/user, provided all requirements of Part MJ are met.

When filler metal is used, the manufacturer shall identify the filler metal in the documentation provided with the component.

MM-5.3.1 Austenitic Stainless Steels. Only the low-carbon grades of stainless steel filler metals may be used to weld these alloys. If a filler metal is used, it should be in accordance with the filler metals listed in Table MM-5.3-1.

MM-5.3.2 Superaustenitic and Duplex Stainless Steels. If a filler metal is used during the manufacture of process components, it should be in accordance with Table MM-5.3-2 or Table MM-5.3-3, as appropriate. If a consumable insert is used, it should be in accordance with Table MM-5.3-5. Other nickel-chromium-molybdenum filler metals or consumable inserts may be used as long as the corrosion resistance of the final weld metal meets or exceeds that of the base metal. The manufacturer shall also identify the filler metal or consumable insert as part of the documentation.

MM-5.3.3 Nickel Alloys. If a filler metal is used, it should be in accordance with the filler metals listed in Table MM-5.3-4.

MM-5.3.4 Copper Alloys. Table MM-5.3.4-1 lists the filler metals to be used for brazing copper tubing.

MM-5.4 Heat Treatment

Heat treatment of process components made from the austenitic stainless steels in Table MM-2.1-1 is not addressed by this Standard.

For the listed superaustenitic and duplex stainless steels, if the filler metals or consumable inserts in Table MM-5.3-2, Table MM-5.3-3, or Table MM-5.3-5 are used, a postweld heat treatment is not required. If

Table MM-5.3-1
Filler Metals for Austenitic Stainless Steels

Base Metal Alloy [Note (1)]			Filler Metal											
			SMAW						GTAW/GMAW/SAW/PAW					
UNS Designation	EN Designation	JIS Designation	AWS Classification	SFA Specification	UNS Designation	ISO 3581-A Designation	EN Designation	JIS Z 3221 Designation	AWS Classification	SFA Specification	UNS Designation	ISO 14343-A Designation	EN Designation	JIS Z 3321 Designation
S30400	...	...	E308-15	5.4	W30810	...	...	...	ER308	5.9	S30880	...	...	...
			E308-16		W30810				ER308L		S30883			
			E308-17		W30810				ER308Si		S30881			
									ER308LSi		S30888			
...	1.4301	...	...	...	...	19 9 L	1.4316	...	...	...	...	19 9 L Si	1.4316	...
						19 9 Nb	1.4551					19 9 Nb Si	1.4551	
...	...	SUS304	...	...	...	...	...	ES308-16 ES308-17	...	...	...	...	...	YS308 YS308L YS308Si YS308LSi
S30403	...	...	E308L-15	5.4	W30813	...	...	...	ER308L	5.9	S30883	...	...	...
			E308L-16		W30813				ER308LSi		S30888			
			E308L-17		W30813									
...	1.4307	...	...	...	...	19 9 L	1.4316	...	...	...	...	19 9 L Si	1.4316	...
						19 9 Nb	1.4551					19 9 Nb Si	1.4551	
...	1.4306	...	...	...	...	19 9 L	1.4316	...	...	...	...	19 9 L Si	1.4316	...
						19 9 Nb	1.4551					19 9 Nb Si	1.4551	
...	...	SUS304L	...	...	...	...	...	ES308L-16 ES308L-17	...	...	...	...	...	YS308L YS308LSi
S31600	...	...	E316-15	5.4	W31610	...	...	...	ER316L	5.9	S31683	...	...	...
			E316-16		W31610				ER316LSi		S31688			
			E316-17		W31610									
...	1.4401	...	...	...	...	19 12 3 L	1.4430	...	...	...	...	19 12 3 L Si	1.4430	...
						19 12 3 Nb	1.4576					19 12 3 Nb Si	1.4576	
						20 25 5 Cu N L	1.4519					20 25 5 Cu L	1.4519	
...	...	SUS316	...	...	...	...	...	ES316-16 ES316-17	...	...	...	...	...	YS316L YS316LSi

Table MM-5.3-1
Filler Metals for Austenitic Stainless Steels (Cont'd)

Base Metal Alloy [Note (1)]			Filler Metal											
			SMAW						GTAW/GMAW/SAW/PAW					
UNS Designation	EN Designation	JIS Designation	AWS Classification	SFA Specification	UNS Designation	ISO 3581-A Designation	EN Designation	JIS Z 3221 Designation	AWS Classification	SFA Specification	UNS Designation	ISO 14343-A Designation	EN Designation	JIS Z 3321 Designation
S31603	...	...	E316L-15 E316L-16 E316L-17 E317L-15 E317L-16 E317L-17	5.4	W31613 W31613 W31613 W31713 W31713 W31713	...	...	...	ER316L ER316LSi ER317L	5.9	S31683 S31688 S31783	...	...	...
...	1.4404	...	...	...	...	19 12 3 L	1.4430	...	...	...	...	19 12 3 L Si	1.4430	...
						19 12 3 Nb	1.4576					19 12 3 Nb Si	1.4576	
												20 25 5 Cu L	1.4519	
...	1.4435	...	...	...	...	19 12 3 L	1.4430	...	...	...	...	19 12 3 L Si	1.4430	...
						19 12 3 Nb	1.4576					19 12 3 Nb Si	1.4576	
						18 16 5 N L	1.4440					18 16 5 N L	1.4440	
						20 16 3 Mn N L	1.4455					20 16 3 Mn L	1.4455	
						20 25 5 Cu N L	1.4519					20 25 5 Cu L	1.4519	
...	...	SUS316L	...	...	...	...	...	ES316L-16 ES316L-17 ES317L-16 ES317L-17	...	...	...	...	...	YS316L YS316LSi YS317L

GENERAL NOTE: The use of AWS/UNS filler metal is recommended for welding of UNS base metal; the use of EN filler metal is recommended for welding of EN base metal; the use of JIS filler metal is recommended for welding of JIS base metal.

NOTE: (1) Alloys listed between horizontal lines are not equivalent, but comparable.

Table MM-5.3-2
Filler Metals for Superaustenitic Stainless Steels

(24)

Base Metal Alloy [Note (1)]		Filler Metal									
		SMAW					GTAW/GMAW/SAW/PAW				
UNS Designation	EN Designation	AWS Classification	SFA Specification	UNS Designation	ISO 14172 Designation	EN Designation	AWS Classification	SFA Specification	UNS Designation	ISO 18274 Designation	EN Designation
N08904	...	ENiCrMo-3	5.11	W86112	...	...	ERNiCrMo-3	5.14	N06625	...	...
		ENiCrMo-4		W80276			ERNiCrMo-4		N10276		
		ENiCrMo-10		W86022			ERNiCrMo-10		N06022		
...	1.4539	...	...	...	20 25 5 Cu N L [Note (2)]	1.4519	...	...	...	20 25 5 Cu N L [Note (3)]	1.4519
					Ni 6625	2.4621				Ni 6625	2.4831
S31254	...	ENiCrMo-3	5.11	W86112	...	...	ERNiCrMo-3	5.14	N06625	...	...
		ENiCrMo-4		W80276			ERNiCrMo-4		N10276		
		ENiCrMo-10		W86022			ERNiCrMo-10		N06022		
		ENiCrMo-14		W86686			ERNiCrMo-14		N06686		
...	1.4547	...	...	...	Ni 6059	2.4609	...	...	...	Ni 6082	2.4806
					Ni 6625	2.4621				Ni 6625	2.4831
N08367	...	ENiCrMo-3	5.11	W86112	...	...	ERNiCrMo-3	5.14	N06625	...	...
		ENiCrMo-4		W80276			ERNiCrMo-4		N10276		
		ENiCrMo-10		W86022			ERNiCrMo-10		N06022		
		ENiCrMo-14		W86686			ERNiCrMo-14		N06686		
N08926	...	ENiCrMo-3	5.11	W86112	...	...	ERNiCrMo-3	5.14	N06625	...	...
		ENiCrMo-4		W80276			ERNiCrMo-4		N10276		
		ENiCrMo-10		W86022			ERNiCrMo-10		N06022		
		ENiCrMo-14		W86686			ERNiCrMo-14		N06686		
...	1.4529	...	...	...	Ni 6059	2.4609	...	...	...	Ni 6059	2.4607
					Ni 6625	2.4621				Ni 6625	2.4831

GENERAL NOTE: The use of AWS/UNS filler metal is recommended for welding of UNS base metal; the use of EN filler metal is recommended for welding of EN base metal.

NOTES:
(1) Alloys listed between horizontal lines are not equivalent, but comparable.
(2) Filler metal designation as per ISO 3581-A.
(3) Filler metal designation as per ISO 14343-A.

(24)

Table MM-5.3-3
Filler Metals for Duplex Stainless Steels

Base Metal Alloy [Note (1)]		Filler Metal [Note (2)]									
		SMAW					GTAW/GMAW/SAW/PAW				
UNS Designation	EN Designation	AWS Classification	SFA Specification	UNS Designation	ISO 3581-A Designation	EN Designation	AWS Classification	SFA Specification	UNS Designation	ISO 18274 Designation	EN Designation
S32101	...	E2209	5.4	W39209		...	ER2209	5.9	S39209		...
		E2553		W39553			ER2307 [Note (3)]		S82371		
		E2593		W39593			ER2553		S39553		
		E2594		W39594			ER2594		S32750		
		E2595		W39595							
...	1.4162	...	...	...	22 9 3 N L	1.4462	...	...	...	22 9 3 N L	1.4462
					23 7 N L	1.4362				23 7 N L	1.4362
					25 9 4 N L	1.4501				25 9 4 N L	1.4501
S32205	...	E2209	5.4	W39209	...	...	ER2209	5.9	S39209 [Note (3)]	...	...
		E2553		W39553			ER2553		S39553		
		E2593		W39593			ER2594		S32750		
		E2594		W39594							
		E2595		W39595							
...	1.4462	...	...	...	22 9 3 N L	1.4462	...	...	...	22 9 3 N L [Note (3)]	1.4462
					22 9 4 N L	1.4501				22 9 4 N L	1.4501
S32750	...	E2507	5.4	W32750	...	...	ER2507	5.9	S32750	...	...
		E2553		W39553			ER2553		S39553		
		E2594		W39750			ER2594		S32750		
		E2595		W32595			ER2509		S39509		
...	1.4410	...	...	...	25 9 4 N L	1.4501	...	...	...	25 9 4 N L	1.4501
					25 7 4 N L	1.4410				25 7 4 N L	1.4410

GENERAL NOTE: The use of AWS/UNS filler metal is recommended for welding of UNS base metal; the use of EN filler metal is recommended for welding of EN base metal.

NOTES:
(1) Alloys listed between horizontal lines are not equivalent, but comparable.
(2) Any super duplex stainless steel filler metal can be used to weld any duplex stainless steel.
(3) Addition of up to 5% of nitrogen to the shielding gas is recommended to aid in obtaining ferrite/austenite balance.

Table MM-5.3-4
Filler Metals for Nickel Alloys

Base Metal Alloy [Note (1)]			Filler Metal											
			SMAW						GTAW/GMAW/SAW/PAW					
UNS Designation	EN Designation	JIS Designation	AWS Classification	SFA Specification	UNS Designation	ISO 14172 Designation	EN Designation	JIS Z 3224 Designation	AWS Classification	SFA Specification	UNS Designation	ISO 18274 Designation	EN Designation	JIS Z 3334 Designation
N10276	...	...	ENiCrMo-3	5.11	W86112	...	...	...	ERNiCrMo-3	5.14	N06625	...	...	...
			ENiCrMo-4		W80276				ERNiCrMo-4		N10276			
			ENiCrMo-10		W86022				ERNiCrMo-10		N06022			
...	2.4819	...	...	...	...	Ni 6059	2.4609	...	...	...	...	Ni 6059	2.4607	...
...	...	NW0276	...	...	...	...	...	ENi6022 ENi6276 ENi6625	...	...	...	...	...	YNiCrMo-3 YNiCrMo-4
N06022	...	...	ENiCrMo-3	5.11	W86112	...	...	...	ERNiCrMo-3	5.14	N06625	...	...	...
			ENiCrMo-4		W80276				ERNiCrMo-4		N10276			
			ENiCrMo-10		W86022				ERNiCrMo-10		N06022			
...	2.4602	...	...	...	...	Ni 6059	2.4609	...	...	...	...	Ni 6059	2.4607	...
...	...	NW6022	...	...	...	...	...	ENi6022 ENi6276 ENi6625	...	...	...	...	...	YNiCrMo-3 YNiCrMo-4
N06625	...	...	ENiCrMo-3	5.11	W86112	...	...	...	ERNiCrMo-3	5.14	N06625	...	...	...
			ENiCrMo-4		W80276				ERNiCrMo-4		N10276			
			ENiCrMo-10		W86022				ERNiCrMo-10		N06022			
...	2.4856	...	...	...	...	Ni 6625	2.4621	...	...	...	...	Ni 6625	2.4831	...
...	...	NCF625	...	...	...	...	...	ENi6022 ENi6276 ENi6625	...	...	...	...	...	YNiCrMo-3 YNiCrMo-4

GENERAL NOTE: The use of AWS/UNS filler metal is recommended for welding of UNS base metal; the use of EN filler metal is recommended for welding of EN base metal; the use of JIS filler metal is recommended for welding of JIS base metal.

NOTE: (1) Alloys listed between horizontal lines are not equivalent, but comparable.

(24)

Table MM-5.3-5
Consumable Inserts for Superaustenitic and Duplex Stainless Steels

Base Metal Alloy [Note (1)]			Insert Alloy [Note (2)]	
UNS Designation	**ACI Designation**	**EN Designation**	**UNS Designation**	**EN Designation**
Superaustenitic Stainless Steels				
N08904	...	...	N06625 N06022 N10276	...
...	...	1.4539	...	2.4856 2.4602 2.4819
N08367	...	...	N06625 N06022 N10276 N06686	...
N08926	...	...	N06625 N06022 N10276 N06686	...
...	...	1.4529	...	2.4856 2.4602 2.4819
S31254	...	...	N06625 N06022 N10276 N06686	...
...	...	1.4547	...	2.4856 2.4602 2.4819
J94651	CN3MN	...	N06625 N06022 N10276 N06686	...
J93254	CK3MCuN	...	N06625 N06022 N10276 N06686	...
...	...	1.4557	...	2.4856 2.4602 2.4819
Duplex Stainless Steels				
S32101	...	...	S32205 S32750 N06625 N06022 N10276	...
...	...	1.4162	...	2.4602 2.4819
S32205	...	...	N06022 N10276	...
...	...	1.4462	...	2.4602 2.4819
J92205	CD3MN	...	N06022 N10276	...
...	...	1.4470	...	2.4602 2.4819
S32750	CE3MN	...	N06022 N10276	...
...	...	1.4410	...	2.4602 2.4819

GENERAL NOTE: The use of UNS consumable inserts is recommended for welding of UNS base metal; the use of EN consumable inserts is recommended for welding of EN base metal.

Table MM-5.3-5
Consumable Inserts for Superaustenitic and Duplex Stainless Steels (Cont'd)

NOTES:
(1) Alloys listed between horizontal lines are not equivalent, but comparable.
(2) See MM-4 for listed rod, bar, or plate specifications from which these consumable inserts may be manufactured.

Table MM-5.3.4-1
Brazing Filler Metals for Copper

Base Metal [Note (1)]		Filler Metal			
UNS Number	EN Designation	AWS Classification	SFA Specification	UNS Designation	EN Designation
C10200	...	BCuP-3	5.8	C55281	...
		BCuP-4		C55283	...
		BCuP-5		C55284	...
		BCuP-6		C55280	...
		BCuP-7		C55282	...
C12000	...	BCuP-3	5.8	C55281	...
		BCuP-4		C55283	...
		BCuP-5		C55284	...
		BCuP-6		C55280	...
		BCuP-7		C55282	...
C12200	...	BCuP-3	5.8	C55281	...
		BCuP-4		C55283	...
		BCuP-5		C55284	...
		BCuP-6		C55280	...
		BCuP-7		C55282	...
...	CW024A	...	...	...	...

GENERAL NOTE: The use of AWS/UNS filler metal is recommended for brazing of UNS base metal; the use of EN filler metal is recommended for brazing of EN base metal.

NOTE: (1) Copper grades listed between horizontal lines are not equivalent, but comparable.

those alloys are welded autogenously, postweld heat treatment is required in accordance with Table MM-5.4-1.

MM-6 MECHANICAL PROPERTIES AND LEAK TESTING

MM-6.1 Tubing/Piping

All tube or pipe used for process contact surfaces and non-process contact surfaces shall meet the mechanical property requirements of the specification to which they are manufactured.

MM-6.2 Fittings and Valves

See DT-2 for pressure and strength requirements for fittings and valves.

When material is cold worked, its mechanical properties can be expected to change from those of the original heat of the raw material. MTRs for fittings are therefore not required to list mechanical properties; however, if they do, they shall conform to the specifications for the raw materials from which the fittings were fabricated.

MM-6.3 Toughness

Some of the materials listed in Tables MM-2.1-1 through MM-2.1-3, as well as Table MM-5.2.5-1, undergo a decrease in toughness when used at low temperatures, to the extent that other applicable codes may require impact tests for applications even at temperatures higher than 20°F (−7°C). It is the responsibility of the owner/user to ensure that such testing is performed and that the requirements of all applicable codes are met.

MM-6.4 Testing

See DT-6 for the testing requirements for fittings and MC-4.3.1.1 for the testing requirements for valves.

(24)

Table MM-5.4-1
Solution Anneal Heat Treatment Requirements for Superaustenitic and Duplex Stainless Steels

Base Metal Alloy [Note (1)]		Solution Anneal Temperature, °F (°C) [Notes (2), (3), and (4)]
UNS Designation	EN Designation	
Superaustenitic Stainless Steels		
N08904	...	2,000 (1 095)
...	1.4539	2,000 (1 095)
S31254	...	2,100 (1 150)
...	1.4547	2,100 (1 150)
N08367	...	2,025 (1 105)
N08926	...	2,010 (1 100)
...	1.4529	2,010 (1 100)
Duplex Stainless Steels		
S32101	...	1,870 (1 020)
...	1.4162	1,870 (1 020)
S32205	...	1,870–2,010 (1 020–1 100)
...	1.4462	1,870–2,010 (1 020–1 100)
S32750	...	1,880–2,060 (1 025–1 125)
...	1.4410	1,900–2,050 (1 040–1 120)

NOTES:
(1) Alloys listed between horizontal lines are not equivalent, but comparable.
(2) Minimum solution anneal temperature unless range is specified.
(3) No minimum anneal time is specified; however, very short anneal times can result in inadequate time at temperature to restore the corrosion resistance of autogenous welds.
(4) Post-solution anneal cooling shall be achieved by a water quench or rapid cooling by other means.

MM-7 POSITIVE MATERIAL IDENTIFICATION

When positive material identification (PMI) is performed, it is limited to alloy verification. See Nonmandatory Appendix W for guidance regarding procedures and data interpretation.

MM-8 CORROSION-RESISTANCE REQUIREMENTS

MM-8.1 General

The specific service environment for which the alloys in Tables MM-2.1-1 through MM-2.1-4 may be used is not within the scope of this Part. The possibility of material deterioration in service should be considered by the owner/user. Carbide phase degradation of corrosion resistance, susceptibility to intergranular corrosion of austenitic materials, and grain boundary attack of nickel-based alloys are among those items requiring attention.

Resistance to corrosion is an essential characteristic of the materials used to fabricate the systems governed by this Standard. Corrosion testing is recommended whenever specific production performance characteristics must be determined. The owner/user shall have the final responsibility for proper material selection.

MM-8.2 Corrosion Testing (24)

Corrosion testing may be performed for the following reasons:

(a) to compare a number of alloys in a specific standard environment

(b) to determine the compatibility of an alloy in an owner/user-defined environment

Once a particular alloy has been selected for an application, more extensive testing may be appropriate. This testing may involve the evaluation of any one of a number of process variables on material performance. These variables include, but may not be limited to, upset temperature conditions, varying concentrations of the corrosive agent or condition, cleaning chemical type and concentration, various surface finishes, welding process, and filler metal alloy. It may be appropriate to use electrochemical test methods or a standard immersion test method to evaluate the effect of the various parameters. Standard ASTM corrosion tests commonly used are discussed in Nonmandatory Appendix F.

Certificate Holders who manufacture welded austenitic stainless steel tube are required to perform the weld decay test in ASTM A249/A249M, Supplement 7 and the intergranular corrosion test in either ASTM A270/A270M, Supplement S1 or ISO 3651-2 Method B on tube heat treated in accordance with their current heat treatment procedure. Evidence of successful test results shall be available.

MM-9 MINIMUM REQUIREMENTS FOR ALLOYS IN PART MM

MM-9.1 General (24)

Metallic materials shall meet the requirements of this section.

MM-9.1.1 Wrought, Cast, and Welded Fabricated Applications (24)

(a) For wrought, cast, and welded fabricated materials to be added to Part MM, the following information shall be provided to the ASME BPE staff secretary:

(1) documentation showing the alloy is listed in an industry-recognized specification or standard including tensile strength properties.

(2) evidence that the proposed material, in both the wrought and welded conditions, will have corrosion resistance equal to or greater than 304L stainless steel (UNS S30403) in a service environment within the scope of this

Standard. Materials that will not be welded (e.g., some castings) do not require corrosion testing in the welded condition.

(3) evidence that the material surface can be mechanically polished, electropolished, or passivated to meet the applicable requirements of Part SF.

(4) one or more recommended welding processes, filler metals, and evidence showing that the combination of base metal, filler metals, and recommended welding processes meets the applicable requirements of Parts MJ and SF. Special restrictions, exceptions, or guidance shall be noted.

(b) Welded austenitic stainless steel tube shall be capable of passing the weld decay test in ASME A249/A249M, Supplement S7 and the intergranular corrosion test in either ASTM A270/A270M, Supplement S1 or ISO 3651-2 Method B. See Nonmandatory Appendix F for additional information.

(24) **MM-9.1.2 Specialty OEM Material Applications** For specialty OEM material to be added to Part MM, the following information shall be provided to the ASME BPE staff secretary:

(a) Documentation showing the alloy is listed in an industry-recognized specification or standard. Tensile strength properties shall also be included unless the material is used only as a coating.

(b) Evidence that the proposed material, in both the wrought and welded conditions, will have corrosion resistance equal to or greater than 304L stainless steel (UNS S30403) in a service environment within the scope of this Standard. Materials that will not be welded (e.g., some castings and coatings) do not require corrosion testing in the welded condition. Sprayed or vapor deposited coatings shall be tested over the base material used in the commercially supplied parts. See Nonmandatory Appendix F for additional information.

(c) Evidence that the material surface can be mechanically polished, electropolished, or passivated to meet the applicable requirements of Part SF.

(d) For sprayed or vapor deposited coatings, one or more recommended spraying processes or vapor deposition processes. Special restrictions, exceptions, or guidance shall be noted.

(e) For welded coatings, one or more recommended welding processes, filler metals, and evidence showing that the combination of base metal, filler metals, and recommended welding processes meets the applicable requirements of Parts MJ and SF. Special restrictions, exceptions, or guidance shall be noted.

PART PM
POLYMERIC AND OTHER NONMETALLIC MATERIALS

(24)

PM-1 PURPOSE AND SCOPE

The purpose of this Part is to provide the basis for selecting and using polymeric and other nonmetallic materials.

This Part describes the types of polymeric and other nonmetallic materials and identifies different ways to characterize materials.

PM-2 MATERIALS

Polymeric and nonmetallic materials have found widespread use in bioprocessing equipment because of their broad range of physical and chemical properties, their ability to be formed into complex shapes, and their biocompatibility. Polymeric materials may be used in a range of applications including static and dynamic seals, hoses, pumps, tubing, barrier coatings, diaphragms, valves, and filters. The choice of material class depends on the design requirements and material performance, both as installed and during use.

For in-depth discussion and guidance on polymeric and nonmetallic materials, see Nonmandatory Appendix O.

(24)

PM-2.1 Materials of Construction

Materials of construction shall be selected to maintain the purity and integrity of the product/process fluid. It is the owner/user's responsibility to select the appropriate materials of construction for the conditions of use. Materials should be compatible with the stated processing conditions, cleaning solutions (where appropriate), and sterilizing conditions (where appropriate), etc., as specified by the owner/user.

PM-2.1.1 Reference Specifications. This subsection provides limitations and requirements for rigid thermoplastic piping and fitting materials based on their properties. Use of these materials in piping systems is also subject to requirements and limitations in other Parts of this Standard.

Standards and specifications adopted by reference in this Standard are listed by product form in this Part. When preparing an MTR, a manufacturer may transcribe data produced by other organizations, provided the manufacturer accepts responsibility for the accuracy and authenticity of the data.

PM-2.1.2 Piping and Fittings. Piping and fittings manufactured in accordance with the following specifications may be used:

ASTM D638. Standard Test Method for Tensile Properties of Plastics. American Society for Testing and Materials.

ASTM D3222. Standard Specification for Unmodified Polyvinylidene Fluoride (PVDF) Molding Extrusion and Coating Materials. American Society for Testing and Materials.

ASTM D4101. Standard Specification for Polypropylene Injection and Extrusion Materials. American Society for Testing and Materials.

ASTM D5575. Standard Classification System for Copolymers of Vinylidene Fluoride (VDF) With Other Fluorinated Monomers. American Society for Testing and Materials.

ASTM D5857. Standard Specification for Polypropylene Injection and Extrusion Materials Using ISO Protocol and Methodology. American Society for Testing and Materials.

ASTM D6713. Standard Specification for Extruded and Compression Molded Shapes Made From Polyvinylidene Fluoride (PVDF). American Society for Testing and Materials.

ASTM F1673. Standard Specification for Polyvinylidene Fluoride (PVDF) Corrosive Waste Drainage Systems. American Society for Testing and Materials.

ASTM F2389. Standard Specification for Pressure-Rated Polypropylene (PP) Piping Systems. American Society for Testing and Materials.

PM-2.1.2.1 Listed Materials. In this subsection, listed materials are materials that conform to one or more specifications as defined in this Standard for piping and fitting manufactured in accordance with PM-2.

(a) Polyvinylidene Fluoride (PVDF). PVDF material selected for the construction of pipe and fittings shall be virgin and unpigmented. All PVDF resin shall be tested in conformance with the United States Code of Federal Regulations (CFR) Title 21 Chapter 1, Part 177.2510 or 2600, Title 21 Chapter 1 Part 177.1520, USP 25 Class VI.

(b) Polypropylene (PP). PP material selected for the construction of pipe or fittings should be either virgin (unpigmented) or pigmented. All PP resin shall be of

the same type and class as described in ASTM D4101 and tested in conformance with the United States Code of Federal Regulations (CFR) Title 21 Chapter 1, Part 177.1520.

(c) Other Materials. Thermoplastic material that is not specifically prohibited by this Standard and meets one of the following requirements shall be considered listed and acceptable:

(1) When referenced in other parts of this Standard, the material shall be used only within the scope of use in the product form permitted by the referencing text.

(2) When used for pressure pipe, the material shall be documented suitable for the design pressure and temperature and conform with the requirements of this Standard.

PM-2.1.3 Limitations on Thermoplastic Materials. A thermoplastic material for pressure pipe applications should not be used at a design temperature above the maximum temperature at which the allowable stress value has been determined for the material or below the minimum temperature recommended by the manufacturer of the thermoplastic. If used outside of these limits, the designer shall have test results at the design temperature to ensure that the thermoplastic material is suitable for the intended application at the design temperature. Consult the material manufacturer's technical documentation for specific details or see ASME NM.3.3.

PM-2.1.3.1 Size or Thickness. Materials within the size or thickness limits given in this Standard should be used. If outside the limits, the material shall be in conformance with the other requirements of the specification and the designer shall document the owner/user's acceptance for use of the material for the application.

PM-2.1.4 Marking of Thermoplastic Materials or Products. Thermoplastic materials or products marked as meeting the requirements of one or more material specifications shall be acceptable provided

(a) one of the markings included the thermoplastic material specification

(b) the type of thermoplastic material is permitted by this Standard

(c) all other requirements of this Standard are satisfied

PM-2.1.5 Unlisted Materials. Thermoplastic materials other than those meeting the requirements of this Standard shall be considered unlisted thermoplastic materials. Unlisted thermoplastic materials shall be used only if they satisfy all of the following requirements:

(a) The designer shall document the owner/user's acceptance for the use of an unlisted thermoplastic material for the application.

(b) All other requirements of this Standard are satisfied.

(c) Unlisted materials shall meet a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, and quality control.

(d) Unlisted materials shall be qualified for service within a stated range of minimum and maximum temperatures and pressures based on data associated with successful experience, tests, or analysis, or a combination thereof.

PM-2.1.6 Unknown Thermoplastic Materials. Thermoplastic materials of unknown specification shall not be used for piping systems or components.

PM-2.1.7 Filler Materials. Filler materials may be used with the materials listed in PM-2.1.2.1 and PM-2.1.5 to enhance properties for uses such as gaskets and seals. Final fabricated products made with filler materials shall be in conformance with the requirements of this Standard.

PM-2.2 General Requirements

Materials shall be selected to not affect the purity or integrity of the drug product. The owner/user is responsible for the qualification of materials for the intended use. The requirements for conformance are summarized in PM-2.2.1. The requirements relate to identification, traceability, biocompatibility, and marking.

Polymeric materials exposed to process fluids and/or that have a high probability of exposure shall comply to the USP directive with regard to USP <87> (or ISO 10993-5) and USP <88> Class VI (or ISO 10993-6, -10, and -11) on biological reactivity (see PM-3.1). Examples of materials that may come into direct contact with process fluids include tubing, pipe, fittings, filters, bags, gaskets, O-rings, diaphragms, pinch tubes, and valve stem seals.

PM-2.2.1 Certificate of Conformance. A Certificate of Conformance shall be issued by the manufacturer to certify conformance to this Standard when required by the end-user. Additional certification documentation may be required. The Certificate of Conformance shall contain the information summarized in Table PM-2.2.1-1.

PM-2.2.2 Labeling and Marking. Manufacturers shall mark the package containing polymer components or assemblies with the manufacturer's name, part number, and lot number or unique identifier (see Table PM-2.2.1-1) to enable the manufacturer to trace back to the raw material or materials and processing conditions used to fabricate the component/assembly. Manufacturers should mark the component/assembly itself to avoid potential loss of traceability and to aid in positive identification of components/assemblies after use.

Table PM-2.2.1-1
Content Required on the Certificate of Conformance

Requirements to Conform to ASME BPE	Applications									
	Polymeric Seals (Includes Diaphragms and Hygienic Union Seals) [Note (1)]	Hoses	Tubing	Filters [Note (2)]	Chroma-tography Columns	Connectors (Includes Steam to/ Through)	Polymeric Containers (Rigid and Flexible)	Other Polymeric Process Components	Nonmetallic Process Components	Single-Use Assemblies
Manufacturer's name	X	X	X	X	X	X	X	X	X	X
Manufacturer's contact information	X	X	X	X	X	X	X	X	X	X
Part number	X	X	X	X	X	X	X	X	X	X
Lot number or unique identifier or serial number	X	X	X	X	X	X	X	X	X	X
Material(s) of construction (process contact)	X	X	X	...	X	X	X	X	X	...
Compound number or unique identifier	X	...	X	...	...	...	...	X	X	...
Cure date or date of manufacture	X	...	X	X	X	...	X	X	...	X
USP <87> or ISO 10993-5	X	X	X	X	X	X	X	X	X	X
USP <88> Class VI or ISO 10993-6, -10, -11	X	X	X	X	X	X	X	X	...	X

GENERAL NOTE: For components subjected to operations such as gamma irradiation or steam, specific certification shall be provided. See Part SU.

NOTES:
(1) For hygienic union seals, the intrusion category shall be provided (see MC-4.2).
(2) Specific lot release criteria may be required for different types of filtration elements depending on their type and application. These additional requirements should be decided by the owner/user and the supplier.

Table PM-2.2.3.2-1
Change Levels and Minimum Change Notification Requirements

Change Level	Description	Typical Examples, Not Representative of All Changes	Notification Requirement	
			Preliminary Change Notification Prior to Change Notification	Change Notification Prior to Change Implementation
Level 3	A change that requires a minimum of 6 months for the end user to plan and a minimum of 12 months for the owner/user to implement	Change impacting leachables and extractables profiles	6 months minimum required	12 months minimum required
Level 2	A change that requires a minimum of 3 months to plan and a minimum of 6 months for the owner/user to implement	Revision to a product specification, change in part number	3 months minimum recommended	6 months minimum required
Level 1	A change that requires a minimum of 3 months for the owner/user to implement	Change in labeling, change in document format (e.g., Certificate of Conformance), editorial update of analytical method	None required	3 months minimum required
Level 0	A change that is not expected to impact the attributes in PM-2.2.3.2	Certain non–process contact changes (e.g., change in carton supplier)	Notification not required	Notification not required
Emergency	An emergency change occurs when the manufacturer does not have prior knowledge that they will be impacted by a change	Force majeure, act of God	The change notification should be expedited to the greatest extent possible appropriate for the level of change	The change notification should be expedited to the greatest extent possible appropriate for the level of change

PM-2.2.3 Change Management

PM-2.2.3.1 General. This section provides standard procedures and guidelines for manufacturers of polymeric or other nonmetallic process contact materials, components, and assemblies to manage and communicate changes.

PM-2.2.3.2 Change Classifications. The magnitude of qualification and regulatory filing requirements for an owner/user to implement a change related to a material, component, or assembly is dependent on the following attributes:

(a) impact on bioprocessing product safety, efficacy, purity, identity, or strength

(b) impact to form, fit, or function of the product, which may include

(1) formulation changes

(2) manufacturing means, methods, or materials changes

(3) changes to published or agreed specifications

(4) discontinuance of a material, component, or assembly

(5) changes in regulatory or compliance status (e.g., USP)

Table PM-2.2.3.2-1 defines four levels of change commensurate with the complexity of change and the amount of time needed for owner/users to address requirements associated with the change. Manufacturers, when selecting the level of change for notification, should consider typical owner/user regulatory constraints as well as technical, business, and supply chain practices to anticipate notification time needed by the owner/user to qualify and implement the change.

PM-2.2.3.3 Owner/User Notification. The manufacturer should provide change notification documentation to the owner/user per the timelines defined in Table PM-2.2.3.2-1. The change notification should include

(a) identification of the manufacturer's products affected by the change

(b) explanation of why the change is being made

(c) description of the change (current state and modified state)

(d) known potential impact to form, fit, or function and impact through the supply chain

(e) documentation and qualification data to characterize the change

(f) change level per Table PM-2.2.3.2-1

In the event of a Level 3 change, the manufacturer should provide preliminary change notification documentation to the owner/user as defined in Table PM-2.2.3.2-1. Preliminary change notification provides advanced warning to the owner/user prior to release of required change notification documentation (e.g., documentation and qualification data) that may not be available at the time of preliminary change notification. A plan for implementation with anticipated timelines should be included in the preliminary notification. Change notification shall include the documentation and qualification data to characterize the plan.

PM-2.2.3.4 Manufacturer's Responsibilities. The manufacturer shall have procedures and documentation that effectively manage changes both internally and throughout the supply chain and defines requirements for owner/user notification. The manufacturer shall maintain a record of notification and change implementation. Manufacturers should establish a single point of contact for change communication.

PM-2.2.3.5 Owner/User Responsibilities. The owner/user should provide a single point of contact for change communication. The method of receiving communication should be electronic (e.g., an e-mail address such as change@companyx.com). The owner/user should acknowledge receipt of the communication to the manufacturer's single point of contact and evaluate the change notification for impact to their processes.

PM-3 PROPERTIES AND PERFORMANCE

Materials should be selected to retain their functional properties and to minimize their impact on the process fluid. Materials should be selected to not affect the purity and integrity of the drug product. This section outlines the requirements for biocompatibility, extractables/leachables, physical properties, and chemical compatibility. Each of the following sections should be considered for the application.

PM-3.1 Biocompatibility

"Biocompatibility" is defined here as the ability of a substance or material to be in contact with living matter such as bacteria or mammalian cells without interfering in any way with its metabolism or ability to live and procreate. Polymer materials shall be biocompatible with the system fluid to ensure that the system fluid is not adversely affected by the polymer material. The biocompatibility and the proper material selection shall be the responsibility of the system user.

Biocompatibility testing of candidate components for qualification requires both in vivo (animal testing) and in vitro (testing in glass) tests. In vivo testing is described in the United States Pharmacopeia (USP) in Chapter <88> (or ISO 10993-6, -10, and -11) and involves intramuscular implantation, intracutaneous injection, and systemic toxicity testing. In vitro testing is described in the United States Pharmacopeia in Chapter <87> (or ISO 10993-5) and is used to place extract from candidate polymers in direct contact with living cells (typically mouse cells) for a prescribed period of time. The amount of cell lysing (death) shall be recorded and reported for the particular polymer material.

Material manufacturers shall provide, on customer request, documentation (test report) of the in vivo USP <88> Class VI and in vitro USP <87> testing on final manufactured parts. Failure of either test indicates unacceptable biocompatibility of candidate material. Such failures are often attributed to leachables from cured elastomeric seals extractables and may include catalyst residues, cross-linking agents, process aids, plasticizers, etc.

PM-3.2 Extractables and Leachables

PM-3.2.1 Extractables. Extractables are chemical substances that can be removed from polymeric materials using appropriate solvents (e.g., polar and nonpolar). Extraction studies are conducted under conditions that exceed typical bioprocess manufacturing or storage conditions (e.g., higher temperature, pH, or concentration or longer exposure time) and are used to generate an extractables profile for a given polymeric material. Manufacturers should provide extractables profile data for polymeric materials used in equipment/components on request by the owner/user. The extractables profile generated may vary depending on both the extraction conditions and the extraction fluids used in the study. Depending on the purpose of the study, one or more of the extraction studies described in PM-3.2.1.1 or PM-3.2.1.2 should be done to generate an extractables profile.

PM-3.2.1.1 Polymeric Material Specific Extraction Study. This study is done to generate an extractables profile that characterizes the total content of soluble chemical substances contained in the polymeric material. The extraction solvent or solvents and conditions shall be appropriate for the particular polymeric material being tested. Nonmandatory Appendix P, P-2 identifies recommended conditions for a polymeric material specific extraction study.

PM-3.2.1.2 Extraction Study in Bioprocess Model Solutions. This study is done to generate an extractables profile under conditions that exceed those typically found

in bioprocessing applications. The model solutions and extraction conditions should be selected based on the intended use of the equipment/component. This study generates an extractables profile that may be used to predict potential leachables. Nonmandatory Appendix P, P-3 identifies recommended conditions for an extraction study in bioprocess model solutions.

PM-3.2.2 Leachables. Leachables, typically a subset of extractables, are chemical substances that migrate into the drug product from process equipment or its container under normal conditions of use and/or storage. Leachables may also be created as a result of chemical reactions with other leachables and/or ingredients in the process fluid or drug product. Leachables studies conducted in process and of the final product shall be the responsibility of the owner/user.

PM-3.2.3 Sample Preparation. Extraction studies shall include careful sample preparation appropriate to the test article and analytical techniques to be used.

The size of the sample should be determined in consideration of the material, test equipment, analytical test sensitivity, and the sample available for testing.

Any tool used for sample preparation shall not adulterate the sample.

Prior to extraction, test samples should be exposed to the same pretreatment process (under worst-case conditions) that the material would see when used as intended.

PM-3.2.4 Documentation. Documentation of results shall include the extraction method(s), analytical technique(s) protocol, sample surface area (or weight) to volume ratio, and extraction time and temperature. Relative limits of detection should be reported.

PM-3.2.5 Risk Assessment. The owner/user should consider supplier data, relevant standards, regulatory guidance, and industry recommendations as listed in Nonmandatory Appendix P, when performing a risk assessment.

The results of the risk assessment should determine the suitability of the equipment/component for its intended use.

PM-3.3 Physical and Mechanical Properties of Thermoplastic Polymers

The physical and mechanical properties of thermoplastics are important to better understand how fluid exposure could affect the polymer's strength, stiffness, inertness, durability, barrier properties, etc. Physical and mechanical properties can be characterized using many different standards (e.g., ASTM, ISO, DIN, and JIS). Typical properties include tensile strength, elongation to break, modulus, and, in some cases, seam strength, weld strength, coefficient of friction, compression set, tensile set, hardness, specific gravity, and transparency.

Common useful tests for evaluating thermoplastic performance are listed in Nonmandatory Appendix L.

The interpretation of immersion test results is dependent on the specific application. In such cases, a different material may be more suitable for the application. The overall life of the equipment may be shortened significantly if the correct polymer is not selected. The end-user must ultimately interpret the relevance of the test results for the applicable process.

PM-3.4 Chemical Compatibility of Thermoplastic Polymers

Chemical concentration, temperature, and duration of exposure can all affect the property retention of thermoplastic polymers. When selecting a thermoplastic polymer for chemical contact, the user should consult the supplier for case histories and test data, where available.

If further testing is required, specific fluids should be used to expose test samples for the necessary time and temperature.

PM-3.5 Physical and Mechanical Properties of Thermoset Polymers

Physical and mechanical properties can be characterized using many different standards (e.g., ASTM, ISO, DIN, and JIS). Typical properties include hardness, tensile strength, elongation to break, modulus, and tear strength. In some cases, abrasion resistance, compression set, specific gravity, transparency, etc., may be important. Properties may be affected by manufacturing and use conditions (e.g., temperature, pressure, physical stress). Common tests for evaluating physical and mechanical properties are listed in Nonmandatory Appendix L. Property requirements should be discussed between the owner/user and the supplier, and the owner/user shall be responsible for determining the suitability of the material for the application.

PM-3.6 Chemical Compatibility of Thermoset Elastomers

Chemical concentration, temperature, and duration of exposure can all affect the property retention of thermoset elastomers. When selecting a thermoset elastomer for chemical contact, the user should consult the supplier for case histories and test data, where available. If further testing is required, specific fluids should be used to expose test samples for the necessary time and temperature. Chemical compatibility is particularly important for materials that are reused. Chemical compatibility testing should be done to screen candidate materials for applications involving cleaning, storage, or exposure to potentially harsh chemicals.

PM-3.7 Physical and Mechanical Properties of Other Nonmetallic Materials

Physical and mechanical properties of other nonmetallic materials, such as those listed in Table O-1.3-1, may be characterized using many different standards (e.g., ASTM, ISO, DIN, and JIS). Typical properties may include, but are not limited to, hardness, strength, self-lubrication, and transparency. In some cases, low friction between sliding surfaces may be important. Properties may be affected by use conditions. Material selection should be discussed between the owner/user and supplier, and the owner/user shall be responsible for determining the suitability of the material for the application.

PM-3.8 Chemical Compatibility of Nonmetallic Materials

Chemical composition, temperature, and duration of exposure may all affect the properties of other nonmetallic materials. When selecting nonmetallic materials, such as those listed in Table O-1.3-1, the user should consult the supplier for test data, where available. If further testing is required, specific fluids should be used to expose test samples for the necessary time and temperature.

PM-3.9 Polymeric Surface Finish

Polymeric material contact surface classifications are found in Part SF.

PM-4 APPLICATIONS

PM-4.1 Single-Use Components and Assemblies

See Part SC, Part SJ, or Part SU.

(24) PM-4.2 Piping

The following shall be considered in the design of polymeric rigid piping and tubing in process contact.

(24) **PM-4.2.1 Sizing Comparison.** Thermoplastic piping systems are produced in a variety of dimensional sizing standards. Schedule (e.g., 40, 80) and Standard Dimensional Ratio (e.g,. SDR 11, SDR 21) are some of the most common standards used (refer to ASTM D2122, ISO 10931, and ISO 15494). Nonmandatory Appendix JJ, Table JJ-1 compares the outside and inside dimensions of these standards. It is important to consider these standards when performing system sizing calculations to enhance dimensional alignment of inner pipe diameters to enable sterility, cleanability, and drainability. Tube inside dimensions are critical for alignment to stainless steel systems.

(24) **PM-4.2.2 Pressure Ratings.** Polymer piping systems have varying pressure ratings depending on material and sizing standards. Valves and mechanical connections such as sanitary adapters, flanges, or threads may carry pressure ratings independent of pipe and fittings. Elevated operating temperatures will decrease overall system rating. Manufacturers shall provide technical documentation regarding pressure ratings per ASME NM.3.3.

PM-4.2.3 Thermal Expansion. Polymeric materials will expand and contract with changing temperature conditions. The effect of thermal expansion shall be considered and designed for in every thermoplastic system.

To compensate for thermal expansion, it is recommended to use loops, offsets, and changes in direction. By using the pipe itself to relieve the stress, the integrity of the pipe system is maintained. The use of bellows or pistons is not recommended due to the formation of pockets and gaps where liquids may be held up. The amount of thermal expansion growth in a pipe system is generally calculated by the following formula:

(U.S. Customary Units)

$$\Delta L = 12 \times L \times \alpha \times \Delta T \quad (2)$$

where

L = length of the pipe run, ft
α = coefficient of thermal expansion, in./in./°F material and temperature dependent
ΔL = change in length, in.
ΔT = temperature change, °F

(SI Units)

$$\Delta L = L \times \alpha \times \Delta T \quad (3)$$

where

L = length of the pipe run, mm
α = coefficient of thermal expansion, mm/m/°C material and temperature dependent
ΔL = change in length, mm
ΔT = temperature change, °C

Typical coefficients of thermal expansion at room temperature by material type are found below. Consult the manufacturer for exact coefficient values.

(U.S. Customary Units)

PVDF 6.6×10^{-5}, in./in./°F
PFA 7.0×10^{-5}, in./in./°F
PP 8.33×10^{-5}, in./in./°F

(SI Units)

PVDF 1.2×10^{-5}, mm/m/°C
PFA 1.2×10^{-5}, mm/m/°C
PP 1.5×10^{-5}, mm/m/°C

ΔT is the maximum (or minimum) temperature minus the installation temperature. If the installation temperature or time of year is unknown, it is practical to increase ΔT by 15% for safety. It is not necessary or practical to use

the maximum temperature minus the minimum temperature unless it will truly be installed in one of those conditions.

PM-4.2.4 System Support Criteria

(24) **PM-4.2.4.1 Support Distances.** Nonrestrictive supports, which allow for axial movement and expansion and contraction of the pipe, shall be placed based on the spacing requirements provided by system manufacturers according to load, material, temperature, pipe wall thickness, and diameter. Operating conditions of all applicable processes, including CIP and SIP, shall also be considered. Hanging criteria generally increase with system operating temperatures. The placement of hangers, guides, and anchors is critical in systems exposed to thermal cycling. Hanger locations should be identified by the system engineer in conformance with the recommendations found within the material manufacturers' technical documentation and laid out to allow for expansion and contraction of the pipe over its life of operation.

(24) **PM-4.2.4.2 Hanger and Clamp Types.** Avoid using hangers that place a pinpoint load on the pipe when tightened. A U-bolt hanger is not recommended for thermoplastic piping. Hangers that secure the pipe 360 deg shall be used where required per piping manufacturers' technical documentation. Nonrestrictive thermoplastic clamps, hangers, and supports are also recommended over metal clamps, as they are less likely to scratch the pipe in the event of movement. Clamps should be evaluated to avoid rough edges that could damage the pipe. Ideally, if a metal clamp is being used, an elastomer material should be used in between the pipe and the clamp. See Part SD for exterior cleanability.

(24) **PM-4.2.5 Joining of Pipe Lengths and Fittings.** Design of piping layouts should minimize the number of mechanical (hygienic) connections. Fusion welded connections [e.g., noncontact infrared (IR), beadless welding] shall conform to MJ-9.3. Hygienic design of connections shall conform to SD-3.1.

CHAPTER 4
DESIGN FOR MULTIUSE

PART SD
SYSTEMS DESIGN FOR MULTIUSE

(24) SD-1 PURPOSE AND SCOPE

The purpose of Part SD is to establish design guidelines applicable to multiuse bioprocessing equipment. Wherever "equipment" is stated in this Part, it shall mean bioprocessing equipment, components, assemblies, and systems.

The purpose of this Part is to provide requirements for the specification, design, fabrication, and verification of process equipment and systems that are fit for intended use, and to minimize risk to the product. Part SD also provides design guidelines that should be applied at the discretion of the owner/user on the basis of assessed risk to the product. Figures in this Part are intended to illustrate accepted applications of general design principles and are not intended to limit alternate designs.

The scope of Part SD encompasses requirements for equipment, process systems, and utilities that could potentially impact product quality. Specific guidance is provided for bioburden control in manufacturing processes, including design requirements for cleaning, sanitization, and sterilization of bioprocess systems.

(24) SD-2 GENERAL GUIDELINES

Equipment and systems shall be designed according to the bioprocessing application, requirements, and specifications of the owner/user. It shall be the responsibility of the owner/user to specify requirements for cleaning or sanitization of the equipment or system.

SD-2.1 Containment

The containment level of the system or individual pieces of equipment should be specified and communicated by the owner/user.

The owner/user shall determine the containment level for the particular type of equipment or system, in accordance with the Centers for Disease Control and Prevention (CDC) and guidelines of the National Institutes of Health (NIH) or directives of the European Union and other applicable local codes or environmental regulations.

SD-2.2 Bioburden Control (24)

Part SD provides recommended design features that should be incorporated into components and equipment that are used in hygienic systems. These design elements, properly implemented and in conjunction with proper bioburden reduction measures such as CIP/SIP, enable systems to control bioburden.

It is the owner/user's responsibility to provide the following information for the designer to determine the design features required to maintain bioburden control:

(a) the acceptable level of bioburden before, during, and at completion of a process step or sanitization interval

(b) the duration that bioburden control needs to be maintained whether in a closed-process or open-process system

This Part does not address self-sanitizing processes but does address features of continuously operated systems such as hot water-for-injection and pure steam that control bioburden by continuous heat and are considered self-sanitizing process utility systems.

SD-2.3 Bioburden Reduction (24)

Bioburden reduction is an activity performed with the purpose of achieving a measured reduction in bioburden levels, in the equipment or product, to allowable levels. Depending on the chosen methodology or goal, the activity may be performed prior to equipment use, between process steps, or during a process step.

(a) For process operations in multiuse systems, bioburden reduction is typically accomplished by, but not limited to

- *(1)* cleaning (with or without chemicals)
  - *(-a)* CIP
  - *(-b)* COP
- *(2)* steaming
  - *(-a)* SIP
  - *(-b)* autoclaving
- *(3)* dry heat
- *(4)* process heating
  - *(-a)* batch heating

(-b) pasteurization
(-c) high-temperature short-time (HTST)
(-d) ultra-high-temperature (UHT)
(5) process filtration
(6) chemical sanitization
(-a) ozone
(-b) vaporous hydrogen peroxide (VHP)
(-c) chlorine dioxide
(-d) other acids, bases, or solvents
(7) ultraviolet light
(b) For single-use systems, see SU-9.

SD-2.3.1 Thermal Sanitization. This section specifies the design requirements for equipment that is sterilized or sanitized by the application of heat. Thermal sanitization includes dry heat treatment, SIP for sanitization, SIP for sterilization, steam out of place (autoclaving), hot liquid sterilization, and hot liquid sanitization.

SD-2.3.1.1 Steam-in-Place. Equipment parts and components subjected to SIP should be designed and constructed to withstand continuous exposure to saturated steam at a minimum temperature of 266°F (130°C; representing 24 psig/1.65 bar under saturated steam conditions) for a duration of at least 100 hr under continuous steady-state conditions. All process contact surfaces subjected to SIP shall reach the required temperatures, under the required saturated steam pressure conditions, during the SIP cycle. Executing SIP operations at temperatures exceeding 266°F (130°C) may cause degradation of elastomers or damage to other components, resulting in reduction of overall equipment life. SIP conditions that are more stringent may be imposed by the owner/user. The use of elastomers (within a piece of equipment or certain process instrumentation) that could thermally degrade during SIP shall be evaluated by the owner/user.

SD-2.3.1.1.1 Requirements. Process systems subject to SIP shall be designed to
(a) provide for air removal within the SIP boundary
(b) provide for removal of condensate within the SIP boundary
(c) be drainable in conformance with SD-2.4.3
(d) have provisions in place for verification of SIP performance
(e) have no dead legs within the SIP boundary

SD-2.3.1.1.2 Recommendations. Process systems subject to SIP should be designed to
(a) avoid concurrent steam supplies from alternate locations to prevent stagnant zones/entrained air
(b) monitor temperature and pressure at appropriate locations (e.g., vessels) that confirm saturated steam conditions within the SIP boundary
(c) monitor temperature at every SIP boundary point during performance verification
(d) enable continuous verification or periodic confirmation of the validated state
(e) maintain the integrity of the system post-SIP
(f) maintain monitored temperature points within 2°C (assuming ±0.5°C accuracy of the RTD) of each other during dwell within the SIP boundary
(g) maintain monitored temperature points within 2°C (assuming ±0.5°C accuracy of the RTD) of the corresponding saturated steam temperature for the system pressure during dwell
(h) maintain monitored temperature points above the minimum specified SIP temperature and in accordance with SD-2.3.1.1 within the SIP boundary during dwell

SD-2.3.1.2 Depyrogenation. [Reserved for future content]

SD-2.3.2 Chemical Sanitization. [Reserved for future content]

SD-2.4 Fabrication (24)

Fabrication shall be performed in facilities where the process contact surfaces are protected from contamination. During field welding and assembly, surface contamination shall be prevented.

Systems, equipment, and components shall be cleaned with a suitable cleaning agent and covered for protection before shipment. The use of preservative fluids is not recommended.

Process contact surfaces that require shipment with preservatives or coatings shall be
(a) mutually agreed to, in advance, by the owner/user and manufacturer
(b) clearly identified to all parties
(c) in conformance to FDA or other applicable regulations, as appropriate for the process

Following installation, to remove construction debris or foreign bodies, process contact liquid service systems should be flushed with water or chemically cleaned, per specifications provided by the owner/user, before being placed into service. The minimum acceptable quality of water used for flushing is noncompendial purified water (e.g., reverse osmosis or deionized water).

The system design should provide for the removal of components (e.g., control valves, spray devices, instrumentation) and equipment (e.g., pumps) that may be damaged by construction debris during flushing. If removal is not practical, the design shall allow for a temporary strainer or screen installed upstream of the component. Temporary strainers or screens shall be removed prior to the system being put into service.

The as-built layout of piping (e.g., pipe diameter change, blocked branches, low points, direction of slope) should be considered when specifying the flushing sequence and flushing parameters (e.g., velocity, volume, time).

The flushing procedure should specify inspection points (e.g., low points, valve diaphragms, hygienic clamp unions, system elastomers, strainers, spray devices, temporary screens) and acceptance criteria to confirm the procedure is complete.

SD-2.4.1 Materials of Construction

SD-2.4.1.1 General. Generally, materials such as stainless steels (e.g., 316-type and 316L-type alloys), duplex stainless steels, and higher alloys have proven to be acceptable. The owner/user shall be responsible for the selection of the appropriate materials of construction for the specific process. Metallic materials of construction are listed in Part MM.

When nonmetallic materials are used (e.g., polymeric materials or adhesives), the owner/user shall specify which one of these materials shall carry a Certificate of Conformance. The conformance of material shall be explicitly stated (e.g., conforming to FDA 21 CFR 177 and USP Section <88> Class VI). Polymeric materials and other nonmetallic materials of construction are listed in Part PM.

SD-2.4.1.2 Process Compatibility

(a) Materials of construction shall be capable of withstanding the temperature, pressure, and chemical corrosiveness of the process.

(b) Materials shall be compatible with the stated bioprocessing conditions, cleaning solutions, and SIP conditions, etc., as specified by the owner/user.

(c) Surfaces exposed to bioprocessing fluids, cleaning, and SIP conditions must be

(1) homogeneous in nature
(2) impervious
(3) inert
(4) nonabsorbent
(5) nontoxic
(6) insoluble by process or cleaning fluids
(7) resistant to corrosion, scratching, scoring, and distortion

(d) Materials that are in contact with bioprocessing fluids shall be identified by an industry-recognized standard (see MM-4).

SD-2.4.1.3 Surface Coatings. Clad or electroplated surface coatings, plating, and surface preparatory chemicals may be used provided approval from the owner/user has been obtained. All surface coatings shall remain intact and be tolerant to the process, SIP and CIP fluids, and temperatures, without peeling or cracking.

SD-2.4.1.4 Transparent Materials

(a) Transparent materials (e.g., glass, polymer) that are used in viewing ports shall be rated for the applicable pressure, temperature range, and thermal shock.

(b) Internally coated glass shall only be used if the coating complies with FDA regulations or another regulatory authority's regulations and is approved by the owner/user.

SD-2.4.2 Cleanability (24)

(a) The following provisions are applicable to tubing, equipment, or systems intended to be cleaned:

(1) Surfaces shall be cleanable. Surface imperfections (e.g., crevices, gouges, obvious pits) should be eliminated whenever feasible.

(2) Surfaces shall be accessible to the cleaning solutions and shall be accessible to establish and determine efficacy of the cleaning protocol.

(3) Fasteners or threads shall not be exposed to the process, steam, or cleaning fluids. The use of threads within the process requires owner/user agreement. Bolted attachments should be eliminated whenever possible.

(4) No engraving or embossing of materials (for identification or traceability reasons) should be made on the process contact side. When markings are required on process contact surfaces, other methods of identification shall be used.

(b) The following provisions are applicable to tubing, equipment, or systems intended to be cleaned in place:

(1) Internal horizontal surfaces should be minimized.

(2) The equipment should be drainable or capable of having energy applied (e.g., pressurized gas, vacuum, heat) to remove liquid. The equipment shall be free of areas where soil or contaminants could collect. The equipment should be free of areas of low flow and velocity or impact where soil or contaminants could collect.

(3) Design of corners and radii should meet the following requirements: All internal angles of 135 deg or less on surfaces shall have the maximum radius possible for ease of cleanability. Where possible, these surfaces shall have radii of not less than $^{1}/_{8}$ in. (3.2 mm) except where required for functional reasons, such as the bonnet/body connection. For special cases, the radii may be reduced to $^{1}/_{16}$ in. (1.6 mm) when agreed to by the owner/user. When the $^{1}/_{16}$ in. (1.6 mm) radii cannot be achieved for essential functional reasons such as flat sealing surfaces and flow control apertures, the surfaces of these internal angles shall be readily accessible for cleaning and examination.

SD-2.4.3 Drainability

SD-2.4.3.1 General. For the purpose of bioburden control and cleaning, gravity is an effective way to enable draining. For drainability, lines should be pitched to designated points at a specific slope. See Nonmandatory Appendix C for suggested method of slope measurement. For drainable piping/tubing systems, the owner/user may define the system slope

Table SD-2.4.3.1-1
Slope Designations for Drainable Lines

Slope Designation	Minimum Slope, in./ft	Minimum Slope, mm/m	Minimum Slope, %	Minimum Slope, deg
GSD1	1/16	5	0.5	0.29
GSD2	1/8	10	1.0	0.57
GSD3	1/4	20	2.0	1.15
GSD0	Line slope not required			

in accordance with one of the designations listed in Table SD-2.4.3.1-1. Drainable piping/tubing systems shall have a continuous pitch that is equal to or greater than the slope designation. Line sections up to 10 in. (25 cm) in length (or longer with advance approval of the owner/user) that are level or have a positive slope less than the slope designation are acceptable if the section is fitting-bound.

SD-2.4.3.2 Drainability Design Considerations. The system's process requirements should be considered in the selection of slope designation.

(a) Process contact lines exposed to liquid should be sloped to minimize pooling in the system.

(b) Lines that are steam sterilized in place should be sloped to enable condensate removal.

(c) Lines that are cleaned in place should be sloped to enable removal of cleaning fluids.

The physical characteristics of the system (e.g., line size, materials, fluid viscosity, fluid surface tension) will influence drainability at a given slope and should also be considered. The owner/user may apply additional criteria in the selection of slope designation to address issues such as product recovery or maintenance. Fluid retention due to surface tension and surface adherence should be considered when using tubing less than 3/4 in. (19 mm). System leveling should be considered for mobile equipment that is designed to be drainable.

SD-2.4.3.3 Slope Considerations. The recommended minimum slope designation for drainable process contact lines is GSD2.

(24) **SD-2.4.3.4 Drain Points**

(a) Piping and equipment should be installed with designated low-point drains and high-point vents for drainability. The number of drain points and vents should be minimized. The equipment manufacturer shall indicate the proper orientation to optimize drainability. The owner/user shall ensure that proper orientation is achieved. Drain point design shall not create a dead leg.

(b) Systems or equipment that cannot be drained should be capable of having energy applied (e.g., pressurized gas, vacuum, heat) to remove the liquid, where required.

SD-2.4.4 Miscellaneous Design Details

SD-2.4.4.1 Lubricants

(a) Grease and other lubricating fluids that are used in gearboxes, drive assemblies, etc., shall be contained to prevent leakage of the lubricants or process, either directly or indirectly (e.g., through seepage, seal leaks).

(b) The equipment manufacturer shall specify the type of lubricants that are to be used for maintenance. If the specified lubricant is not accepted by the owner/user, the choice of an alternative shall be agreed to by the owner/user and the equipment manufacturer.

(c) The owner/user shall give approval for the lubricants that could come in contact with the process. These lubricants shall be identified by name, manufacturer, and grade and shall conform to FDA or other applicable regulatory codes.

(24) **SD-2.4.4.2 Exterior Design.** Equipment located in clean areas may be periodically cleaned by wash-down or manually cleaned by wipe-down with harsh cleaning solutions. Such equipment shall conform to the following:

(a) Materials of construction should be corrosion resistant, easily maintained, cleaned, and sanitized without flaking or shedding.

(b) Finishes shall be compatible with the area/room classification as agreed to by the owner/user and manufacturer.

(c) Components shall be capable of being chemically cleaned, steam cleaned, or pressure washed.

(d) Burrs or weld marks shall be removed.

(e) Hinges should be easily removable or cleanable.

(f) Equipment mounted on cabinets that are exposed to the environment should be mounted flush.

(g) Skids should have no openings in the frame allowing water retention. Supporting skid frame structures and modules should be constructed from fully sealed tubes or pipes that are easily cleaned. Frames should have rounded rather than sharp edges.

(h) Motors, gearboxes, and similar equipment should not retain fluids or cleaning solutions on their external surfaces.

(i) Nameplates for tagging equipment should be constructed from corrosion-resistant material, such as stainless steel or polymeric material, and should have minimal crevices. The nameplates should be attached and sealed or attached with a corrosion-resistant wire loop.

(j) There should be adequate clearance below or under the equipment for cleaning. Clearance for discharge should be provided. Elevated equipment under open frames should have a minimum clearance of 6 in. (150 mm) for wash-down and cleaning. In other cases a minimum of 4 in. (100 mm) would be adequate.

(k) Joints and insulation materials shall be sealed and impervious to moisture and cleaning agents.

(l) Electrical enclosures and conduit should be cleanable and use materials of construction that are compatible with cleaning agents.

(m) Painted surfaces shall be identified by the fabricator and have the advance approval of the owner/user.

SD-2.4.4.3 Surface Finishes. The finishes of process contact surfaces shall be specified by the owner/user in accordance with the definitions of Part SF in this Standard.

SD-2.5 Hygienic System Design (24)

The hygienic design of the system shall incorporate the applicable functionality for flushing, passivation, cleaning, sanitization, steam-in-place, process fluid distribution, and process parameter measurement and control. The system's hygienic physical (general arrangement) design shall be integral with its operations including, but not limited to, valve sequencing, parameter measurement, and controls. The owner/user and designer should evaluate the design across all operations to confirm that the design mitigates contamination risk to the product and to identify installation, operational, and performance verification testing requirements.

SD-2.5.1 Tube/Pipe Branches. Tube/pipe branches that are closed (e.g., closed valve, capped branch tee) during an operation should be designed and installed to mitigate contamination risk. Tube/pipe branches closed during CIP/SIP operations, designed to meet the minimal dimensional and orientation criteria detailed in SD-3.1.2.2, are not dead legs if they are operated, cleaned, or sanitized under specified conditions (e.g., velocity, temperature, time). Tube/pipe branches that are open during CIP/SIP shall be designed to enable flow of cleaning/sanitizing fluids under specified conditions. Tube/pipe branches with valves that are cycled during processing operations should be designed to mitigate cross-contamination risk and are not dead legs if they are toggled, cleaned, or sanitized under specified conditions (e.g., flow/impingement, steam penetration, temperature, time).

SD-2.5.2 Tube/Pipe Instruments. Process tubing/piping instrumentation and associated connection points should be designed to mitigate the risk of contamination due to extended ferrule connections and any annular space around the sensor. Instrument tees or short-outlet tees conforming to DT-4.1.2 should be used where feasible, maintaining $L/A < 2$ [see Figure SD-3.4.3-1, illustration (a)]. When an instrument tee or short-outlet tee is not used, the tee should be oriented such that cleaning and sanitization fluids circulate into the branch and annular space around the instrument sensor, and air is not trapped, to avoid the formation of a dead leg. The system designer shall identify instrument locations where L/A or $L/d < 2$ is not met.

SD-2.5.3 Equipment Nozzles. Equipment nozzles used to accommodate agitators, controls, instrumentation, or process fluid transfer should be designed to mitigate contamination risk due to extended connections or the annular space around the inserted appurtenance by meeting the dimensional and orientation criteria detailed in SD-3.5.1 and SD-3.4.3. Equipment nozzles closed during CIP/SIP operations shall be designed to meet the minimal dimensional and orientation criteria detailed in SD-3.4.2 and are not dead legs if they are cleaned or sanitized under specified conditions (e.g., flow/impingement, steam penetration, temperature, time).

SD-2.6 Animal-Derived Ingredients (24)

DELETED

SD-3 PROCESS COMPONENTS AND EQUIPMENT

SD-3.1 Connections, Fittings, and Piping

SD-3.1.1 General (24)

(a) Design of equipment should minimize the number of connections. Butt-welded connections should be used wherever practical.

(b) Connections to equipment shall use acceptable hygienic design connections, mutually agreeable to the owner/user and manufacturer.

(c) Connections subjected to cleaning and sanitization shall be capable of CIP and SIP. Fittings shall be so designed that there will not be any crevices or hard-to-clean areas around the gasketed joint. ASME raised-face or flat-face flanged joints should be avoided where possible (see Figure SD-3.1.1-1).

(d) Ferrules and ferrule connections should not constitute a dead leg. The use of short welding ferrules should be incorporated into the design to promote enhanced cleanability or bioburden reduction of the system.

(e) Process contact fittings exposed to liquid should be drainable when properly installed.

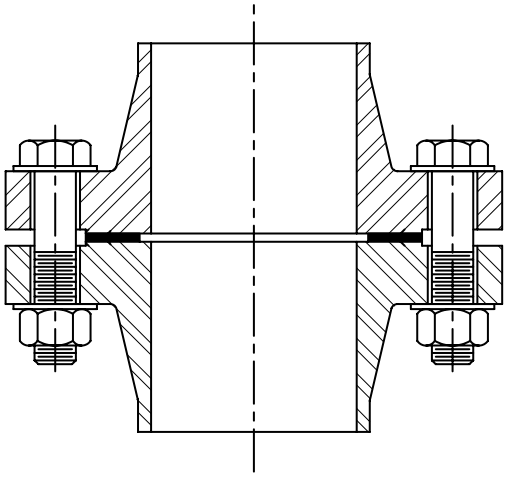
(f) Threaded fittings, exposed to process fluid, are not recommended (see Figure MC-2.2.2-5).

(g) The use of flat gaskets may be acceptable, when agreed to by the owner/user and manufacturer, for applications where it is considered self-sanitizing (i.e., in pure steam distribution systems).

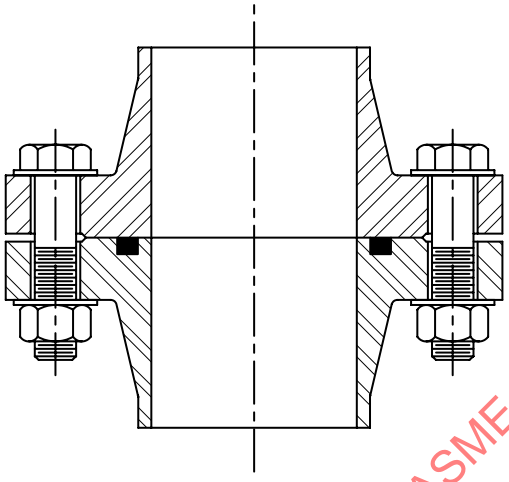
(h) The centerline radius of factory-bent tubes shall be in accordance with Table DT-3-1, CLR, (*R*).

(i) Piping systems described in Part SD refer to hygienic tubing systems. Caution should be exercised if using pipe (instead of tube) to ensure that the requirements of this Standard are met. The requirements of hygienic tubing (e.g., surface finish, dimensions, and tolerances) are not typically met by pipe.

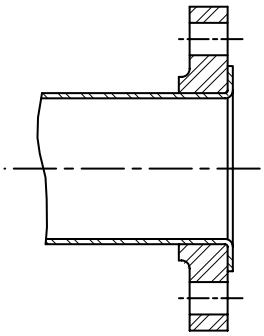
Figure SD-3.1.1-1
Flat Gasket Applications



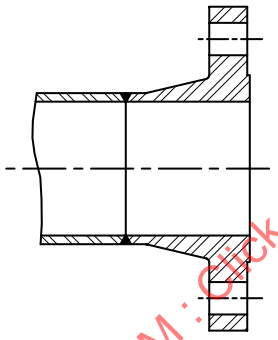
(a) Flange With Flat Gasket



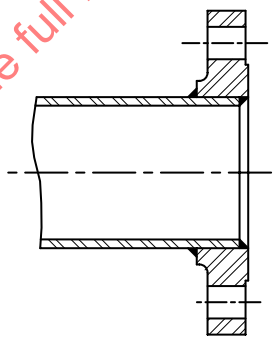
(b) Flange With O-Ring



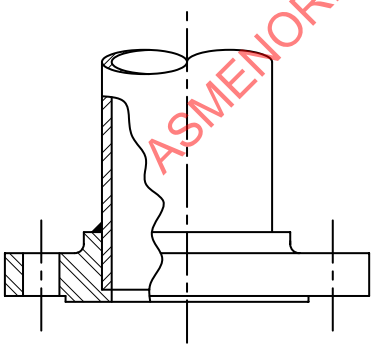
(c) Stub-End / Lap Joint



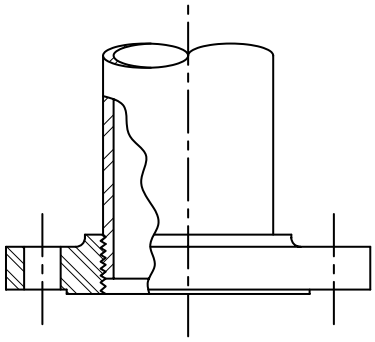
(d) Weld Neck



(e) Slip On

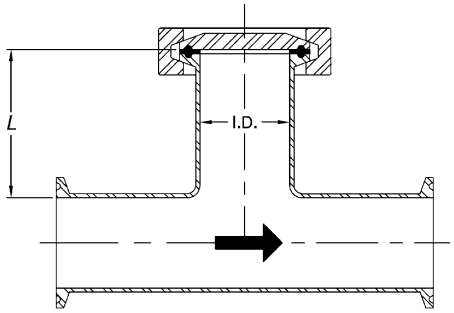


(f) Socket Weld



(g) Threaded

Table SD-3.1.2.2-1
***L/d* Dimensions for Flow-Through Tee: Full-Size Standard Straight Tee With Blind Cap**



Nominal Size, in.	Wall Thickness	I.D. (*d*)	Branch, *L*	*L/d* (Branch)
1/4	0.035	0.180	2.16	12.00
3/8	0.035	0.305	2.10	6.88
1/2	0.065	0.370	2.07	5.58
3/4	0.065	0.620	2.07	3.33
1	0.065	0.870	2.19	2.52
1 1/2	0.065	1.370	2.14	1.56
2	0.065	1.870	2.44	1.30
2 1/2	0.065	2.370	2.44	1.03
3	0.065	2.870	2.44	0.85
4	0.083	3.834	2.83	0.74
6	0.109	5.782	4.24	0.73

SD-3.1.2 System Design

SD-3.1.2.1 General

(a) Product holdup volume in the system should be minimized.

(b) Bioprocessing piping and tubing design should have routing and location priority over process and mechanical support systems.

(c) Piping and connections to in-line valves should be of all-welded construction where feasible, practical, and agreed to by the owner/user and manufacturer. To ensure the highest degree of hygienic design, the piping systems should use welded connections except where make-break connections are necessary.

(24) **SD-3.1.2.2 Closed Tube/Pipe Branches.** Closed tube/pipe branches will be measured by the term *L/d*, where *L* is the leg extension from the I.D. wall normal to the flow pattern or direction, and *d* is the I.D. of the extension or leg of a tubing fitting or the nominal dimension of a valve or instrument. For valves, *L* shall be measured to the seal point of the valve. Tables SD-3.1.2.2-1 and SD-3.1.2.2-2 indicate *L/d* values based on the BPE definition for various tubing geometries and configurations.

There is evidence that an *L/d* of 2 or less may prevent the branch from being a dead leg; however, the size and shape of the branch are also important in determining if the branch could lead to contamination. With sufficient flow through a primary pipeline, a branch may not constitute a dead leg.

The orientation of a branch is critical to the cleanability of the system. The branch shall be oriented to avoid a dead leg (e.g., a vertical branch with an *L/d* of 2 or less may still result in a dead leg with trapped gas or residual materials).

For high-purity water systems, an *L/d* of 2 or less is attainable with today's manufacturing and design technology. For other bioprocessing systems, such as purification, filtration, and fermentation having cluster, block, and multiport valves, an *L/d* of 2 or less is achievable. However, it may not be achievable with certain equipment and process configurations as they are currently manufactured. An *L/d* of 2 or less is recommended but shall not be construed to be an absolute requirement. The system designer and manufacturer shall make every attempt to eliminate system branches with an *L/d* greater than 2. It will be the responsibility of the system manufacturer or designer to identify where exceptions exist or where the *L/d* of 2 or less cannot be met.

An *L/d* of 2 or less may not be achievable for weir-type valves clamped to tees and certain sizes of close welded point-of-use valves, as shown in Figure SD-3.1.2.2-1, illustrations (b) through (f). For the header and valve size combinations where the *L/d* of 2 cannot be met using these configurations, a specific isolation valve design, such as shown in Figure SD-3.1.2.2-1, illustration (a), may be required to achieve the desired ratio.

SD-3.1.2.3 System Piping

(a) Routing of piping should be as direct and short as possible to ensure a minimal quantity of CIP solution to fill a circuit and eliminate excessive piping and fittings.

(b) Cross-contamination of process streams shall be physically prevented. Methods of separation used in industry are

(1) removable spool piece

(2) U-bend transfer panel

(3) double block-and-bleed valve system (see Figure SD-3.1.2.3-1)

(4) mix-proof valving

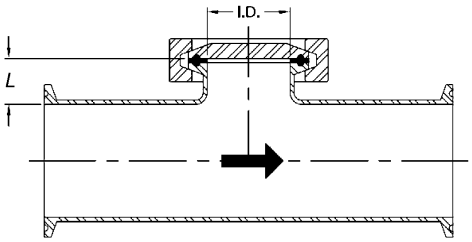
(c) The use of fluid bypass piping (around traps, control valves, etc.) is not recommended.

(d) The use of redundant in-line equipment is not recommended due to the potential creation of dead legs.

(e) Eccentric reducers shall be used in horizontal piping to eliminate pockets in the system.

(f) The system shall be designed to eliminate air pockets and prevent or minimize air entrainment.

Table SD-3.1.2.2-2
L/d Dimensions for Flow-Through Tee: Short-Outlet Reducing Tee With Blind Cap



Nominal Tee Size, in.	Nominal Branch Size, in.	Tee Wall Thickness	Branch Wall Thickness	Branch I.D., *d*	Branch, *L*	*L/d* (Branch)
3/8	1/4	0.035	0.035	0.180	0.85	4.71
1/2	1/4	0.065	0.035	0.180	0.82	4.53
1/2	3/8	0.065	0.035	0.305	0.82	2.67
3/4	1/4	0.065	0.035	0.180	0.69	3.83
3/4	3/8	0.065	0.035	0.305	0.69	2.26
3/4	1/2	0.065	0.065	0.370	0.69	1.86
1	1/4	0.065	0.035	0.180	0.69	3.83
1	3/8	0.065	0.035	0.305	0.69	2.26
1	1/2	0.065	0.065	0.370	0.69	1.86
1	3/4	0.065	0.065	0.620	0.69	1.11
1 1/2	1/4	0.065	0.035	0.180	0.69	3.83
1 1/2	3/8	0.065	0.035	0.305	0.69	2.26
1 1/2	1/2	0.065	0.065	0.370	0.69	1.88
1 1/2	3/4	0.065	0.065	0.620	0.69	1.11
1 1/2	1	0.065	0.065	0.870	0.69	0.79
2	1/4	0.065	0.035	0.180	0.69	3.83
2	3/8	0.065	0.035	0.305	0.69	2.26
2	1/2	0.065	0.065	0.370	0.69	1.86
2	3/4	0.065	0.065	0.620	0.69	1.11
2	1	0.065	0.065	0.870	0.69	0.79
2	1 1/2	0.065	0.065	1.370	0.69	0.50
2 1/2	1/4	0.065	0.035	0.180	0.69	3.83
2 1/2	3/8	0.065	0.035	0.305	0.69	2.26
2 1/2	1/2	0.065	0.065	0.370	0.69	1.86
2 1/2	3/4	0.065	0.065	0.620	0.69	1.11
2 1/2	1	0.065	0.065	0.870	0.69	0.79
2 1/2	1 1/2	0.065	0.065	1.370	0.69	0.50
2 1/2	2	0.065	0.065	1.870	0.69	0.37
3	1/4	0.065	0.035	0.180	0.69	3.83
3	3/8	0.065	0.035	0.305	0.69	2.26
3	1/2	0.065	0.065	0.370	0.69	1.86
3	3/4	0.065	0.065	0.620	0.69	1.11
3	1	0.065	0.065	0.870	0.69	0.79

Table SD-3.1.2.2-2
***L/d* Dimensions for Flow-Through Tee:**
Short-Outlet Reducing Tee With Blind Cap (Cont'd)

Nominal Tee Size, in.	Nominal Branch Size, in.	Tee Wall Thickness	Branch Wall Thickness	Branch I.D., *d*	Branch, *L*	*L/d* (Branch)
3	1½	0.065	0.065	1.370	0.69	0.50
3	2	0.065	0.065	1.870	0.69	0.37
3	2½	0.065	0.065	2.370	0.69	0.29
4	¼	0.083	0.035	0.180	0.71	3.93
4	⅜	0.083	0.035	0.305	0.71	2.32
4	½	0.083	0.065	0.370	0.71	1.91
4	¾	0.083	0.065	0.620	0.71	1.14
4	1	0.083	0.065	0.870	0.71	0.81
4	1½	0.083	0.065	1.370	0.71	0.52
4	2	0.083	0.065	1.870	0.71	0.38
4	2½	0.083	0.065	2.370	0.71	0.30
4	3	0.083	0.065	2.870	0.71	0.25
6	¼	0.109	0.035	0.180	0.86	4.77
6	⅜	0.109	0.035	0.305	0.86	2.82
6	½	0.109	0.065	0.370	0.86	2.32
6	¾	0.109	0.065	0.620	0.86	1.39
6	1	0.109	0.065	0.870	0.86	0.99
6	1½	0.109	0.065	1.370	0.86	0.63
6	2	0.109	0.065	1.870	0.86	0.46
6	2½	0.109	0.065	2.370	0.86	0.36
6	3	0.109	0.065	2.870	0.86	0.30
6	4	0.109	0.083	3.834	0.86	0.22

Figure SD-3.1.2.2-1
Accepted Point-of-Use Designs

(24)

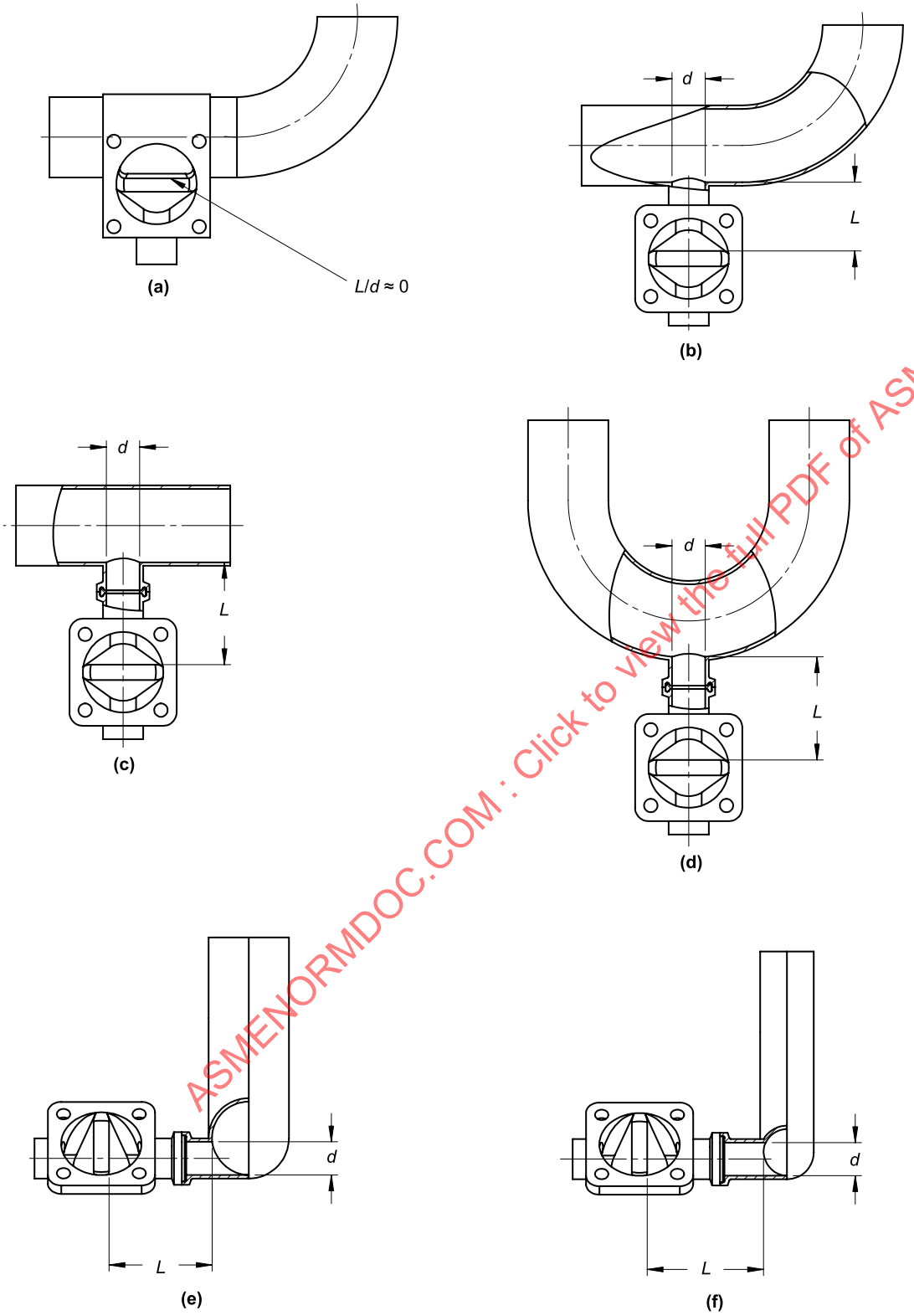
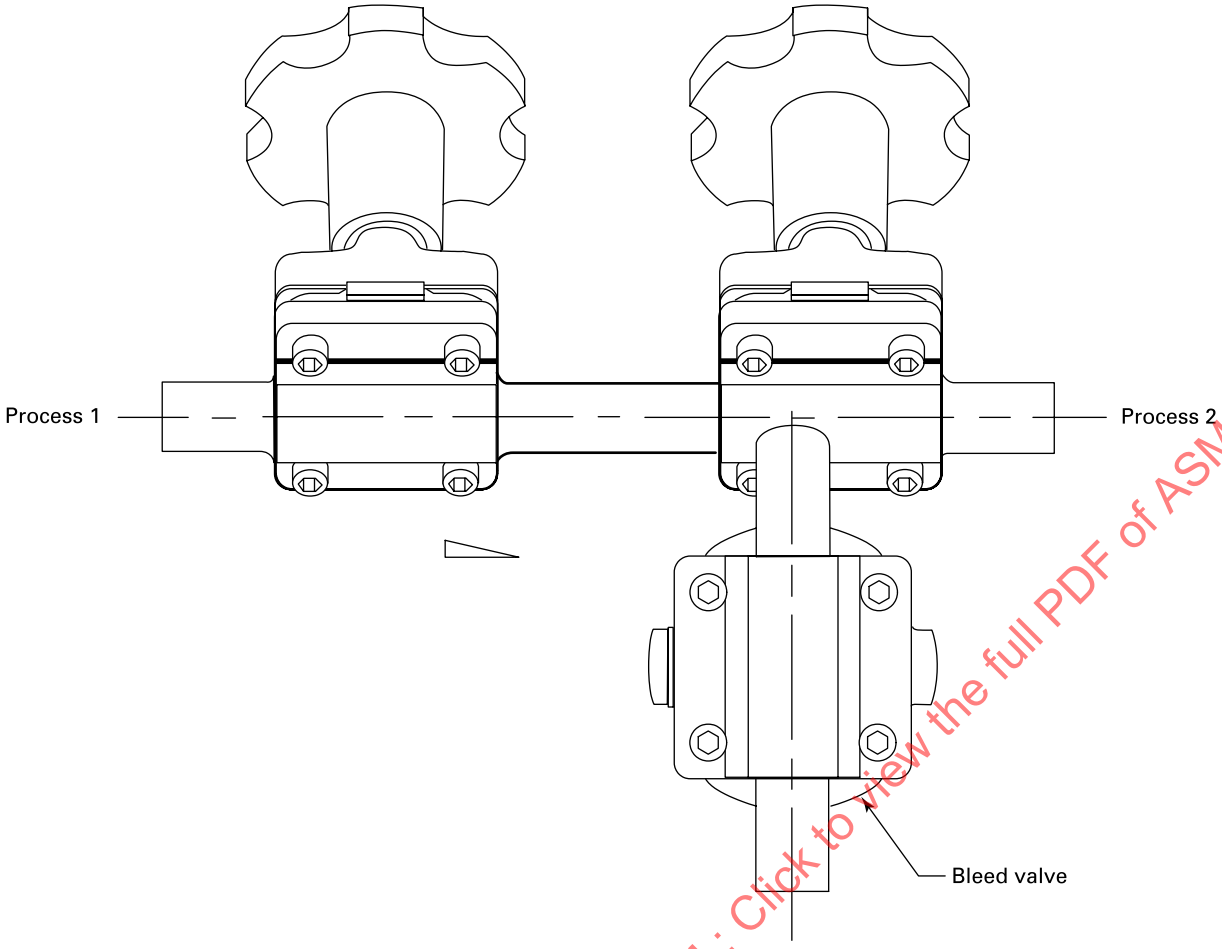


Figure SD-3.1.2.3-1
Double Block-and-Bleed Valve Assembly



(g) Field bending of tubing is permitted for diameters up to and including ½ in. (15 mm). The centerline radius of field-bent tubes should be not less than 2.5 times the nominal tube diameter to mitigate the risk of interior surface damage (e.g., wrinkles, striations, and cracks). Field bending of tubing in larger diameters or smaller bend radii may be used with the approval of the owner/user when appropriate examination techniques and procedures (e.g., visual, borescope, and sectioning) are used.

(h) Ball valves are not recommended in fluid hygienic piping systems. See SD-4.2.3(b) for further comments.

(i) See SF-2.4 regarding cleaning and passivation. Passivation of electropolished surfaces is not required unless the surface has been altered (e.g., welded or mechanically polished) or exposed to external contamination after electropolishing.

(j) The use of blind welds in piping systems should be avoided. Proper installation sequencing of the piping system can reduce the number of blind welds. See MJ-7.3.3(b) and GR-5.3.4 for further details.

SD-3.1.2.4 Hygienic Support Systems

(a) Hygienic supports should be used within classified spaces. Hygienic support design should incorporate drainable geometry to facilitate cleanability, have no exposed threads, and have minimal potential for collecting and trapping debris or liquids on the hanger. Materials of construction shall be corrosion resistant and compatible with the chemical, thermal, and physical performance requirements of the installed location. The materials shall have adequate strength and durability to withstand the application of any continuous or cyclic thermal exposure that may be encountered in the designed service.

(b) The piping should maintain proper continuous slope for drainability. Hygienic support systems shall assist in maintaining the required slope and alignment

under all operating conditions, taking into account thermal cycling, distortion, settling, moment loads, fluid specific gravity, etc. The support system should be designed to distribute loads and stresses from any potential movement. The supports shall be installed without adding stress to the tube or pipe in an attempt to achieve a desired slope.

(c) The support systems shall provide for, and control, the intended movement of the system. The designer should take into account system and equipment movement when planning the design. Anchoring systems should be designed to avoid piping motion in any of the three Cartesian axes. Guiding systems should be designed to allow piping axial motion due to thermal or mechanical loads. An anchor serves to secure the piping in place, and a guide will allow axial motion of the piping and is used to allow for thermal expansion.

(d) Supports/hangers should be installed close to each change in direction of piping. The only exception is on short subassemblies using small-diameter tube [<1.000 in. outside diameter (O.D.)] that is installed in a drainable position and does not bear any additional weights or loads from other process equipment. Hangers shall be of adequate strength and durability to withstand the imposed loads per MSS SP-58, Table 1. Per manufacturer's recommendations, supports/hangers should be installed as close as possible to (and on both sides of, if possible) concentrated loads including valves, instrumentation, and filter housings.

SD-3.1.2.4.1 Pipe Hangers and Supports for Metallic Piping. Metallic piping system hangers and supports shall be installed in conformance to MSS SP-58, MSS SP-69, MSS SP-89, and ASME B31.3 standards. To enable drainability, the metallic pipe or tube to be installed shall meet the straightness criteria of ASTM A1016. The support spacing shall not exceed a distance that will permit the piping to deflect under operating conditions.

SD-3.1.2.4.2 Pipe Hangers and Supports for Nonmetallic Piping

(a) Nonmetallic piping system hangers and supports shall be engineered based on the specific materials selected. When properly installed, stress concentration points will be minimized. The supports and hangers shall be installed to ensure drainability and overcome any deflection. Refer to manufacturer's recommendations for spacing, which is based on calculations that take into consideration the piping material, density, modulus of elasticity, diameter and wall thickness of the pipe, specific gravity of the fluids being transported, operating temperature, and thermal expansion properties.

(b) The requirement of a continuous support shall be determined based on the operating temperatures and the specific gravity of the process fluid being transported. Support channels may be available in a "V" or "U" section and shall be manufactured with no sharp edges that may embed or cause damage to the pipe exterior. These are commonly available in stainless steel or fiberglass reinforced plastic (FRP) materials. These supports cannot restrict axial movement of the piping and shall be approved by the owner/user.

SD-3.2 Hose Assemblies

SD-3.2.1 General

(a) Permanently installed hose assemblies shall be installed and supported for drainability [see Figure SD-3.2.1-1, illustrations (a) and (b)]. In temporary runs, hose assemblies may be manually drained after disconnecting.

(b) Hose assemblies shall be installed to avoid strain on end connections. Hose assemblies shall not be used as a substitute for rigid tube fittings or as tension or compression elements.

(c) Hose assembly length should be minimized and fitted for purpose.

(d) Hose assemblies shall be easy to remove for examination or cleaning.

(e) Hose assembly shall be clearly marked or tagged with the design-allowable working pressure/vacuum and design temperature range.

(f) Hose assemblies shall be inspected and maintained on a scheduled basis.

SD-3.2.2 Flexible Element

(a) The flexible element of the hose assembly shall be constructed of materials that permit the appropriate degree of movement or drainable offset at installation.

(b) The interior surface of the flexible element shall be cleanable and drainable.

(c) The materials used shall be compatible with cleaning and SIP conditions.

SD-3.2.3 End Connections

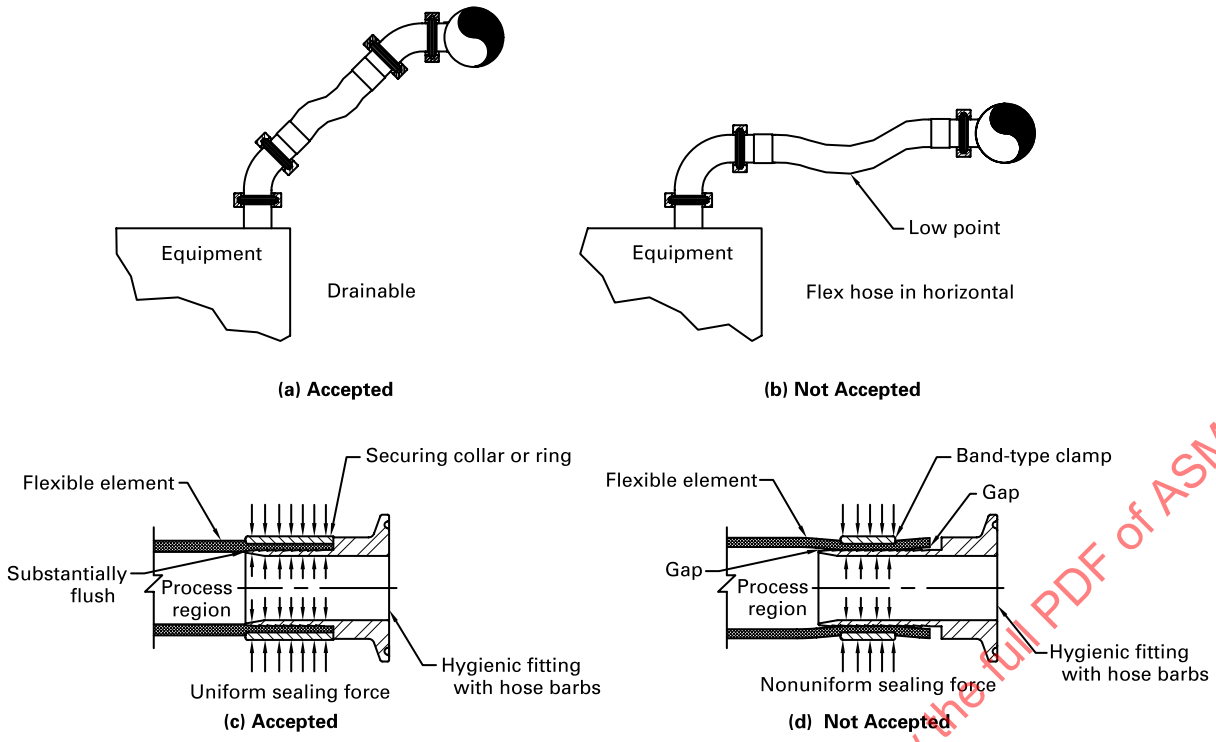
(a) End connections shall be of a material and design sufficiently rigid to withstand the combined forces of the burst pressure rating of the flexible element and the compression forces required to affect the secure assembly with the flexible element. [See Figure SD-3.2.1-1, illustrations (c) and (d).]

(b) End connections shall be of a material compatible with the process fluid, cleaning solutions, and steam where applicable. Materials shall meet the requirements of SD-2.4.1 or Part PM.

(c) End connections shall meet all surface finish requirements of Part SF.

(d) End connections shall be a hygienic connection design per MC-3.3.2.

Figure SD-3.2.1-1
Flexible Hygienic Hose Design



SD-3.3 Pumps

SD-3.3.1 Diaphragm Pumps

(a) Diaphragm pumps may be used in positive displacement pump applications. Diaphragm pumps are available that provide features such as low shear, constant flow or pressure, low pulsation, high turndown ratio (e.g., 1,000:1), and low particle generation.

(b) The owner/user shall evaluate whether holdup volume and drainability characteristics of a diaphragm pump are acceptable for the application. Some process applications require the process system, including the diaphragm pump, to remain continuously flooded with sanitizing solution instead of being drained.

(c) Process contact diaphragms, O-rings, gaskets, and seals shall conform to Part MC. Process contact metallic materials of construction shall conform to Part MM. Nonmetallic process contact surfaces including diaphragms shall conform to Part PM.

(d) Where applicable, check valves shall conform to SD-3.13

(e) Where used, diaphragm fasteners shall be attached within the pump head such that crevices or threads are not exposed to the process fluids.

(f) The owner/user should consider leak detection and leak path design of the pump to identify a failure that can lead to process contamination or biohazards.

SD-3.3.2 Hygienic Pumps

SD-3.3.2.1 General

(a) Pumps shall be cleanable. Pumps shall be selected according to the operating conditions determined by the owner/user (e.g., process, CIP, SIP, passivation).

(b) All process contact connections to the pump shall be of a hygienic design (see Figures MC-2.2.2-1 through MC-2.2.2-4).

SD-3.3.2.2 Centrifugal Pumps

(a) Hygienic centrifugal pumps shall be capable of CIP.

(b) All process contact surfaces shall be drainable without pump disassembly or removal.

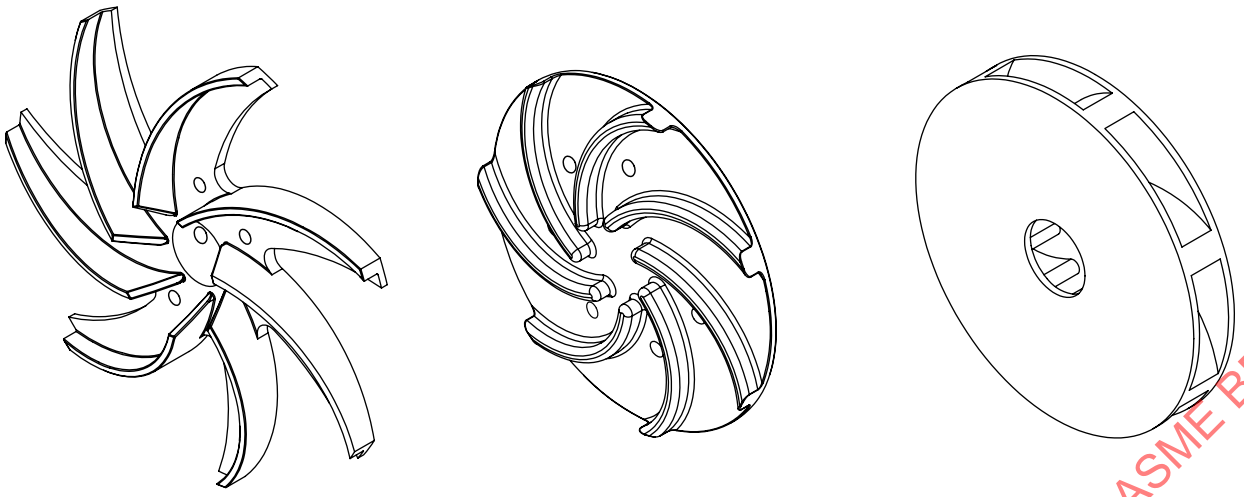
(c) Shrouded/closed impellers should not be used. Figure SD-3.3.2.2-1 illustrates open, semi-open, and closed impeller configurations.

(d) The impeller shall be attached to the shaft in such a way that all crevices and threads are not exposed to the process. Threads, such as in an impeller nut/bolt, shall be sealed by an O-ring or hygienic gasket. See Figure SD-3.3.2.2-2. The use of O-rings or hygienic gaskets shall be consistent with Part MC.

(e) Suction, discharge, and casing drain connections shall be an integral part of the pump casing.

(f) Casing drains shall be at the lowest point of the casing, to ensure drainability (see Figure SD-3.3.2.2-3).

Figure SD-3.3.2.2-1
Pump Impeller Configurations



(a) Open

(b) Semi-Open

(c) Shrouded/Closed

(g) The use of an elbow-type casing drain is not recommended without the use of an automatically controlled drain. The casing drain connection shall be designed to minimize the L/d as shown in Figure SD-3.3.2.2-4.

(h) The pump discharge connection should be tilted to allow for full venting of the casing (see Figure SD-3.3.2.2-3).

(i) All pump seals should be designed to minimize seal material degradation.

(j) Shaft seals shall conform to Part MC.

SD-3.3.2.3 Positive Displacement Pumps

(a) When possible, positive displacement pumps should be configured with vertically mounted inlets and outlets to promote drainability and venting.

(b) When using internal bypass pressure relief devices, they shall be of a hygienic design. It is preferred that an external, piping-mounted relief device (hygienic rupture disk) rather than a pump-mounted bypass be used.

SD-3.3.2.4 Rotary Lobe Pumps

(a) The owner/user shall specify the chemical, thermal, and hydraulic operating conditions of the pump (e.g,. process, CIP, SIP) to ensure proper component selection. Hygienic rotary lobe pumps are temperature sensitive (e.g., rotor to casing contact due to thermal expansion).

(b) The pump should be designed and installed to minimize holdup volume.

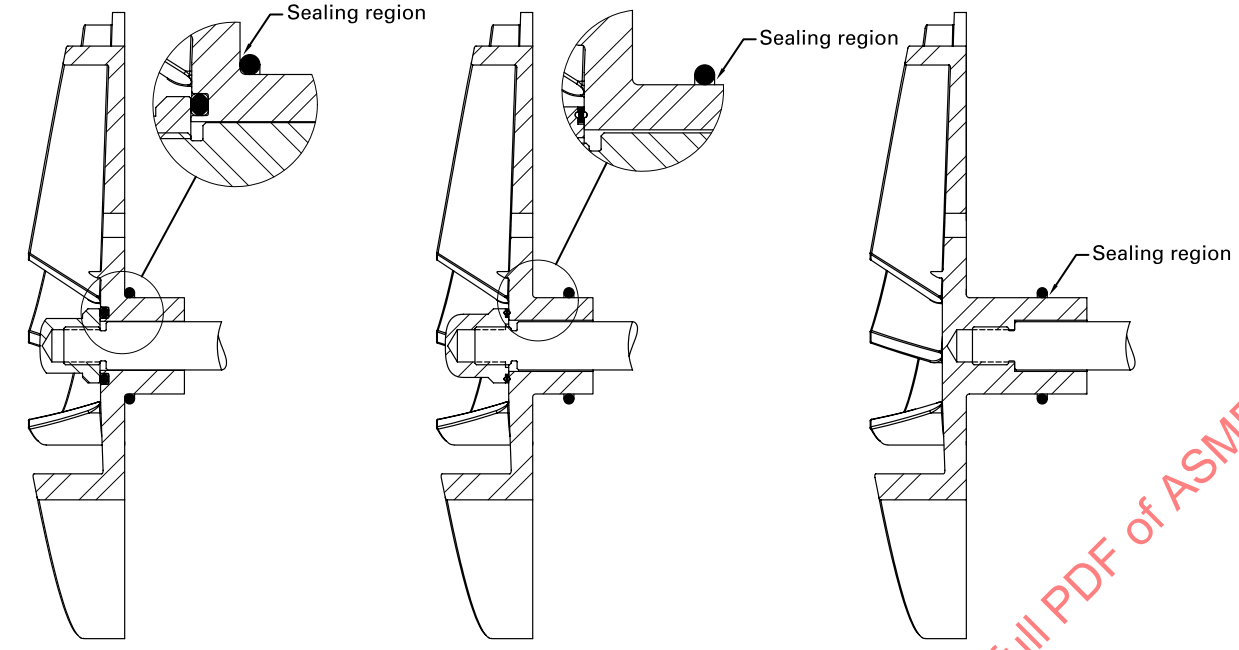
(c) Rotor fasteners shall be attached to the shaft in a way that crevices and threads are not exposed to the process. Threads and crevices shall be isolated from the process fluid by an appropriate hygienic seal, such as an O-ring or hygienic gasket (see Figure SD-3.3.2.4-1).

(d) The pump cover shall seal against the pump body by means of an O-ring or hygienic gasket.

(e) All process contact O-rings, gaskets, and shaft seals shall conform to Part MC.

(f) If a pressure relief device is used, it shall be of hygienic design in conformance with SD-3.15.

Figure SD-3.3.2.2-2
Acceptable Impeller Attachments

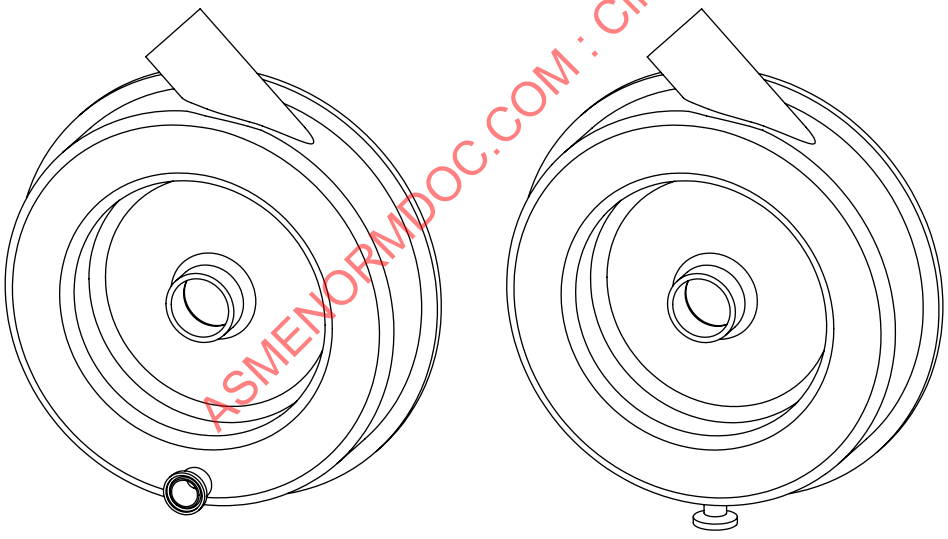


(a) Impeller Nut With O-Ring

(b) Impeller Nut With Hygienic Gasket

(c) No Impeller Nut

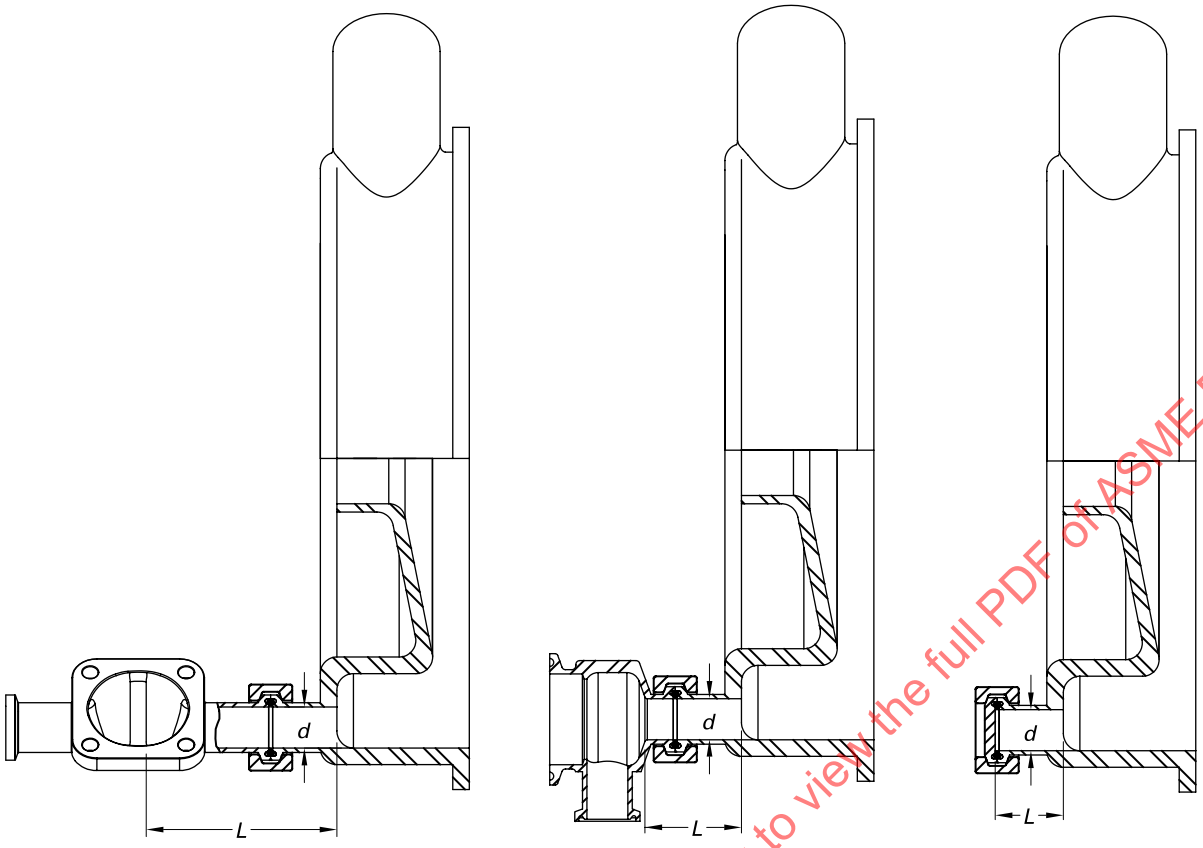
Figure SD-3.3.2.2-3
Casing Drain Configurations



(a) Horizontal

(b) Vertical

Figure SD-3.3.2.2-4
Casing Drain *L*/*d* Ratios

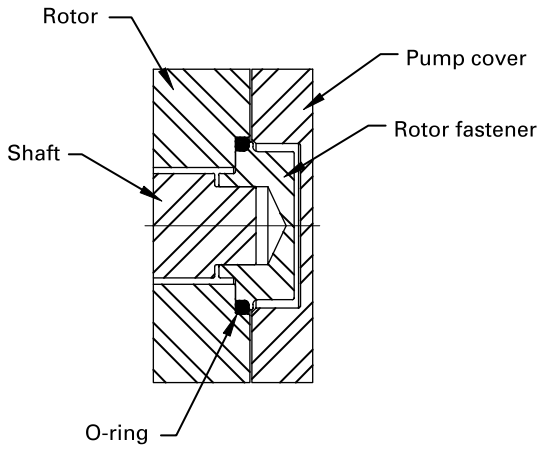


(a) Weir-Style Diaphragm Valve

(b) Radial-Style Diaphragm Valve

(c) Capped

Figure SD-3.3.2.4-1
Rotary Lobe Pump Rotor Attachment



(24) SD-3.4 Metallic Vessels

SD-3.4.1 General. This section provides requirements for the design, fabrication, and supply of pressurized and nonpressurized biopharmaceutical vessels.

(a) Design and fabrication of vessels and internal components shall ensure that surfaces are free of ledges, crevices, pockets, and other surface irregularities. If more restrictive tolerances are required, they shall be included as part of the fabrication specifications for the project.

(b) All heat transfer surfaces should be drainable and ventable.

(c) Materials that are welded to the vessel's non-process contact surfaces for support or mounting (e.g., reinforcing pads, doubler plates, poison pads) should be constructed of the same material as the vessel. Vent holes shall not be used on process contact surfaces.

(d) Vessels that are to be exposed to temperatures above 176°F (80°C) [e.g., SIP, hot water-for-injection (WFI), hot U.S. Pharmacopeia (USP) waters, and hot CIP solutions] should be designed for full vacuum service [maximum allowable working pressure-external of 15 psig (1 barg)].

(e) Top and bottom heads on vessels that are cleaned in place shall be drainable. Dished heads such as torispherical [e.g., ASME flanged and dished (F&D), 80:10 F&D], elliptical, and hemispherical are the most common types. Flat or conical heads should slope at not less than $\frac{1}{8}$ in./ft (10 mm/m) to a common drain.

(f) All internal surfaces should be sloped or pitched for drainability.

(g) Test protocols for drainability shall be agreed on in advance by all the parties (see SD-7.4). All vessels should be checked for drainability during fabrication.

SD-3.4.2 Vessel Openings

(a) Nozzles that are designed to be cleaned by a spray device should have the smallest L/d ratio possible. For non-flow-through nozzles, an L/d of 2 or less is recommended (see Figure SD-3.4.2-1).

(b) Nozzles less than 1 in. (25 mm) in diameter are not recommended unless the system design provides for SIP and CIP through the nozzle.

(c) Hygienic clamp union nozzles shall meet the I.D., flange, and gasket groove dimensions defined in Table DT-7.1-1 (all variables except *A*). Nozzle O.D. dimensions (Table DT-7.1-1, variable *A*) may be increased to satisfy ASME BPVC, Section VIII minimum nozzle neck thickness requirements, provided that clearance is achieved per DT-9.4(e).

(d) Bottom-mounted agitators, valves, pads, etc., shall not interfere with the drainability of the vessel.

(e) Sidewall instrument probes and nozzles should be sloped for drainability, unless the instruments used require horizontal mounting (see Figures SD-3.4.2-2 and SD-3.4.2-3).

(f) Blank covers or hygienic plugs used in process contact applications shall have the same finish as the vessel internals.

(g) Drain valves should be drainable, designed with a minimum branch L/d, sized, and installed to enable vessel drainability for all operations.

(h) The number and location of spray devices should be selected to eliminate shadowing of components (e.g., manways, mixer shafts, dip tubes, baffles, sidewall nozzles).

(i) Manways should be located on the vessel top head. If sidewall manways are required, they shall be sloped for drainability.

(j) Sample valves shall be designed and installed in accordance with SD-3.11.

(k) As required by the process, inlet nozzles tangential to the vessel surface may be used (see Figure SD-3.4.2-4).

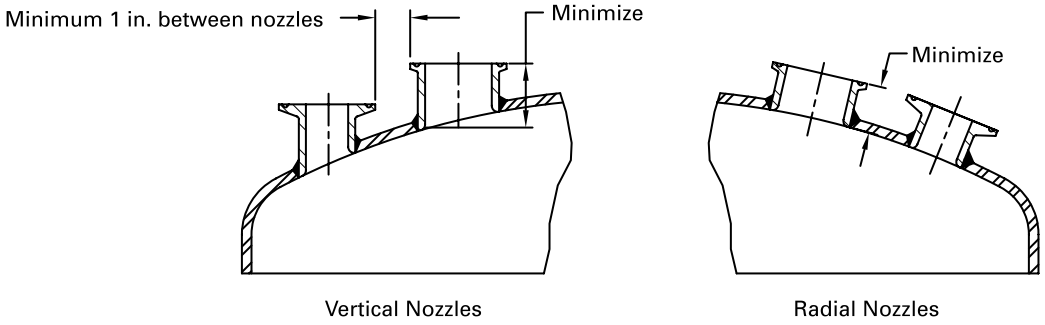
(l) Manway covers should be dished rather than a flat design.

(m) Flanges that have metal-to-metal contact on the process contact side shall not be used.

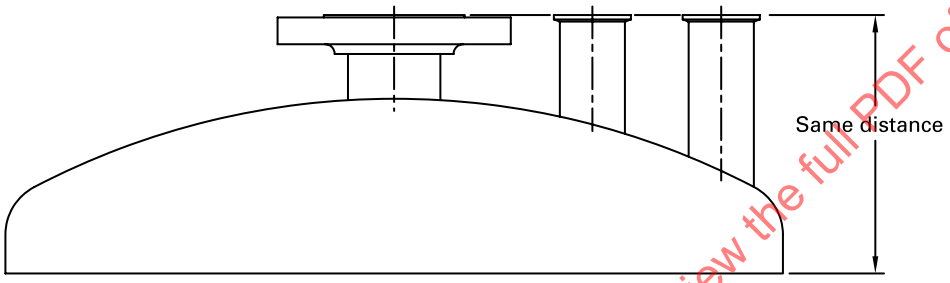
(n) All nozzles should be flush and radiused with the interior of the vessel except where projections are required to ensure additives are directed into the process fluid (e.g., chemical addition) (see Figure SD-3.4.2-5).

(o) Flanges for bottom, centerline-mounted agitators should be designed in accordance with Nonmandatory Appendix EE (see EE-3.3).

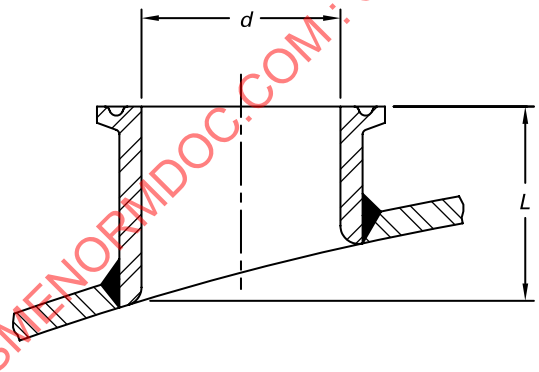
Figure SD-3.4.2-1
Nozzle Design



(a) Allow for Clamp Access [Notes (1) and (2)]



(b) [Notes (3) and (4)]

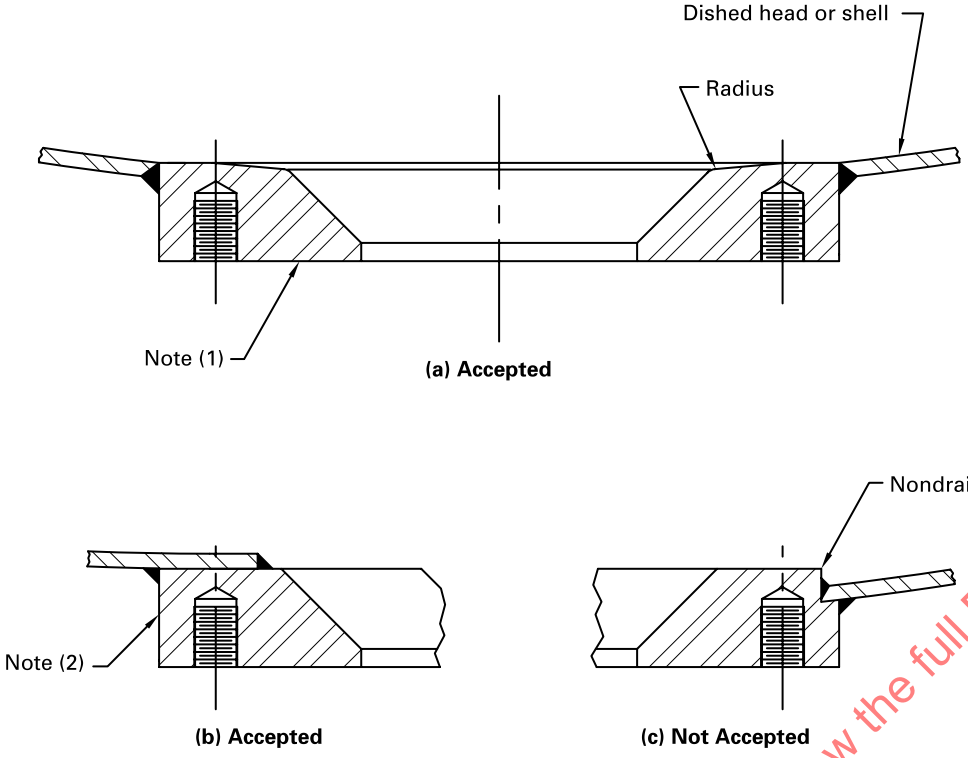


(c) [Note (5)]

NOTES:
(1) Less dead space.
(2) Better CIP/SIP capabilities.
(3) Potential problems with CIP and SIP with capped connections.
(4) Dead space: stagnant areas.
(5) All L/d ratios to be calculated on long-side dimensions for vessel heads.

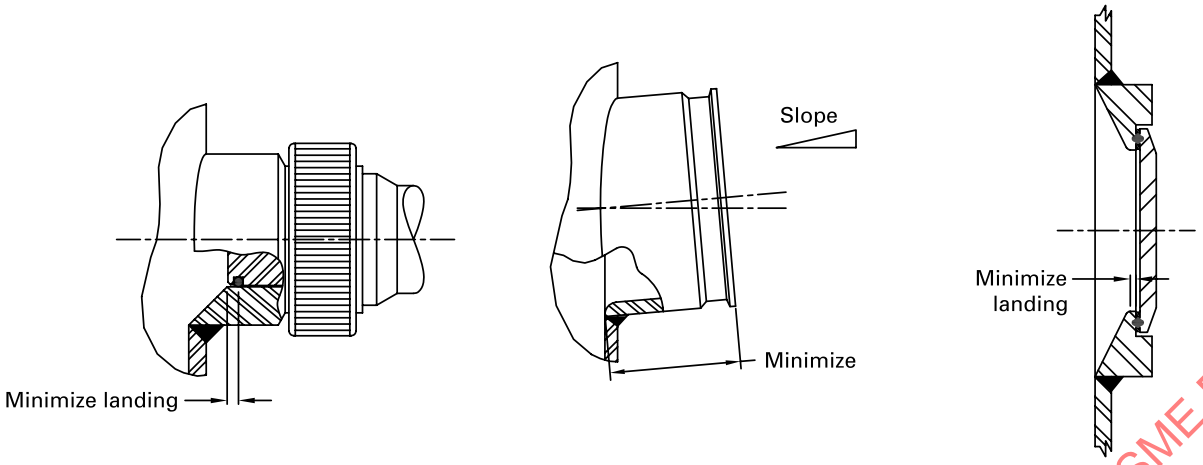
(24)

Figure SD-3.4.2-2
Side and Bottom Connections



NOTES:
(1) If a flat gasket is used, mismatch of diameters can result in crevices.
(2) Vent hole required.

Figure SD-3.4.2-3
Sidewall Nozzles



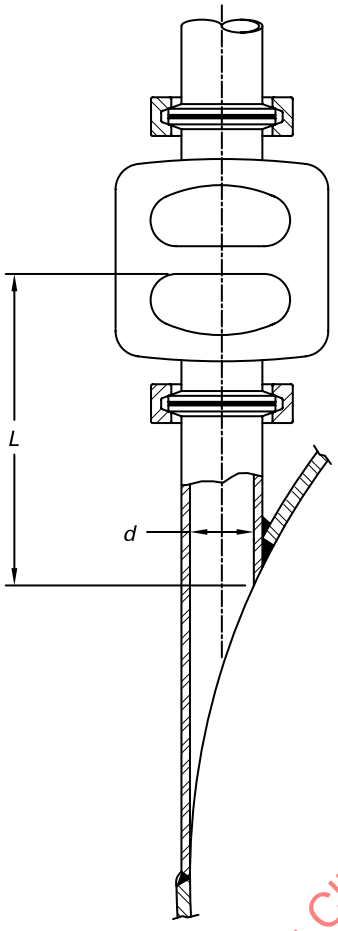
(a) Accepted
[Notes (1) and (2)]

(b) Accepted
[Note (3)]

(c) Accepted
[Notes (1) and (4)]

NOTES:
(1) May also be pitched per application.
(2) Installed plug, instrument, or device may require manual cleaning out of place.
(3) Direct CIP impingement required.
(4) Mounting hardware removed for clarity.

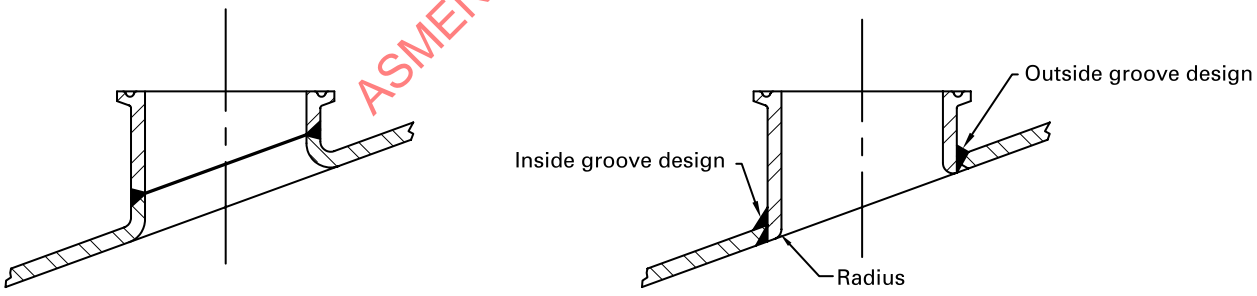
Figure SD-3.4.2-4
Vessel Design Tangential Nozzles



Definition of *L/d* for Tangential Inlet: Top Section View

GENERAL NOTE: CIP through nozzle is recommended.

Figure SD-3.4.2-5
Typical Nozzle Detail



(a) Swage/Butt Weld Design (Accepted: If Vessel Wall Is Thin Enough to Flare)

(b) Full Penetration Groove Weld With Fillet Design (Accepted)

Table SD-3.4.3-1
Annular Spacing Recommendations for Hygienic Dip Tubes

Dip Tube Size Tube O.D.		Mount Nominal Size	
in.	mm	in.	mm
½	12.7	2	50
¾	19.1	2	50
1	25.4	3	75
1½	38.1	3	75
2	50.8	4	100
2½	63.5	4	100
3	76.2	6	150
4	101.6	6	150

SD-3.4.3 Internal Components

(a) Sparger and dip tubes shall be designed in accordance with SD-3.4.1(a), SD-3.4.1(d), SD-3.4.1(f), and SD-3.4.1(g). Sparger and dip tubes shall incorporate low-point drains [where applicable, i.e., horizontal lines should slope at not less than ⅛ in./ft (10 mm/m)] and be properly supported to ensure drainability. See Table SD-2.4.3.1-1 to determine the appropriate slope designation.

(b) Dip tubes and spargers mounted in the nozzle neck should have an annular space between the O.D. of the dip tube or sparger and the I.D. of the nozzle neck in accordance with Table SD-3.4.3-1. An L/A of 2 or less is recommended (see Figure SD-3.4.3-1, illustration (a)]. If a larger L/A exists, a method for cleaning this space shall be specified. In all cases, sufficient annular space to allow access for CIP coverage shall be provided.

(c) Dip tubes shall be designed for CIP or cleaning out of place (COP). Spargers should be designed for CIP. Where the sparging device cannot be CIP'd, the device shall be removable for COP or replaceable.

(d) Removable dip tubes and spargers shall be designed to ensure that the installation orientation conforms with the design intent.

(e) Spray devices shall meet the requirements of SD-3.9.

(f) Internal support members shall be solid, rather than hollow, because hollow support members have a higher risk of fatigue and contamination problems (see Figure SD-3.4.3-2).

(g) Mitered fittings for internal pipe work should be avoided. When mitered joints are used, they shall be designed and fabricated in accordance with the appropriate codes.

SD-3.4.4 Fabrication

(a) Weld joint designs shall conform to MJ-3.2. For process contact surfaces, butt joints should be used and the use of lap joints should be minimized. Intermittent welds shall not be used on process contact surfaces.

(b) Flanges are not recommended for process contact applications, and their use should be minimized. The bore of weld neck flanges shall be the same as the I.D. of the connected components to prevent ledges and nondrainable areas.

(c) Where slip-on flanges are used, the process contact fillet weld shall be designed for drainability and CIP.

SD-3.4.5 Finishes

(a) Surface finishes shall be specified in R_a values (see Table SF-2.4.1-1).

(b) Process contact surface finish specifications shall pertain to all the wetted or potentially wetted surfaces (e.g., vapor space, nozzle necks, agitators, thermowells, dip tubes, baffles).

(c) The polishing of a connection face, body flange, etc., shall extend up to the first seal point.

SD-3.4.6 Sight Glasses

(a) Sight glasses on vessels should be designed with reference to SD-3.4.2(a). Sight glasses on vessels should be designed with the smallest L/d possible and incorporate a static seal in accordance with MC-2.2 (see Figure SD-3.4.6-1).

(b) See PI-9.1.2.3 for additional sight glass requirements.

(c) Surface finish for the metal frame shall meet the requirements of Part SF in this Standard.

(d) Sight glasses shall be marked with the glass type, maximum pressure, and temperature rating per DT-11.1 and DT-11.1.1.

(e) Part MC requirements shall be met when mounting a sight glass.

(f) Preferred sight glass mountings are shown in Figure SD-3.4.6-1.

SD-3.4.7 Portable Vessels

(a) Casters shall be cleanable and compatible with cleaning solutions used for external cleaning.

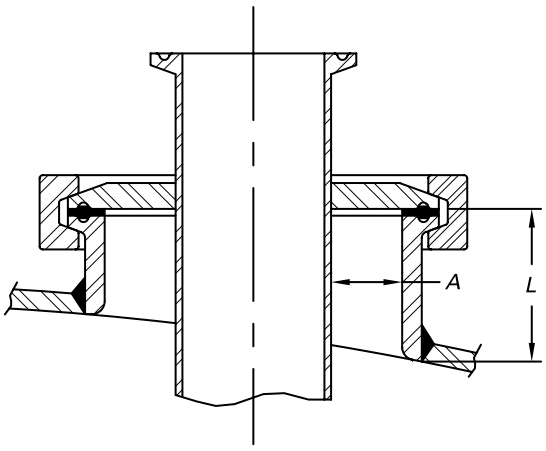
(b) Casters should be designed for the environment in which the vessel will be used.

(c) Portable vessels should be designed to resist overturning during normal operating conditions.

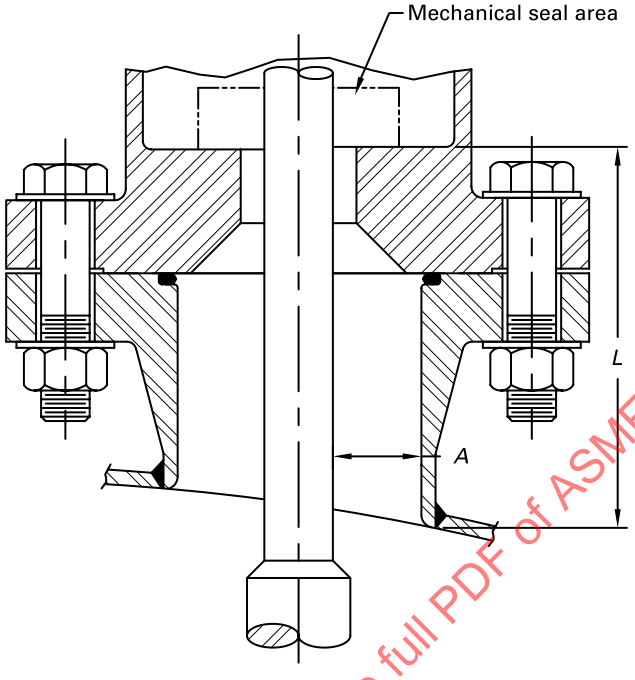
(d) Flexible hoses used to connect portable vessels shall meet the requirements of SD-3.2.

(e) Provisions for static grounding should be evaluated and incorporated into the vessel design, if required. The connections for static grounding should be designed to be cleanable.

Figure SD-3.4.3-1
Accepted Nozzle Penetrations



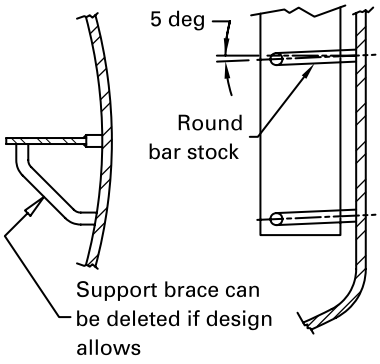
(a) Dip Tube or Sparge
[Notes (1) – (3)]



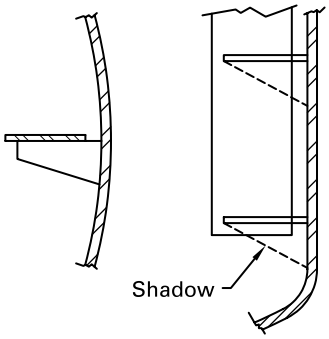
(b) Agitators
[Notes (2) and (4)]

NOTES:
(1) Nozzle and dip tube size per Table SD-3.4.3-1.
(2) *L/A* less than 2:1.
(3) Requirements also apply to nozzles with instrument penetrations.
(4) *A* = 1 in. (25 mm) minimum.

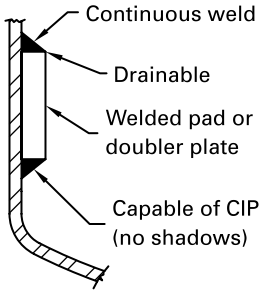
Figure SD-3.4.3-2
Internal Components



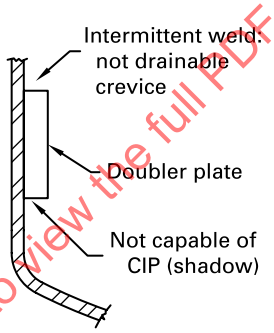
(a) Hygienic Design
(Accepted: Sloped, Minimum Shadow, and Curved Surface)



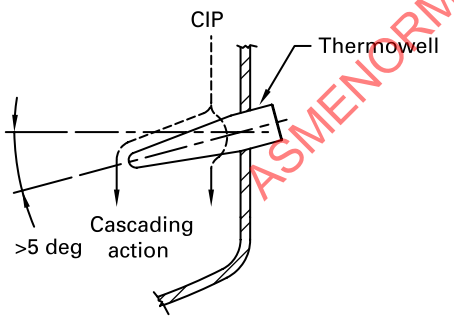
(b) Nonhygienic Design
(Not Accepted: Flat Surfaces, Ledges, and CIP Shadows)



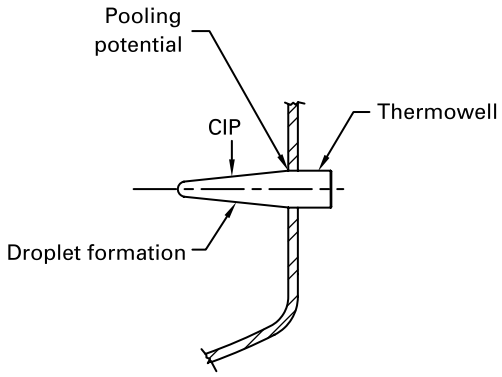
(c) Good Design
(Accepted)



(d) Poor Design
(Not Accepted)

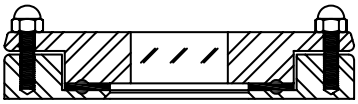


(e) Positive Slope in All Directions
(Accepted)



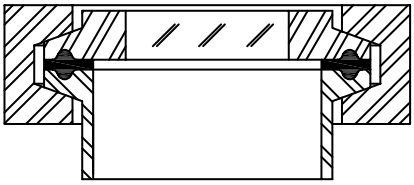
(f) Positive Slope in Only One Direction
(Accepted)

Figure SD-3.4.6-1
Sight Glass Design (Accepted)

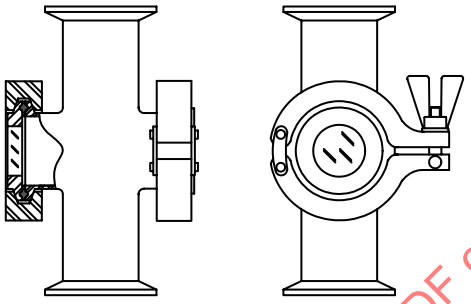


(a) Full Flange Sight Glass on Hygienic Pad Connection

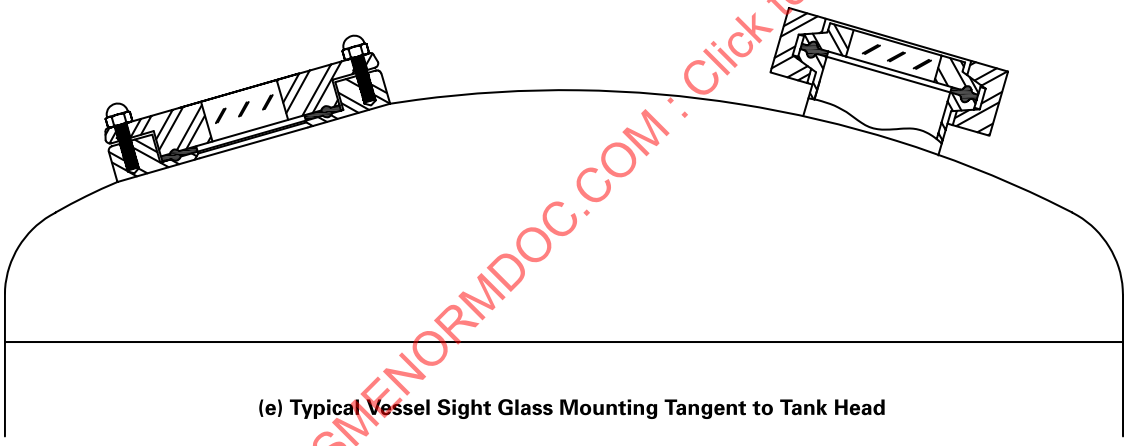
(b) Hygienic Clamp on Hygienic Pad Connection [Note (1)]



(c) Hygienic Clamp Sight Glass



(d) Hygienic Cross Sight Flow Indicator



(e) Typical Vessel Sight Glass Mounting Tangent to Tank Head

NOTE: (1) Mounting hardware removed for clarity.

SD-3.4.8 Media Bulk Containers. [Reserved for future content]

SD-3.4.9 Cryogenic Containers. [Reserved for future content]

SD-3.5 Agitators and Mixers

SD-3.5.1 General

(a) All process contact surfaces of agitators and mixers with their associated components shall be accessible to the cleaning fluids for clean-in-place service (CIP; e.g., via spray, directed flow, immersion).

(b) Process contact surfaces should be drainable and shall not interfere with vessel drainability.

(c) Machined transitions (shaft steps, coupling surfaces, wrench flats, etc.) should be smooth, with 15-deg to 45-deg sloped surfaces.

(d) The annular space between the agitator shaft and the agitator nozzle shall, for cleaning purposes, have an *L/A* of 2 or less, or a minimum of 1 in. (25 mm) gap, whichever is larger, to facilitate CIP spray coverage [see Figure SD-3.4.3-1, illustration (b)].

(e) The manufacturers of agitators and mixers shall provide a design that meets the cleaning and sterilization specifications provided by the owner/user. The manufacturer shall verify that their equipment is capable of being cleaned.

(f) Top-entering mixers with shaft seals are typically mounted to a vessel using a flanged or hygienic clamp connection [see Figure SD-3.5.1-1, illustrations (a), (b), and (c)]. The designer shall ensure that

(1) the use of O-rings or hygienic gaskets to seal between mating surfaces shall be consistent with the current guidance provided in Part MC (see Figure MC-3.3.2.2-1).

(2) the selected mounting arrangement will support the agitator mounting design loads while achieving an appropriate seal.

(3) the flange and nozzle construction is consistent with requirements of other applicable codes and standards (e.g., ASME BPVC, Section VIII; ASME B31.3)

(g) Bottom, centerline-mounted agitators should be designed in accordance with Nonmandatory Appendix EE (see EE-3.1).

(h) Socket head cap screws shall not be used in process contact applications.

(i) The design of agitator process contact parts should minimize the occurrence of void spaces. All voids should be closed by either fabrication (welding) or approved sealing techniques (O-ring seals, etc.).

(j) The use of in-tank nonwelded connections (shaft couplings, impeller hub-to-shaft, impeller blade-to-hub, etc.) should be avoided to minimize potential cleanability issues.

(k) Agitator mechanical seal performance and the seal's ability to maintain a closed system for bioburden control, process containment, etc., is a function of agitator shaft and drive assembly mechanical integrity. Agitator design should address the dynamic forces that act on the shaft and impeller assembly (e.g., maximum applied torque and impeller hydraulic forces) and the resonant frequency of the assembly to ensure that component alignment and deflection are within the manufacturer's tolerance. The agitator torque, bending moment, and vertical downward mounting loads shall be provided by the manufacturer to support design of the associated vessel mounting flange/nozzle.

SD-3.5.2 In-Tank Shaft Couplings

(a) Welded in-tank shaft connections are preferred.

(b) The use of in-tank shaft couplings shall be agreed to by the owner/user.

(c) In-tank couplings shall be of an accepted hygienic design. See examples in Figure SD-3.5.2-1.

(d) In-tank coupling location should be driven by process and mechanical considerations.

(e) Threaded shaft connections are accepted for in-tank couplings [see Figure SD-3.5.2-1, illustration (a)].

(1) Shaft rotation is limited to a single direction for threaded shaft connections to ensure that shaft sections do not separate.

(2) The designer will ensure that the use of a threaded shaft connection is appropriate for the selected shaft diameter and design loads.

(3) Hygienic bolted coupling construction may be used where appropriate for the particular application [see Figure SD-3.5.2-1, illustration (b)].

(f) Threads shall not be exposed in any type of shaft or coupling hardware connection.

(g) The preferred location for fastener hardware is on the underside of couplings. Accepted fastener types include

(1) hex-head cap screws

(2) acorn-head cap screws

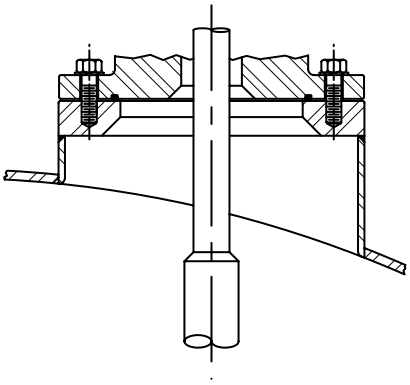
(3) threaded studs with acorn nuts

(h) Fastener heads shall be free of raised or engraved markings that might inhibit cleanability.

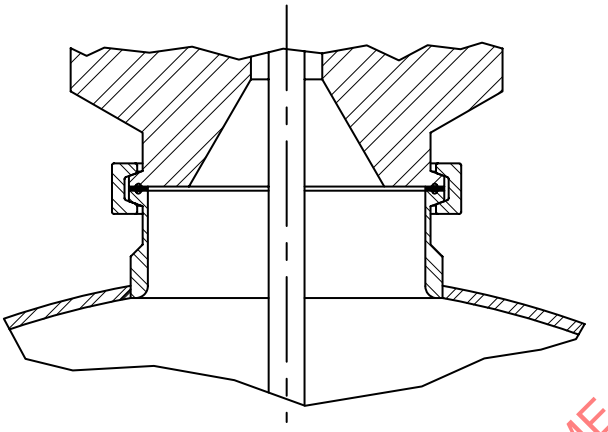
(i) O-rings rather than flat gaskets are preferred to seal coupling mating surfaces. Figure SD-3.5.2-2 presents the following acceptable approaches for seal applications:

(1) O-ring located in a single groove inboard of the coupling O.D. [see Figure SD-3.5.2-2, illustration (a)]; O-ring compression, internal space to accommodate compression, and outboard clearance space all designed to minimize the intrusion of process fluid between the coupling faces and to facilitate flow of CIP fluid.

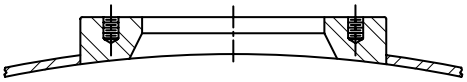
Figure SD-3.5.1-1
Agitator Mounting Flanges



(a) Bolted Flange With O-Ring

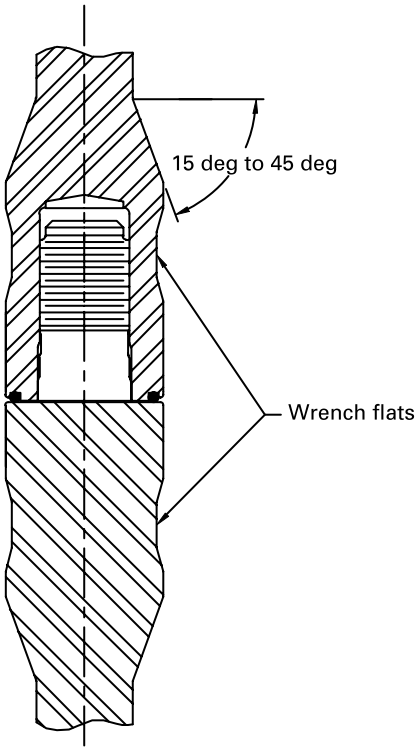


(b) Hygienic Union With Gasket

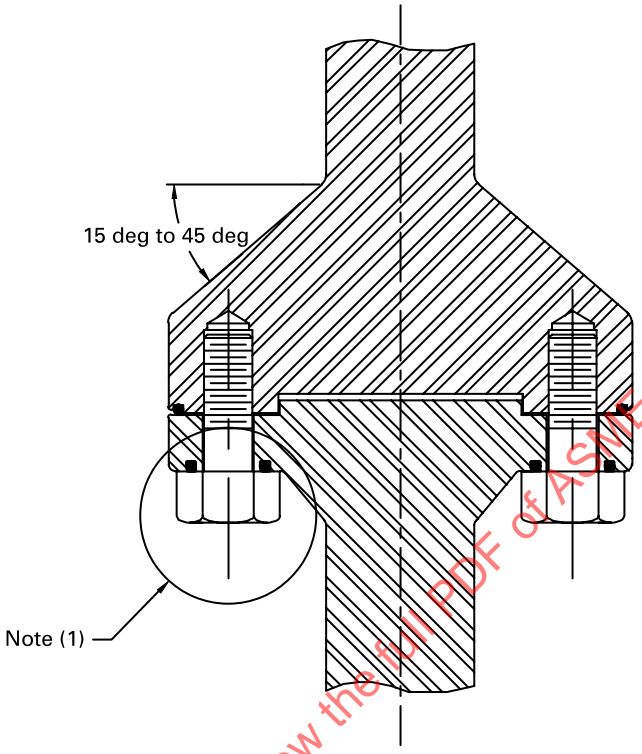


(c) Pad Flange

Figure SD-3.5.2-1
Shaft Coupling Construction



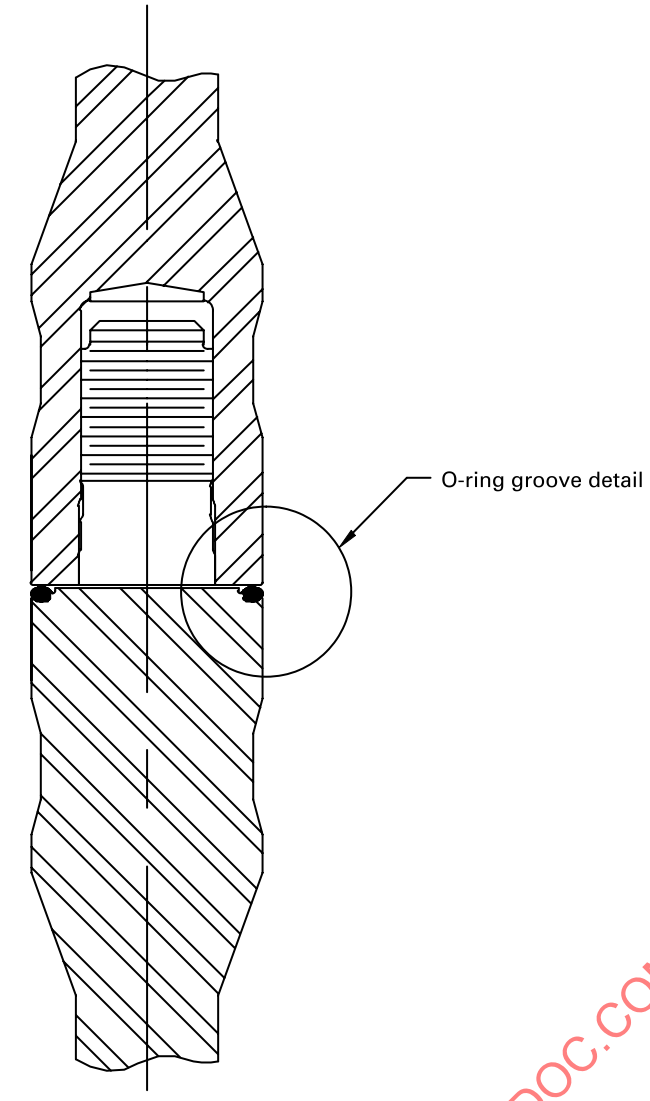
(a) Threaded Coupling
(Accepted)



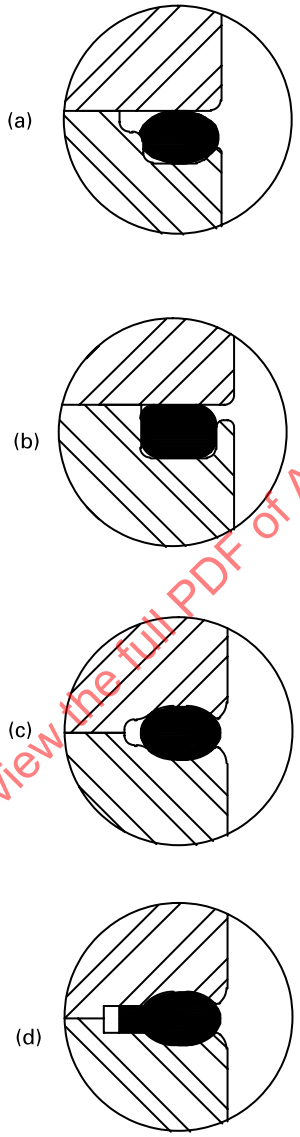
(b) Bolted Coupling
(Accepted)

NOTE: (1) See Figure SD-3.5.2-3 for alternative bolt seals.

Figure SD-3.5.2-2
Shaft Coupling Seal Arrangements



Threaded Coupling Example



Detail, Accepted Alternatives

(2) Alternate construction for O-ring located in a groove just inboard of the coupling O.D. [see Figure SD-3.5.2-2, illustration (b)]; O-ring restrained by lip at coupling circumference with clearance space provided as above to ensure cleanability of the coupling area.

(3) Alternate construction for O-ring located in grooves in both coupling halves inboard of the coupling O.D. [see Figure SD-3.5.2-2, illustration (c)]; outboard clearance space provided as above to ensure cleanability of the coupling area.

(4) O-ring with attached inboard flat segment located between coupling faces [see Figure SD-3.5.2-2, illustration (d)]; outboard clearance space provided as above to ensure cleanability of the coupling area.

(j) Bolted flanges shall be sealed. Examples of accepted fastener seals are shown in Figure SD-3.5.2-3 as follows:

(1) O-ring seal [illustration (a)]

(2) O-ring seal alternate [illustration (b)]

(3) seal washer with metal core [illustration (c)]

SD-3.5.3 Shafts and Keyways

(a) One-piece shaft construction, without mechanical couplings, is preferred.

(b) Solid shafts are preferred over hollow shafts.

(c) Hollow shafts, if used, shall be of sealed (welded) construction, inspected for integrity, and accepted per criteria given in Part MJ prior to installation.

(d) Keyways exposed to the process are not recommended.

(e) Keyways, where employed due to mechanical design considerations, shall have edge radii as specified by SD-2.4.2(b)(3).

(f) Keyways may require additional design or cleaning practice to ensure drainage and cleanability (e.g., spray ball or wand additions, increased CIP flow, and adjusted spray coverage).

(g) Permanent shaft hardware, installed on the process contact side, that may be required for routine maintenance (e.g., support collars for mechanical seal installation and removal, lifting eyes for shaft or impeller installation and removal) shall be drainable and cleanable.

SD-3.5.4 Hubs and Impellers

(a) All-welded impeller assemblies (e.g., hubs, blades) are preferred.

(b) Impeller hubs welded to the shaft are preferred over removable hubs.

(c) Removable, hygienic impellers may be used where impeller adjustment or substitution is required for process reasons or where impeller removal is required due to mechanical design and/or installation considerations.

(1) Removable impellers may be one-piece or split hygienic construction.

(2) Hub-to-shaft clearance for removable impellers shall be sufficient to preclude shaft surface finish damage during installation and removal.

(3) Removable hardware (e.g., impeller hub and shaft, impeller set-screws and hub) should be sealed in a manner consistent with the guidance provided for in-tank couplings (see SD-3.5.2).

(d) Removable impellers and impellers with flat, horizontal surfaces (e.g., flat-blade disk turbines, concave-blade disk turbines) may require additional design or cleaning practice to facilitate liquid removal and cleanability (e.g.,drain holes, spray ball or wand additions, increased CIP flow, adjusted spray coverage, impeller rotation).

SD-3.5.5 Impeller and Shaft Support Bearings

(a) Normal operation of a shaft steady bearing or a magnetically driven mixer with in-tank impeller or shaft support bearings (see Figures SD-3.5.5-1 and SD-3.5.5-2) generates particulate debris. It is the responsibility of the owner/user to establish compliance with applicable standards (e.g., USP limits for particulate material in injectables) as appropriate.

(b) Tank plates that support bottom-mounted magnetically driven mixers shall not interfere with vessel drainability.

(c) When an application mandates the use of shaft steady/foot bearings, design features and procedures are required to ensure cleanability (e.g., drain holes, spray ball or wand additions, increased CIP flow, operating the steady bearing immersed in CIP fluid).

(d) Shaft steady bearings, where used, shall not interfere with vessel drainability.

(e) Shaft steady bearing pedestal support members may be of solid or hollow construction. Hollow pedestal supports, if used, shall be of sealed (welded) construction, inspected for integrity, and accepted per criteria given in Part MJ after installation.

(f) Magnetically driven mixers require design features and procedures to ensure cleanability (e.g., drain holes, spray ball or wand additions, increased CIP flow, operating the agitator with the magnetically driven impeller immersed in CIP fluid).

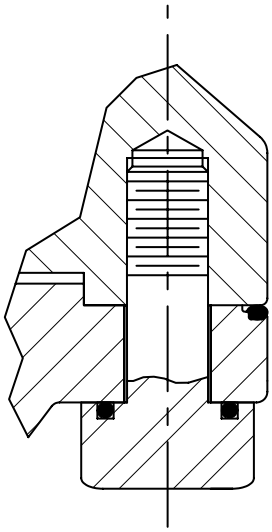
(g) The arrangement of wear surfaces (bushing, shaft, or shaft sleeve) shall enable drainability.

SD-3.5.6 Mechanical Seals

(a) Mechanical shaft seals shall incorporate design features for drainability, surface finish, material of construction, etc., as outlined in Part SD, and shall be suitable for the application (e.g., process, CIP, SIP, passivation).

(b) Normal operation of a mechanical seal generates particulate debris. It is the responsibility of the owner/user to establish compliance with applicable standards

Figure SD-3.5.2-3
Fastener Seal Arrangements: Alternative Bolting Designs



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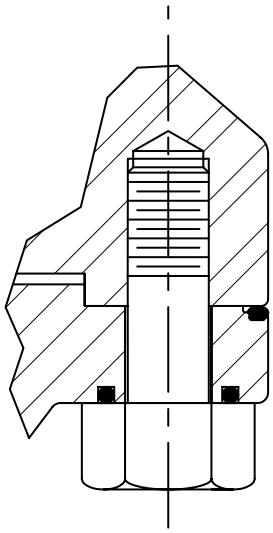
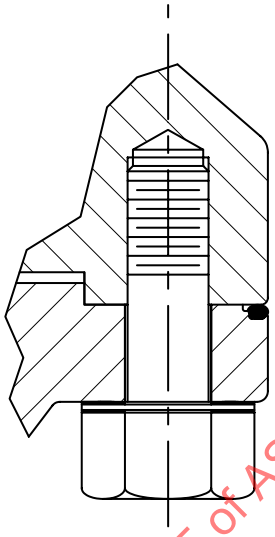
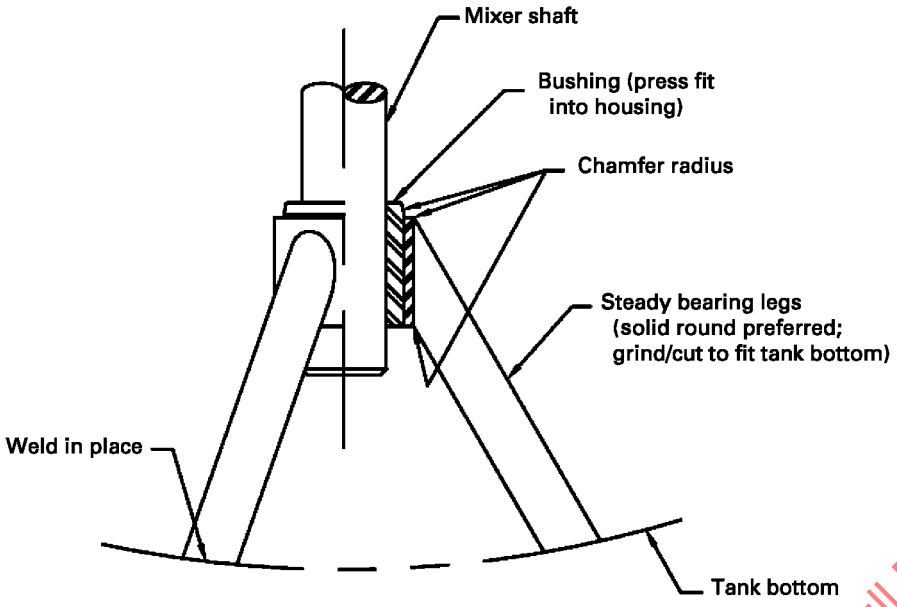


(b) Accepted

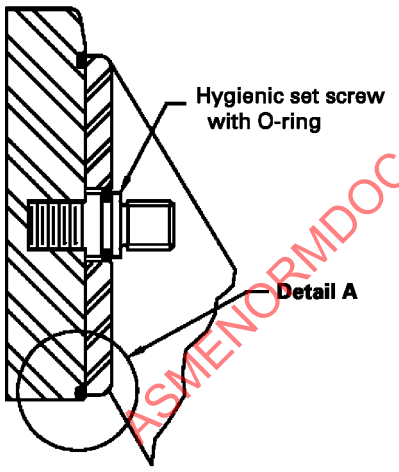


(c) Accepted

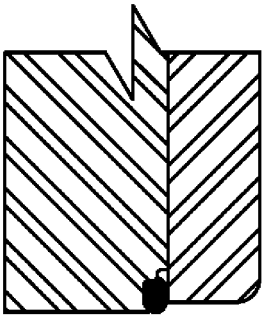
Figure SD-3.5.5-1
Shaft Steady Bearing



(a) Hygienic Tripod Steady Bearing
(Alternative Design — Flat Bar Legs With Rounded Edges)

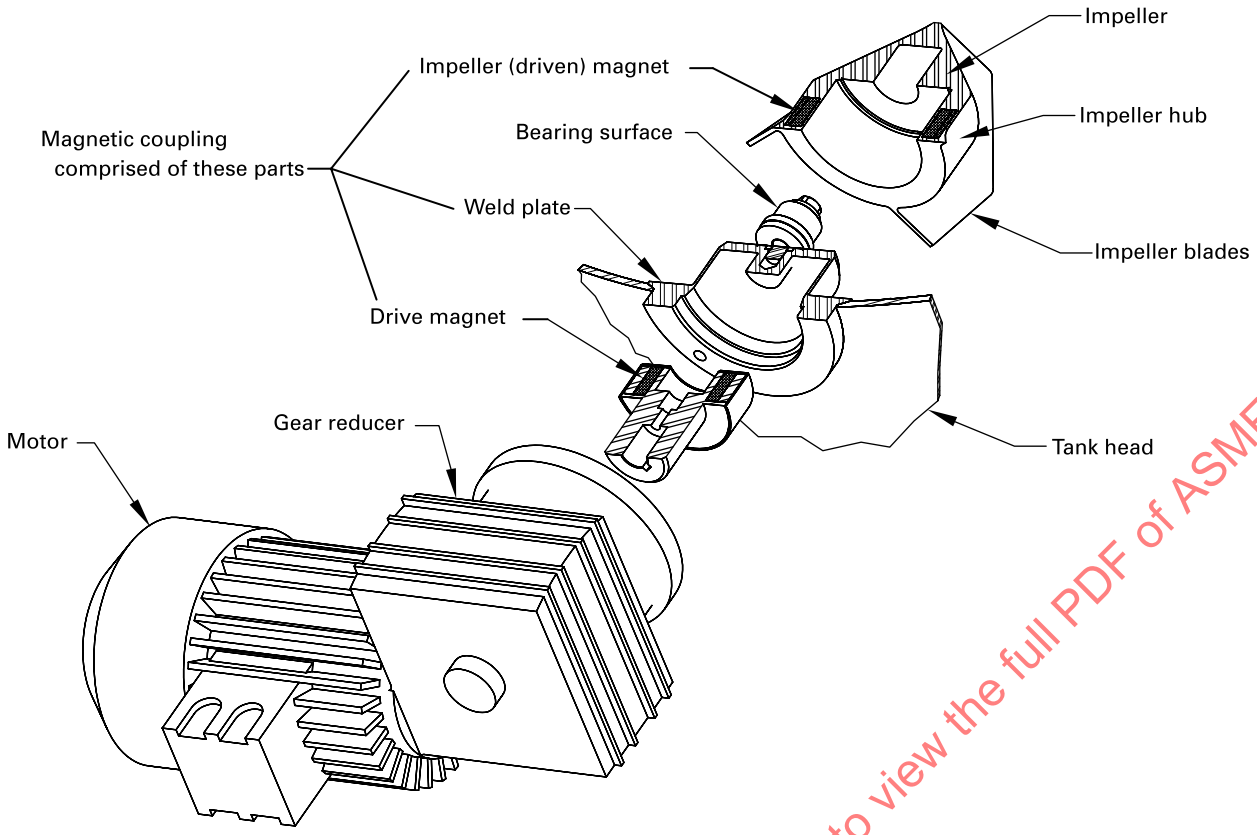


(b) Alternative Bushing Securing Method



Detail A
O-Ring With Groove Exposed for Flushing

Figure SD-3.5.5-2
Magnetically Coupled Mixer (Typical Bottom-Mount)



(e.g., USP limits for particulate material in injectables) as appropriate.

(c) Seal debris wells or traps (see Figure MC-2.3.2.3-2) may be used to prevent ingress of seal face wear particles that could contaminate the process fluid.

(d) See Part MC for specific seal design details.

(e) Mechanical seals for bottom, centerline-mounted agitators should be designed in accordance with Nonmandatory Appendix EE (see EE-3.2).

SD-3.6 Heat Exchange Equipment

(a) Required operating conditions should be established prior to the design or selection of the heat exchanger. The manufacturer's design shall take into account the most demanding of these operating conditions.

(b) To reduce process contamination risk, systems using heat exchangers should be designed such that the operating pressure for the process contact side is greater than the operating pressure of the non-process side.

(c) Process contact surface finishes shall be fully inspectable to confirm surface finish quality. When inspection is not practical, prior to fabrication or procurement, the manufacturer should provide inspectable samples representative of the fabrication process.

SD-3.6.1 Application Design Considerations

(a) The heat exchanger should be designed and fabricated to provide smooth, crevice-free process contact surfaces.

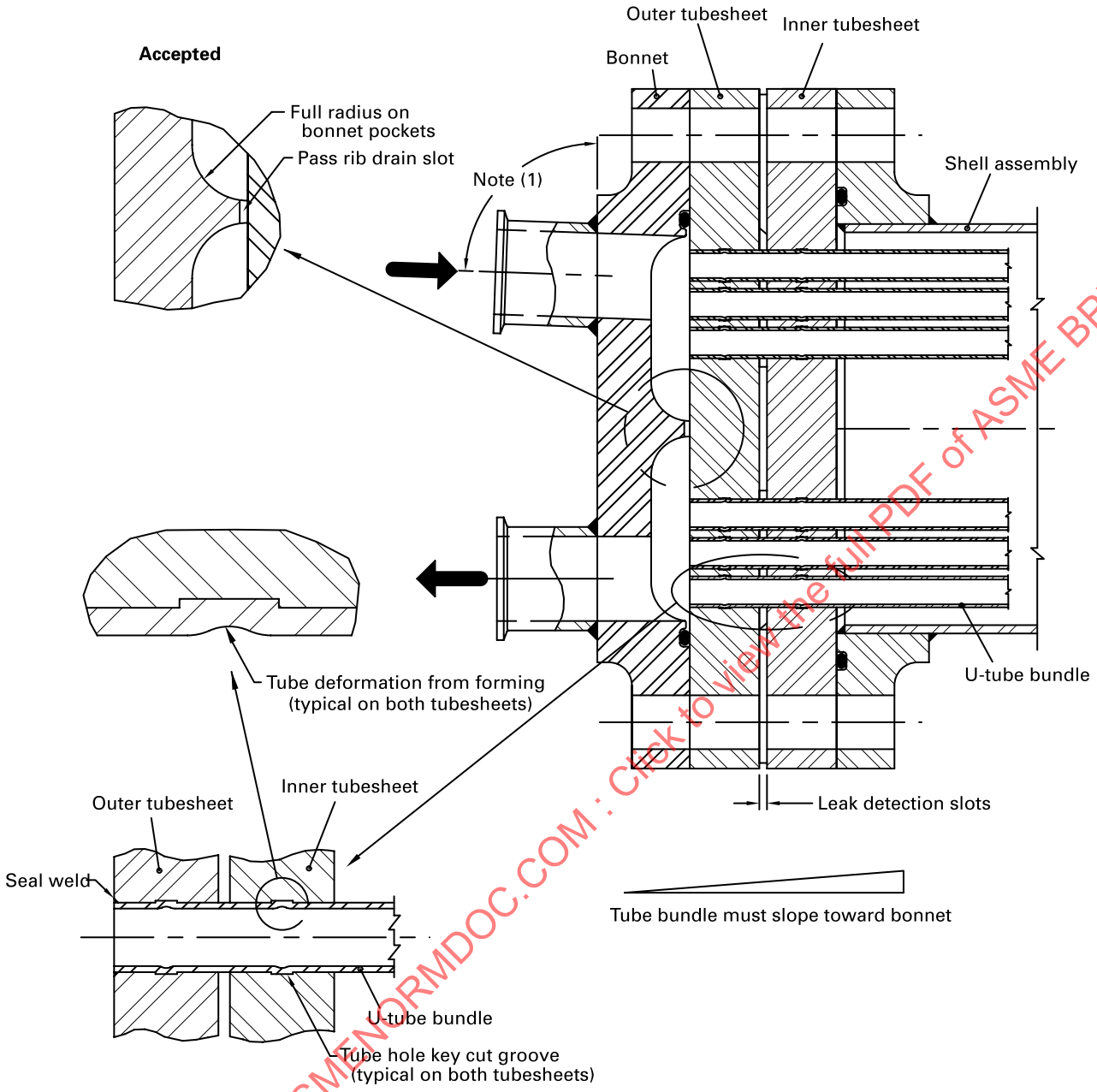
(b) For hygienic heat exchanger applications where crevices cannot be avoided (e.g., product on the shell side), the system shall be designed to mitigate contamination risk through operational controls (e.g., self-sanitizing conditions).

SD-3.6.2 Shell and Tube

(a) Shell-and-tube heat exchangers shall be of a double tubesheet design to prevent product contamination in the case of a tube-to-tubesheet joint failure (see Figure SD-3.6.2-1).

(b) After the tubes are expanded into the inner and outer tubesheets, the process contact surface shall meet the specified surface finish requirement.

Figure SD-3.6.2-1
Double Tubesheet Heat Exchanger Bonnet Design



NOTE: (1) Owner/user to specify inlet tubing slope. Heat exchanger manufacturer to slope inlet on bonnet to match inlet tubing slope.

(c) Tubes shall be welded to the outer tubesheet to eliminate any crevices.

(d) The distance between inner and outer tubesheets shall be sufficient to allow leak detection.

(e) The process contact side of the heat exchanger system shall be drainable or capable of having liquid removed by other means (e.g., pressurized gas, vacuum, heat). The manufacturer should specify the required drainable orientation for the heat exchanger.

(f) When transverse baffles are required, they should be notched to allow for drainage.

(g) The heat exchanger bonnet, tube bundle, and shell shall have a positioning device or mark to ensure proper orientation and installation.

(h) The manufacturer's performance calculations shall take into account any bonnet bypass implemented to aid drainage.

SD-3.6.2.1 Straight Tube Design. Expansion or contraction for all specified differential thermal conditions shall be evaluated when designing the heat exchanger.

SD-3.6.2.2 U-Tube Design

(a) The technique used to form U-bend tubes shall ensure the bending process does not create structural imperfections (e.g., cracks, voids, gouges). The technique should minimize surface imperfections (e.g., orange peel, rippling).

(b) If requested by the owner/user, the manufacturer shall supply a sectioned sample of the bend area.

(c) The sectioned sample should be from the same tube batch or heat that will be used to fabricate the heat exchanger.

(d) The sectioned sample shall be the smallest bend radius in the exchanger.

(e) The sample shall be sectioned so that the bend centerline is visible.

(f) The internal surface of the U-bends shall be free of relevant liquid penetrant indications, as defined by ASME BPVC, Section VIII.

(g) The I.D. of the U-bends should be large enough for a borescopic examination.

(h) Minimum recommended bend radii for heat exchangers should be as follows:

Nominal Tube O.D.		Minimum Bend Radius	
in.	mm	in.	mm
0.375	9.5	0.625	15.2
0.500	12.7	0.750	19.1
0.625	15.8	0.938	23.8
0.750	19.1	1.125	28.6
1.000	25.4	1.500	38.1

For tubes not included in the table, a minimum bend radius of 1.5 times the tube diameter is recommended; however, SD-3.6(c) should be consulted.

SD-3.6.3 Plate and Frame. Plate-and-frame-type heat exchangers should be used only by agreement between the owner/user and designer due to the difficulty of CIP and SIP.

SD-3.7 Transfer Panels

SD-3.7.1 General

(a) The transfer panel shall be constructed so that the process contact surfaces can be cleaned by a CIP fluid or other method specified by the owner/user. The process contact surfaces shall be free of crevices, pockets, and other surface irregularities.

(b) The transfer panel nozzle elevation shall be properly designed with respect to the connecting equipment such as tank and pump to ensure drainability, cleanability, and bioburden control during process transfer, CIP, and SIP.

(c) Design and fabrication of the transfer panel and associated components must ensure that the piping system can be drained when properly installed. This is not to imply that panel nozzles or subheaders should be sloped (see Figure SD-3.7.1-1).

(d) Tagging/labeling of the transfer panel and its components shall be per SD-2.4.4.2(i). Tagging nozzles on the back side of panels will help reduce the number of incorrect piping connections during field installation.

SD-3.7.2 Nozzles or Ports

(a) Nozzle construction shall accommodate a design feature that will assist in the elimination of internal surface anomalies caused in part by joining the nozzle to the panel structure.

(b) The method of joining a nozzle into a panel structure shall be of hygienic design. Acceptance criteria for these welds shall meet the requirements of Table MJ-8.5-1.

(c) Each front nozzle connection shall be of a hygienic design and the horizontal projection minimized to enable liquid removal.

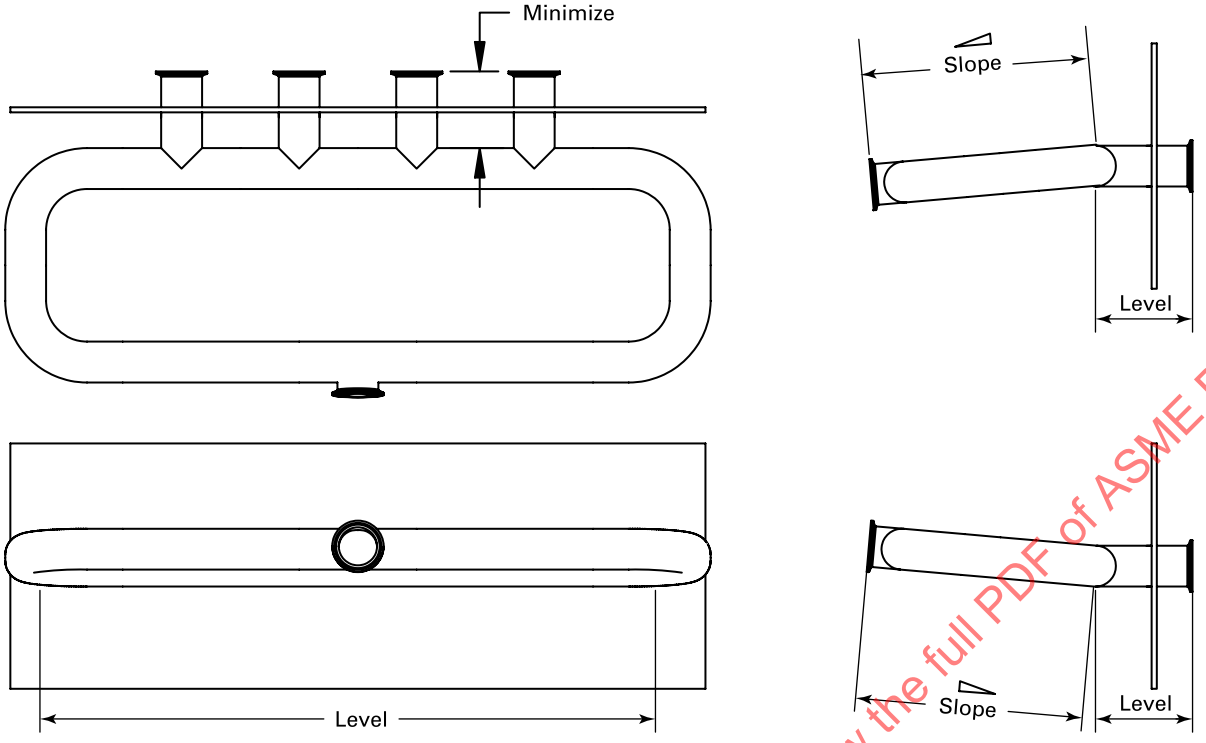
(d) To ensure proper panel functionality and joint connection integrity, panel nozzles shall not be sloped (see Figure SD-3.7.2-1).

(e) Nozzle-to-nozzle clearance shall be such that jumper drain valve interference, if applicable, will not occur when jumpers are connected in all possible operating and cleaning configurations.

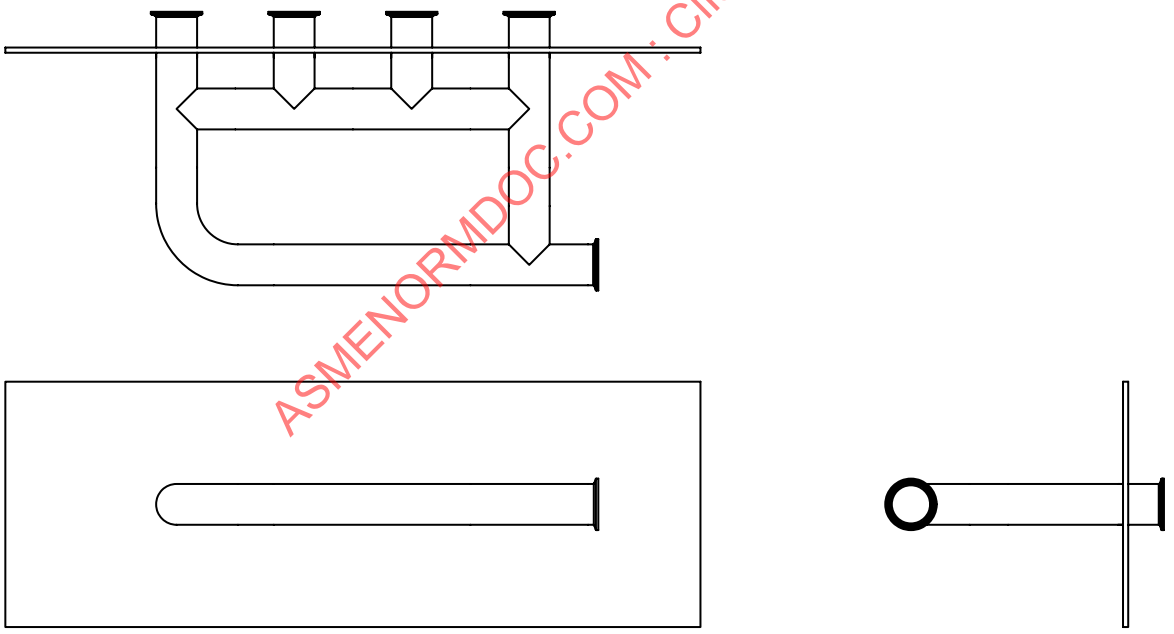
(f) Nozzles shall be capable of being capped. Caps may include bleed valves or pressure indicators for safety or operating purposes.

(g) Nozzle position and parallelism tolerances are extremely critical to proper panel functionality and should meet the recommended tolerances per Table DT-7.3-1 and Figure SD-3.7.2-1.

Figure SD-3.7.1-1
Transfer Panel Looped Headers

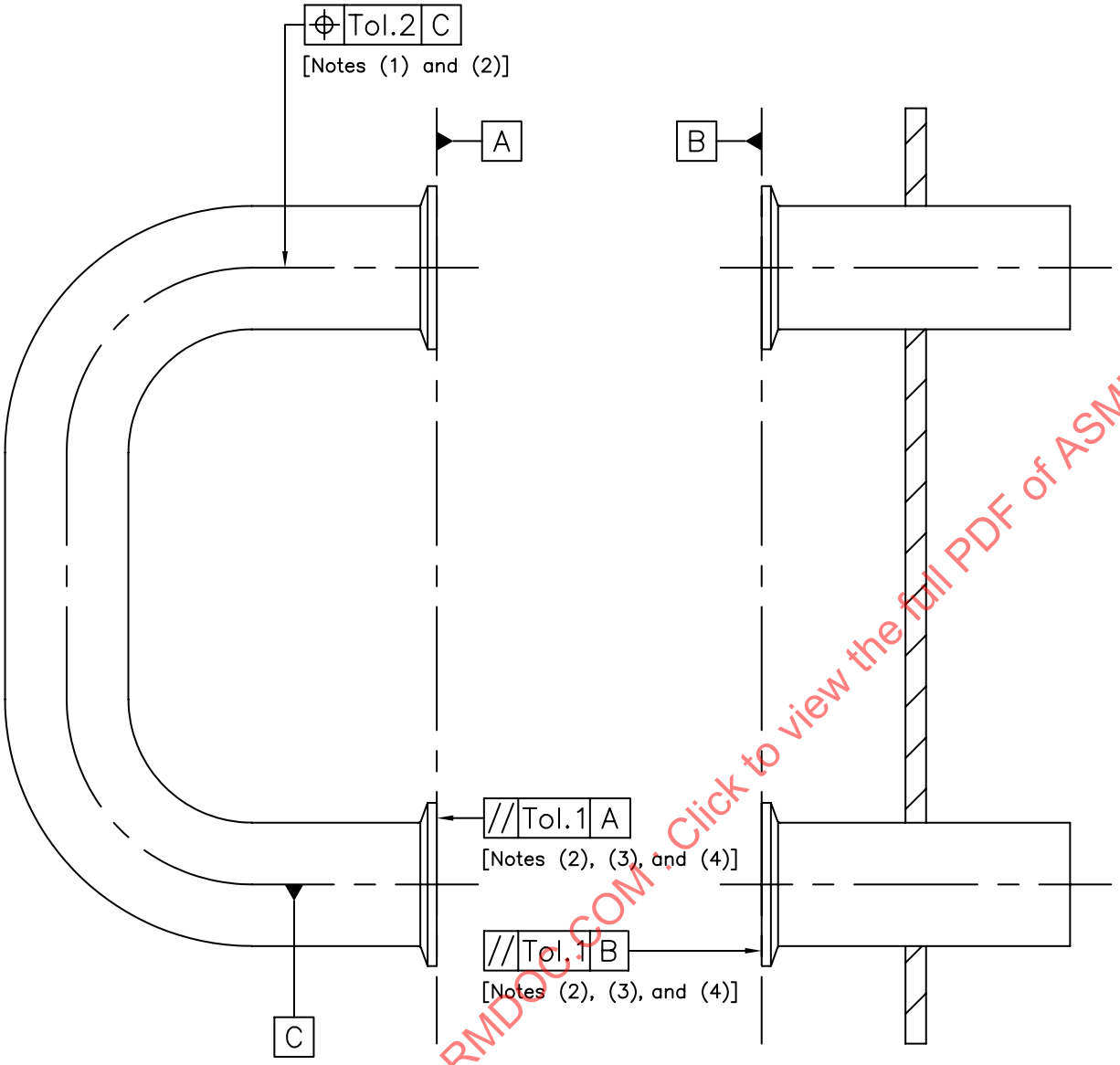


(a) Accepted



(b) Not Accepted

Figure SD-3.7.2-1
Transfer Panel Tolerances



NOTES:
(1) For position tolerance Tol.2, see Table DT-7.3-1.
(2) For testing parallelism and position, the use of specifically made test panels is recommended.
(3) For flatness tolerance of singular sealing faces of ferrules, see Table DT-3-1.
(4) For parallelism tolerance Tol.1, see Table DT-7.3-1.

SD-3.7.3 Headers or Pre-Piped Manifolds

(a) When a looped header design is employed, the branch length at capped or unused nozzles, or to the weir of the unused point-of-use valve, should be minimized. The dimension of the subheader leg to the nozzle face should not exceed an L/d of 2 (see Figure SD-3.7.1-1). A dead-ended or unlooped subheader is not recommended.

(b) For nozzle drainability, regardless of use, subheaders and pre-piped manifolds shall not be sloped. All-encompassing lines including long runs with the exception of subheaders, manifolds, and nozzles may be sloped as defined in SD-2.4.3.

SD-3.7.4 Jumpers or U-Bends

(a) Jumpers shall be constructed with hygienic connections on both ends designed to mate with the panel nozzles.

(b) Jumpers may have a low-point drain to provide for both draining and vacuum break after the liquid transfer has been completed (see Figure SD-3.7.4-1). The branch L/d of a low-point drain connection should be minimized. Zero-static diaphragm valves are recommended for low-point drains if available from the manufacturer [see Figure SD-3.7.4-1, illustrations (a) and (d)]. Low-point drain designs that incorporate a spool piece allow for full rotation of the drain valve [see Figure SD-3.7.4-1, illustrations (a), (b), and (c)]. This design ensures that the drain valve is always at the true low point of the assembled jumper connection in any specified orientation.

(c) Jumper position and parallelism tolerances are extremely critical to proper panel functionality. Recommended tolerances are per Table DT-7.3-1 and Figure SD-3.7.2-1.

(d) Reducing jumpers shall not be used unless the reducing jumper is drainable in all orientations. Any reduction in line size should be made behind the primary nozzle connection (behind panel structure), thus allowing all connections to be the same size on the front of the panel.

(e) The overall panel design should be such that the quantity of unique jumper centerline dimensions is minimized.

(f) The same jumper should be used for process transfer, CIP, and SIP.

(g) If a pressure indicator is installed on a jumper, it shall be a hygienic design and mounted in a manner that maintains drainability in all jumper positions. The L/d should be 2 or less.

SD-3.7.5 Drain or Drip Pans

(a) Drain pans, if used, shall be built as an integral part of the transfer panel. The intended function is to collect spilled fluids that can occur during jumper or cap removal.

(b) Drain pans shall slope [preferred minimum of $\frac{1}{4}$ in./ft (21 mm/m)] to a low point and be piped to the process drain. The depth of the drain pan is determined by calculating the largest spill volume and accommodating it with a sufficient pan holding volume. Consideration should be given to increasing the drain port connection size in lieu of increasing pan depth. The preferred drain port location is central bottom draining or central back draining.

(c) The elevation of the pan should take into account the clearance required for the jumper drain valve position when a connection is made to the bottom row of nozzles. The pan should extend horizontally to accommodate the furthest connection or drain point from the face of the panel.

SD-3.7.6 Proximity Switches

(a) Proximity switches are used to detect the presence or absence of a jumper with a stem positioned between selected nozzles.

(b) The use of magnetic proximity switches that are mounted behind the panel structure to avoid penetration of the panel face is preferred. This elimination of structural penetration removes any unnecessary cracks, crevices, or threads at the point of attachment, effectively mitigating risk of process fluid entrapment or contamination.

(c) Jumpers will contain a magnetic stem to activate the corresponding proximity switch. The use of a ferrous magnetic material is required; however, it shall be fully encapsulated to ensure that the ferrous material does not contaminate the classified manufacturing area. The acceptance criteria for welds joining the sensor stem to the jumper shall meet the requirements of Table MJ-8.5-1.

(d) The magnet should be of sufficient gauss rating to properly activate the corresponding proximity switch. In addition, the temperature rating of the magnet should withstand the specified temperature ranges for process and SIP without compromising the magnet performance.

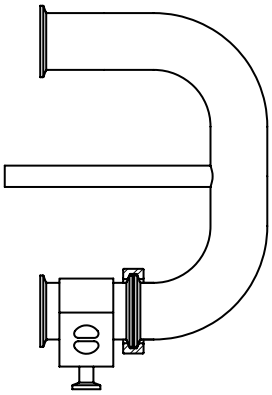
(e) The proximity switch mounting shall be fabricated to maintain the specified design location. The proximity switch shall not interfere with the function, cleaning, or maintenance of the transfer panel to which it is mounted.

SD-3.8 Filtration Elements and Components

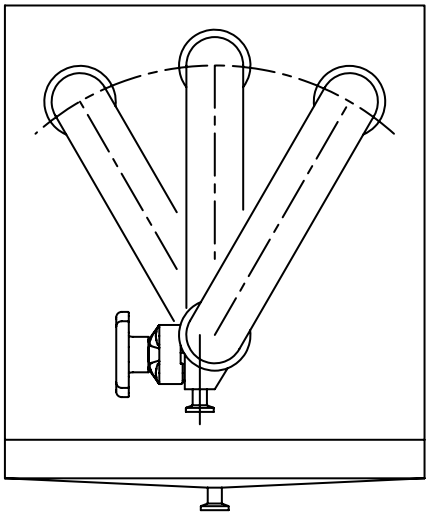
SD-3.8.1 General. This section defines and recommends design elements related to hygienic filtration processes. This section includes aseptic and nonaseptic processes and includes the following filtration components: housings, holders, and elements. More information on filtration elements and components may be found in Nonmandatory Appendix T.

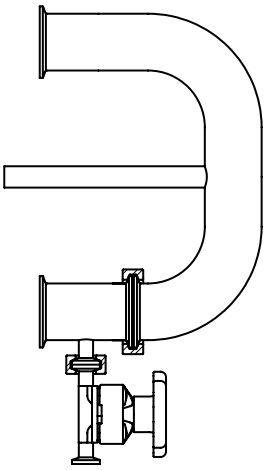
SD-3.8.2 Filtration Formats. There are two basic modes of filtration: direct flow and tangential flow. For multiuse filters, cleaning and/or sanitization should be

Figure SD-3.7.4-1
Transfer Panel Jumpers



(a) Accepted





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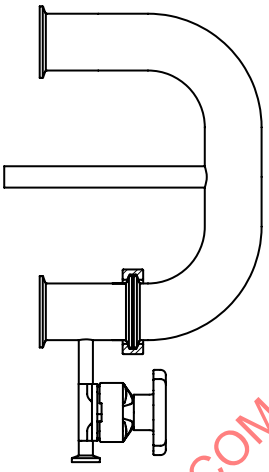
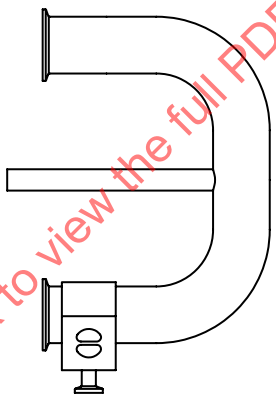
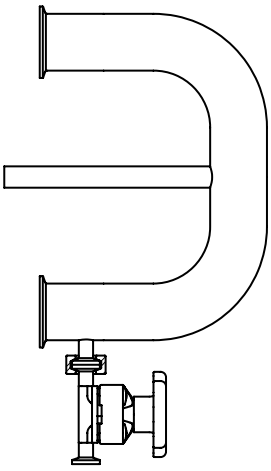


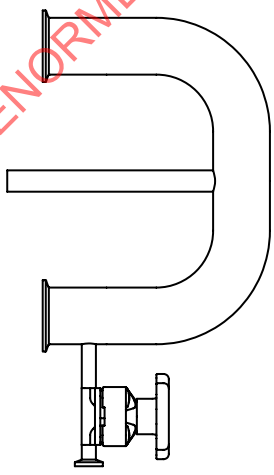
(c) Accepted



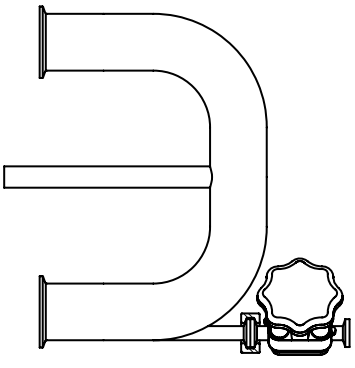
(d) Accepted



(e) Not Accepted



(f) Not Accepted



(g) Not Accepted

considered. For single-use filters, sanitization requirements shall be determined by the owner/user.

SD-3.8.3 Housing and Encapsulation. Filter housings and encapsulated components are wetted and are vessels operating under pressure. Requirements for vessels operating under pressure are found in ASME BPVC, Section VIII, as referred to in GR-1. The owner/user shall be responsible for informing the manufacturer of all expected operating conditions to which the filter housings may be exposed. The manufacturer shall be responsible for ensuring the filter housing and encapsulated components will operate safely under said conditions.

SD-3.8.3.1 Housings. Housings shall be designed in accordance with SD-5.4.4. Materials used in the construction of filtration housings shall conform to Part MM for metallic materials or Part PM for polymeric materials. All dimensions of hygienic clamp ferrules on polymeric filter housings shall conform to Table DT-7.1-2.

SD-3.8.3.2 Encapsulation. Encapsulated filtration elements are designed for handling purposes or in place of metallic housings. Materials used in the encapsulation of filtration elements shall conform to Part MM for metallic materials or Part PM for polymeric materials.

SD-3.8.3.2.1 Holders. Materials used in the construction of holders shall conform to Part MM for metallic materials or Part PM for polymeric materials.

SD-3.8.3.3 Code 7 Cartridge Lock Design. The ASME BPE Code 7 lock is designed to be used with filter cartridges using an SAE AS 568-226 double-O-ring seal and a two-locking-tab design.

SD-3.8.3.3.1 Design Features. This design consists of the following features:

(a) a socket bore that is machined into a base or cartridge plate into which the filter cartridge O-ring adapter is inserted.

(b) a locking tab retainer mechanism that captures the cartridge locking tabs when the cartridge is inserted into the socket bore.

(1) Table DT-4.5.1-1 shows a recessed tapered lock retainer design in which the locking tab retainers are machined into a plate and the machined recesses capture the cartridge locking tabs as the cartridge is rotated into position.

(2) Table DT-4.5.2-1 shows an external tapered lock retainer design in which a set of metal cages captures the cartridge locking tabs as the cartridge is rotated into position.

(c) the locking retainers shall be designed with a taper to provide a secure lock for the cartridge. The cartridge tabs shall travel through the narrowing tab retainers until a tight fit is achieved. The taper shall be on the upper portion of the tab retainer. Full capture of cartridge tabs by the locking tab retainers is not required to secure cartridges for operation.

(d) all surfaces of the cartridge socket shall meet the required finish for the wetted surfaces as specified by the owner/user.

(e) the cartridge O-ring(s) shall be completely contained within the socket bore.

SD-3.8.3.3.2 Testing. The cartridge manufacturer shall validate that its cartridge design fits, seals, and remains in place with one of the housing designs shown in Tables DT-4.5.1-1 and DT-4.5.2-1.

SD-3.8.4 Design for Cleaning and Sanitization

SD-3.8.4.1 Filter Elements. Filtration elements shall be designed in accordance with SD-3.1 and shall be compatible with the cleaning agents (to be agreed by the manufacturer and owner/user).

SD-3.8.4.1.1 Seals. All seals shall conform to Part MC.

SD-3.8.4.1.2 Exterior Surfaces. All exterior surfaces shall conform to SD-2.4.4.2.

SD-3.8.5 Sanitization

SD-3.8.5.1 Filter Elements

SD-3.8.5.1.1 Chemical Sanitization. Chemical sanitization processes are used to reduce bioburden. All product contact surfaces shall be compatible with the sanitization agents selected (to be agreed by the manufacturer and owner/user).

SD-3.8.5.1.2 Thermal Sanitization. Thermal sanitization requirements should be considered during the design process. The components shall be designed to accommodate the elevated temperatures and the expansion and contraction during exposure and cooldown stages. Special consideration should be given when designing for potential vacuum situations. Filtration elements should be tested and verified for multiple steam cycles per vendor qualification methods. Filtration elements shall conform to SD-2.3.1.

SD-3.8.6 Filtration Performance. The owner/user shall be responsible for informing the manufacturer of all the conditions under which the filter elements may be expected to operate. This shall include the methods, frequency, and duration of cleaning and sanitization procedures. In addition to the service temperature and pressure, any parameters that may affect the filtration performance shall be provided.

SD-3.8.6.1 Service Temperature and Pressure. Filtration elements shall be capable of withstanding thermal and pressure cycling between the rated upper and lower temperature and pressure limits.

SD-3.8.6.2 Routine Maintenance. To ensure continued filtration performance, consideration shall be given to the accessibility of all filtration components for routine maintenance.

SD-3.8.6.2.1 Integrity Testing and Permeability

(a) Integrity Testing. Tests may be required to ensure that the filtration elements and components are integral and meet specific process requirements. Sterilizing-grade membranes should be tested to the specific bacterial retention protocol (refer to 2004 cGMP Filtration Guideline and ASTM F838). The following are typical integrity test procedures that may be performed:

(1) pressure decay test
(2) bubble point test
(3) diffusional flow test
(4) water intrusion test

Other integrity testing methods should be agreed on between the manufacturer and owner/user. Integrity testing may be performed either pre- or postprocess.

(b) Normalized Water Permeability. During tangential flow applications, a normalized water permeability test (NWP; see Nonmandatory Appendix T, T-2.5) or clean water flux test may be performed.

SD-3.8.7 Installation. Installation shall be in accordance with the manufacturer's guidelines.

SD-3.8.8 Conformance Requirements

SD-3.8.8.1 General Requirements. A unique identifier shall be indelibly marked on the filtration element or support structure. The unique identifier shall enable the owner/user to identify the supplier and the supplier to identify the raw material and processing conditions used to fabricate the article. A Certificate of Conformance shall be issued by the filtration element manufacturer to certify conformance to this Standard when required by the owner/user.

SD-3.8.8.2 Certificate of Conformance. The Certificate of Conformance shall contain the following information:

(a) manufacturer's name
(b) date of manufacture of the element
(c) unique identifier of the element
(d) material of construction of process contact items
(e) compliance to USP <87> (or ISO 10993-5) and USP <88> Class VI (or ISO 10993-6, -10, and -11)

Other certifications of conformance should be agreed on by the manufacturer and owner/user.

SD-3.9 Spray Devices

SD-3.9.1 General. This section covers spray devices intended for use in bioprocessing equipment that either remains in place or is removed during production. Recommendations in this section are valid for water-based cleaning solutions. The flow rate recommendations in this section are for metallic vessels.

(a) Spray devices distribute rinse and cleaning solutions to interior surfaces of bioprocessing equipment by direct spray and use sheeting action for remaining targeted areas. Spray devices are also used in other applications (e.g., water systems to maintain coverage of the storage tank head space and in COP cabinet washers).

(b) The differential pressure across the spray device generates liquid velocity exiting through the spray device orifices, nozzles, or slots. Differential pressure and its resulting flow are key parameters of spray devices. Flow is the recommended control parameter because it is independent of temperature and location of the measurement device.

(c) The spray pattern, as it exits the device, is determined by the spray device design. Spray patterns are typically streams/jets or fans.

(d) The impact pattern is determined by the interaction over time of the spray pattern and the geometry of the equipment.

(e) During design, consideration should be given to the following in the selection of spray device(s):

(1) residue characteristics
(2) equipment geometry and appurtenances
(3) physical location and orientation of spray device(s)
(4) process requirements including air-purge and steaming, if applicable
(5) cleaning system capacity
(6) installation of screen/strainer to protect the functionality of the spray device
(7) cleaning cycle time
(8) cleaning chemistry compatibility with materials of construction
(9) potential orifice erosion (e.g., from CIP and SIP)

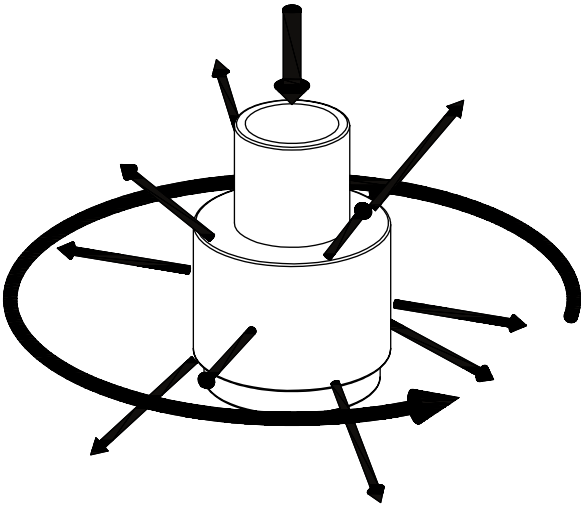
(f) Spray devices are either static or dynamic.

(1) Static spray devices continuously produce a defined impact pattern by stationary direct spray. Static spray devices have no moving parts. Examples of static spray devices include static spray balls, stationary nozzles, and spray wands.

(2) Dynamic spray devices are either single axis or multiaxis. Both produce a defined impact pattern by moving multidirectional spray(s). Dynamic spray device rotation is rinse water/cleaning solution driven or motor driven. Dynamic spray devices have moving parts, which may include bearings, gears, and turbines.

(-a) In single-axis dynamic spray devices (see Figure SD-3.9.1-1), when the orifices/nozzles/slots are manufactured at an angle, the resulting force spins the spray head. Rotation can also be turbine or motor driven.

Figure SD-3.9.1-1
Dynamic Spray Device: Single Axis



GENERAL NOTE: Spray pattern is for illustration purposes.

(-b) Multiaxis dynamic spray devices rotate in more than a single plane (see Figure SD-3.9.1-2). When rinse water/cleaning solution driven, the flow through the spray device turns a turbine wheel, which typically turns the body around one axis as well as the nozzle(s) around a second axis, creating a repeatable indexed pattern. When motor driven, the body and nozzles are turned mechanically by the motor.

(g) Spray devices can be designed as removable, retractable, or to remain in place.

(h) Spray device(s) are specific to the application and equipment. Spray devices are generally not interchangeable without considering the specific flow, pressure, equipment design, spray pattern, and drainability of the spray device(s).

SD-3.9.2 Spray Device Requirements

(a) Materials of construction shall conform to SD-2.4.1.2 or as otherwise agreed on with the owner/user.

(b) When installed, spray devices shall be drainable and cleanable inside and outside or as otherwise agreed on with the owner/user.

(c) Spray device(s) shall be installed per manufacturer's instructions.

(d) When operated within specification, the spray device(s) shall produce repeatable effective coverage over a defined area of the equipment.

(e) Effective coverage shall not be affected by flow rate variations of 10% or as otherwise agreed on by the owner/user.

(f) Spray devices shall be accessible for functionality verification, inspection, and maintenance.

(g) Removable spray device(s) shall be capable of being re-installed in a repeatable manner by unique identifiers to ensure proper installation location.

(h) Spray device selection, orientation, and location shall be designed to ensure the equipment and the targeted surfaces of its appurtenances (e.g., manways, dip-tubes, baffles, nozzles, agitator shaft, and impellers) are exposed to rinse water/cleaning solution.

(i) Spray device(s) shall be provided with a level of documentation that is consistent with the equipment for which it is to be installed and in accordance with GR-5 documentation requirements.

(j) Process contact surface finish of a spray device should be consistent with the equipment for which it is installed or as otherwise specified by the owner/user and in accordance with the definitions of Part SF.

(k) Spray devices shall not use lubricants other than the process liquid. Dynamic devices are typically lubricated by the rinse/cleaning solution(s).

SD-3.9.2.1 Static Spray Device Requirements

(a) Static spray devices shall have a positioning device (preferred) or mark to allow for proper orientation during re-installation, as static devices are orientation sensitive (see Figure SD-3.9.2.1-1).

(b) Weld-on or self-cleaning slip-joint/clip-on connections are acceptable. Provision shall be made to ensure proper orientation and location if one or more slip-joint/clip-on-style static spray devices are used.

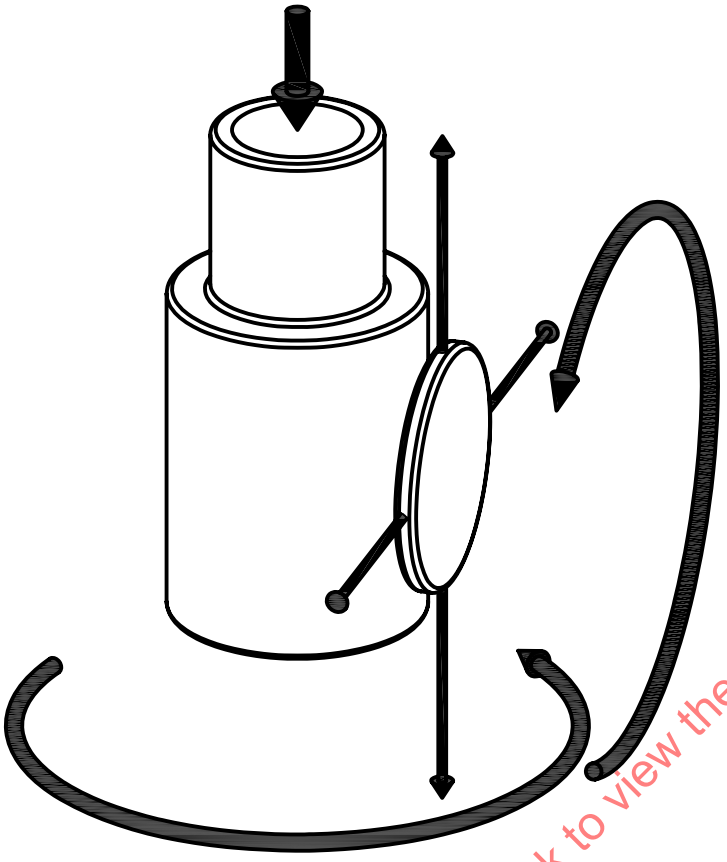
(c) A portion of the flow is directed toward the specific appurtenances.

(d) The flow rate guideline for vertical cylindrical vessels with dished heads is 2.5 gal/min/ft to 3 gal/min/ft (31 L/min/m to 37 L/min/m) of inner vessel circumference. See Figure SD-3.9.2.1-2. The majority of the flow is directed toward the upper head to ensure coverage of appurtenances and provide the sheeting action.

(e) The flow rate guideline for horizontal cylindrical vessels with dished heads is 2 gal/min/ft to 3 gal/min/ft (25 L/min/m to 37 L/min/m) of perimeter ($2L + 2d$). See Figure SD-3.9.2.1-3. The majority of the flow is directed toward the upper one-third of the vessel to ensure coverage of appurtenances and provide the sheeting action.

(f) Flow requirements for the specific application should be confirmed with the spray device manufacturer, equipment manufacturer, or other subject matter experts.

Figure SD-3.9.1-2
Two-Axis Dynamic Spray Device



GENERAL NOTE: Number of jets is for illustration purposes.

Figure SD-3.9.2.1-1
Static Spray Device

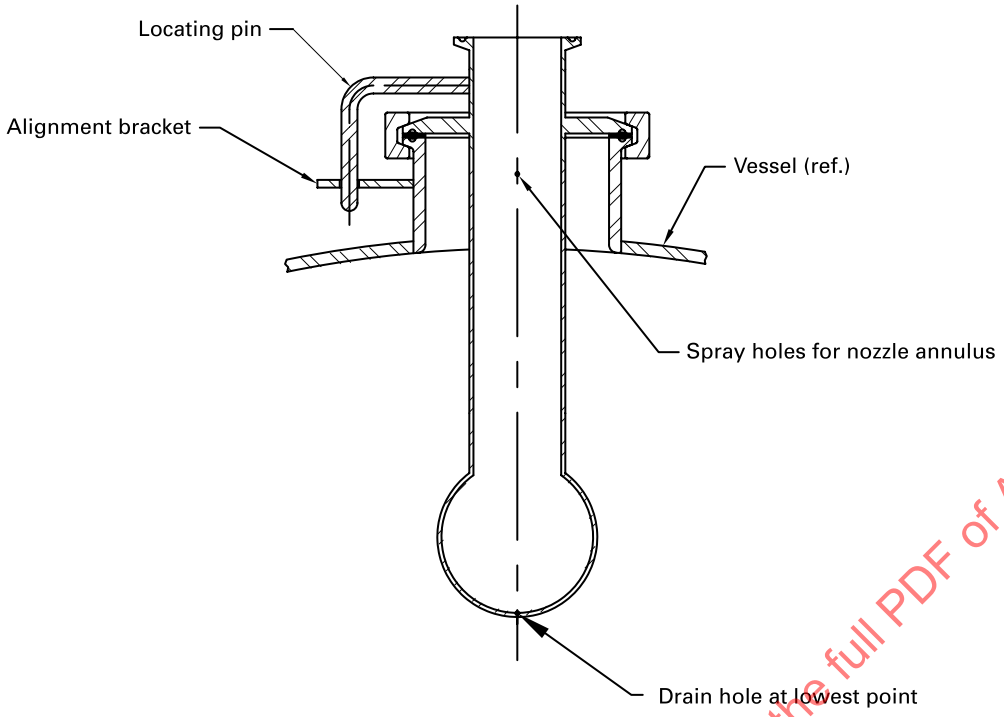


Figure SD-3.9.2.1-2
Flow Rate Guideline for Vertical Cylindrical Vessels

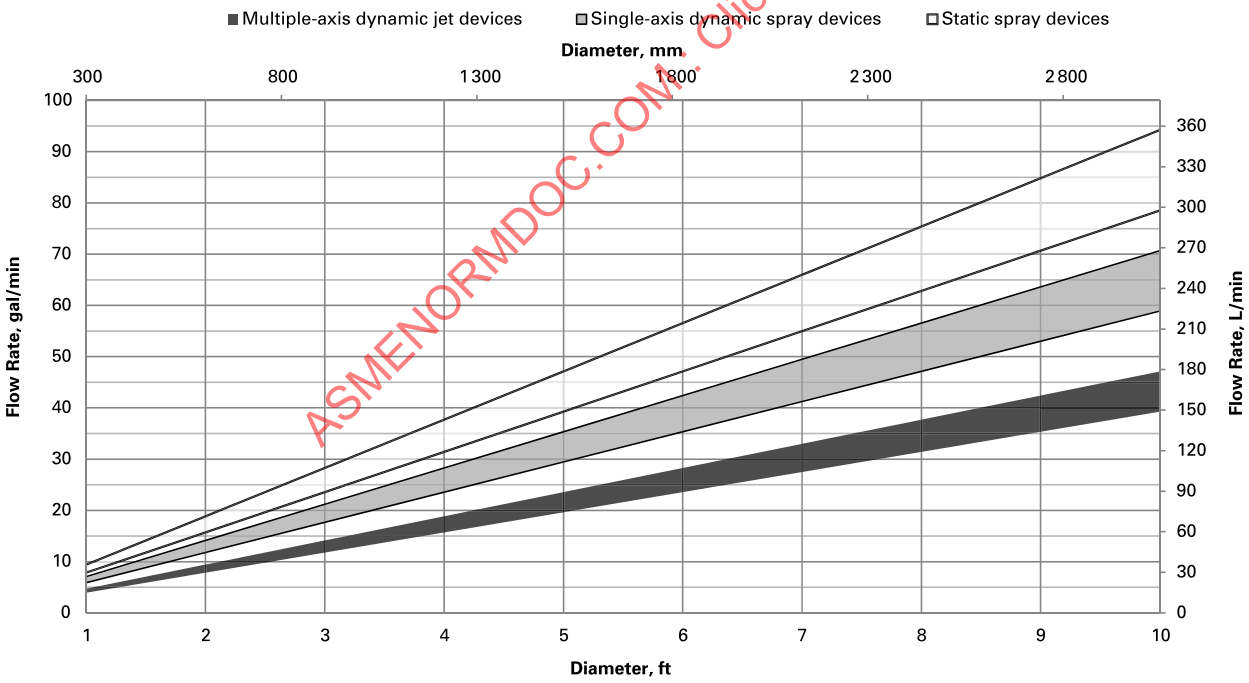
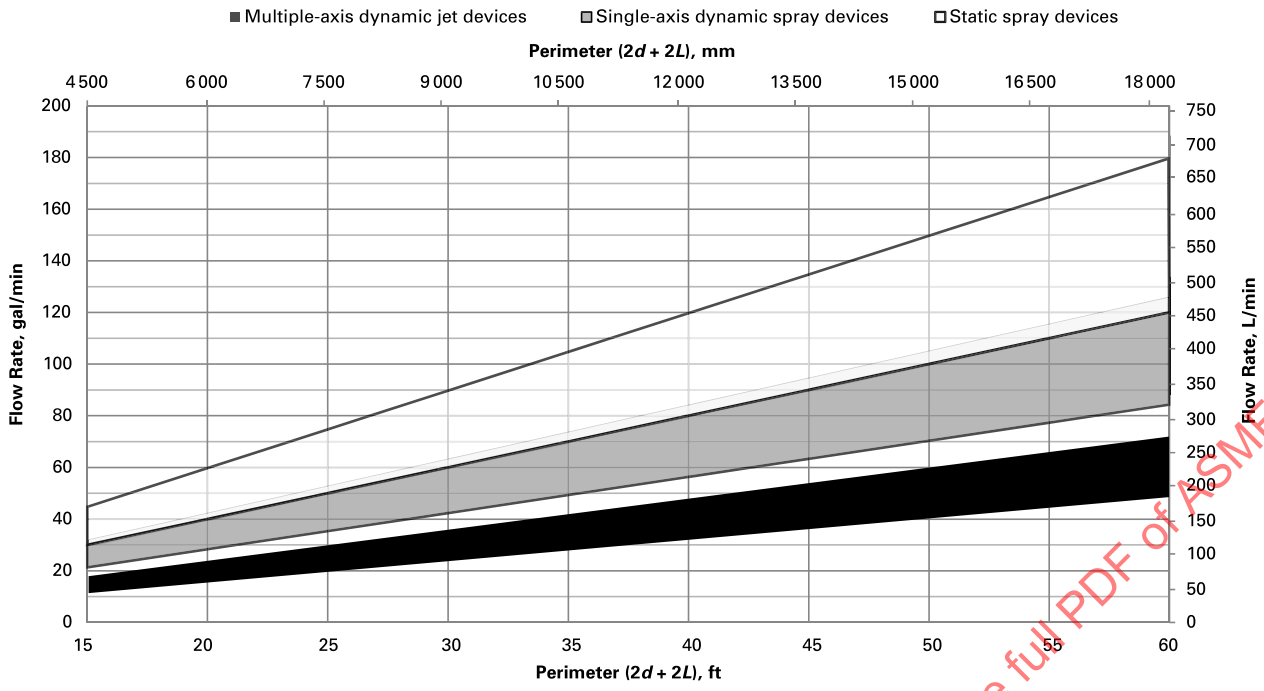


Figure SD-3.9.2.1-3
Flow Rate Guideline for Horizontal Cylindrical Vessels



SD-3.9.2.2 Single-Axis Dynamic Spray Device Requirements

(a) The installation or the design should allow for rotation verification or frequency verification or both.

(b) Weld-on or self-cleaning slip-joint/clip-on connections are acceptable. Other hygienic alternatives shall be agreed on with the owner/user.

(c) The flow rate guideline for vertical cylindrical vessels with dished heads is 1.9 gal/min/ft to 2.3 gal/min/ft (23.6 L/min/m to 28.6 L/min/m) of inner vessel circumference. The majority of the flow is directed toward the upper head to ensure coverage of appurtenances and provide the sheeting action.

(d) The flow rate guideline for horizontal cylindrical vessels with dished heads is 1.4 gal/min/ft to 2.1 gal/min/ft (17.4 L/min/m to 26.1 L/min/m) of perimeter ($2L + 2d$). The majority of the flow is directed toward the upper one-third of the vessel to ensure coverage of appurtenances and provide the sheeting action.

(e) Flow requirements for the specific application should be confirmed with the spray device manufacturer, equipment manufacturer, or other subject matter experts.

(f) High-velocity gas flow from air-blows or steam passing through liquid-driven spray devices can result in wear to bearing surfaces. Consideration should be taken to restrict gas flow through the spray device according to the manufacturer's recommendation.

SD-3.9.2.3 Multiaxis Dynamic Spray Device Requirements

(a) The installation or the design should allow for rotation verification or frequency verification or both.

(b) The time to complete a full impact pattern (see Figure SD-3.9.2.3-1) at a specified pressure or flow rate shall be provided by the manufacturer.

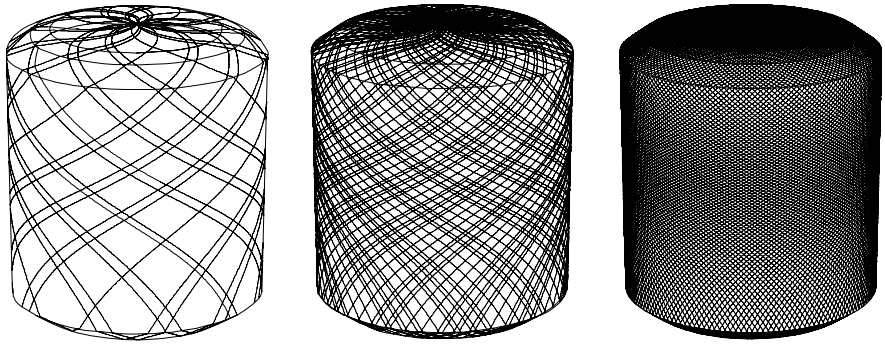
(c) Weld-on or self-cleaning slip-joint/clip-on connections are acceptable. Other hygienic alternatives shall be agreed on with the owner/user.

(d) The flow rate guideline for vertical cylindrical vessels with dished heads is 1.3 gal/min/ft to 1.5 gal/min/ft (16.1 L/min/m to 18.6 L/min/m) of inner vessel circumference to ensure coverage of appurtenances and provide the sheeting action.

(e) The flow rate guideline for horizontal cylindrical vessels with dished heads is 0.8 gal/min/ft to 1.2 gal/min/ft (9.9 L/min/m to 14.9 L/min/m) of perimeter ($2L + 2d$) to ensure coverage of appurtenances and provide the sheeting action.

(f) Flow requirements for the specific application should be confirmed with the spray device manufacturer, equipment manufacturer, or other subject matter experts.

Figure SD-3.9.2.3-1
Impact Pattern Buildup



(g) High-velocity gas flow from air-blows or steam passing through liquid-driven spray devices can result in wear to bearing surfaces. Consideration should be taken to restrict gas flow through the spray device according to the manufacturer's recommendation.

SD-3.10 Disposables That Require Presterilization or Poststerilization

[Reserved for future content]

SD-3.11 Sampling Systems

SD-3.11.1 General

(a) Sampling equipment in the biopharmaceutical industry is used for the collection of samples that then undergo chemical or microbiological evaluation. Sampling may be either aseptic or nonaseptic.

(b) Sampling systems shall not adulterate the process fluid being sampled nor affect the sample characteristics being tested.

(c) Aseptic sampling systems shall be steamable or presterilized single-use.

(d) Hygienic sampling systems shall either be cleanable or single-use.

(e) Aseptic sampling systems shall be closed to isolate the process; protect the sample, sample container, and sample transfer process from the environment; and obtain representative samples.

SD-3.11.2 Aseptic Sampling Systems

SD-3.11.2.1 Basic Requirements

(a) Steamable sample systems shall meet the relevant requirements of SD-2.3.1.1.

(b) Sampling systems intended for multiple-use shall be cleanable.

(c) Sample valves shall meet the requirement of MC-3.3.2.3.

(d) In septum sample devices, the needles shall be sterilized prior to insertion into the vessel or process line.

(e) Collecting devices shall be designed, connected, and disconnected in ways that maintain the integrity of the sample.

SD-3.11.2.2 Installation. The sampling device shall be installed to maintain the aseptic barrier between the process fluid being sampled and the environment. Consideration should be given to ease of assembly and subsequent handling of the sample.

SD-3.11.2.3 Sample Collecting

(a) When using single-use collecting devices, consideration shall be given to maximum pressure ratings of valves, adaptors, and bags.

(b) Consideration should be given to the impact of absorption and off-gassing that could lead to nonrepresentative samples. Polymeric material requirements for leachables and extractables are listed in Part PM.

SD-3.11.3 Nonaseptic Sampling. [Reserved for future content]

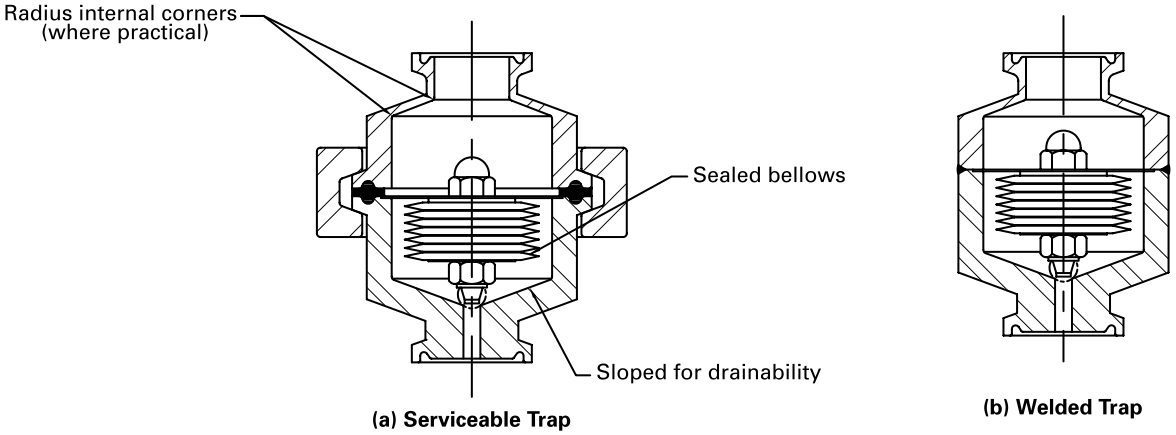
SD-3.12 Steam Traps

(a) Steam traps are not considered hygienic. Steam trap bodies shall have an internal surface finish (excluding the bellows assembly) as agreed to by all parties. Surface finish specification shall match the clean steam condensate tube finish specification unless the condensate downstream of the trap is used in the process or sampled for quality assurance.

(b) Where used in process systems, the traps shall be capable of effectively venting air.

(c) Where installed on process systems, traps shall be maintainable to allow easy examination and cleaning. Welded traps are acceptable if agreed to by the owner/user.

Figure SD-3.12-1
Steam Traps for Clean Steam Systems



(a) Serviceable Trap

(b) Welded Trap

(d) The trap design and mode of operation shall be such that the risk of soil attachment to the wetted surfaces is minimized, especially around the bellows and seat (see Figure SD-3.12-1).

(e) The trap shall be sized and installed to operate such that there is no backup of condensate into the process equipment and clean steam system under operating conditions. Operating conditions include heat-up, hold, and cooldown.

(f) The trap shall be designed such that the normal mode of mechanical failure is in the open position.

(g) Thermostatic steam traps, installed in vertical trap legs, are preferred for use in clean steam systems (see Figure SD-3.12-1).

(h) Trap operation/reactivity should be improved by the installation of an uninsulated section of tubing upstream of the trap [suggested 12 in. (30 cm) as recommended by supplier] (see Figure SD-4.2.2-2).

(24) **SD-3.13 Check Valves**

(a) Check valves that are used in product contact applications shall be of hygienic design.

(b) Check valves in process contact applications should be installed in a manner that enables draining. Nondrainable valves may be used for liquid streams that flow continuously (e.g., a compendial water loop) or where valves are wetted with a sanitizing medium when not in use (e.g., chromatography system that is filled with sodium hydroxide solution between uses).

(c) The flow direction and required orientation for drainability should be clearly identified on the device. Where the valve is integral to equipment (e.g., diaphragm pumps, homogenizers), indication of the flow direction is not required.

(d) The use of check valves with springs in product contact should be avoided. Use of check valves using an exposed coil spring in non-product contact applications should be evaluated for acceptability. Applications where check valves using an exposed coil spring do not introduce bioburden risk include condensate removal lines and dry process gases. Check valves may be used for backflow prevention in waste and biocontainment applications or systems with bacteriostatic solutions (e.g., cleaning agents) where cleaning and sanitizing are not considerations.

(e) Check valve design shall conform to MC-3.3.2.3.

SD-3.14 Orifice Plates

Orifice plates, when required and used in hygienic piping systems, shall be installed in a drainable position.

SD-3.15 Relief Devices

(a) Rupture disks (or other hygienic pressure relief devices approved by the owner/user) shall be installed in a hygienic manner without compromising the safety or efficiency of the system.

(b) The cleaning system design shall ensure that the rupture disk (or other hygienic pressure relief devices approved by the owner/user) will not be damaged by the cleaning process (e.g., mechanical forces, chemical compatibility).

(c) Rupture disk (or other hygienic pressure relief devices approved by the owner/user) installation shall conform to the L/d ratios mentioned in SD-3.1.2.2.

(d) Rupture disks shall be installed in the manufacturer's recommended holder to ensure proper functionality and cleanability.

(e) Relief devices, including discharge piping, shall be installed in conformance to applicable codes (e.g., flammable liquids and combustibles in accordance with NFPA 30).

(f) Pressure relief valves that are used in product contact applications shall meet the requirements of MC-3.3.2.3(a) on both sides of the valve seat. Crevices and holdup volumes should be minimized.

(g) Safety pressure relief valves that are used in product contact applications shall meet the requirements of MC-3.3.2.3(a) up to the valve seat.

(h) Pressure and safety pressure relief valves shall be installed in a manner that permits draining on both the process and discharge sides of the valve seat.

(i) Pressure relief valves that are used in product contact applications shall be CIP capable. If required for CIP or SIP, an override that allows flow through the valve shall be included.

(j) Pressure relief valves that are used in product contact applications shall conform to MC-3.3.2.3.

SD-3.16 Liquid Pressure Regulators

(a) Regulators should be installed to be drainable through the outlet or inlet ports.

(b) There shall be no voids or crevices within the area wetted by the fluid. Regulator designs, where a portion of the valve stem penetrates the sensing diaphragm, shall be avoided unless provisions are made to avoid entrapment of foreign matter and any leakage through the interface between stem and diaphragm, especially after SIP.

(c) Due to the inherent design characteristics of self-contained regulators, manual means of override may be required to allow for cleaning and draining.

SD-3.17 Strainers

SD-3.17.1 General. Strainers as described in this section are intended for process component and equipment protection (see Figure SD-3.17.1-1) and are not designed for bioburden control. Strainers are permitted in locations where they reduce the risk of contamination of a process (e.g., CIP return line).

SD-3.17.2 Design and Manufacture

(a) Strainers intended for single-direction flow shall have the flow direction indicated on the strainer body.

(b) The strainer body should have the same surface finish as specified for the process piping or equipment in which it is being installed.

(c) Surface finish achievement or measurement may not be possible for all areas of straining surfaces (e.g., strainer element holes, openings, or mesh).

(d) For strainers in-line within process piping, the manufacturer should state the operating flow coefficient, C_v, when free of solid particulate loading and maximum allowable pressure drop.

(e) Strainer body design features (e.g., sight glasses) shall not create a dead leg.

SD-3.17.3 Selection, Installation, and Operation

(a) Perforated strainer elements that are free of crevices are preferred for use in permanent hygienic installations. Where perforated strainers cannot be used, the use of other types of strainers (e.g., wire mesh, wedgewire) is permitted if the risk of contamination to the process is mitigated.

(b) When specifying strainer elements, the owner/user should provide strainer element hole/mesh size and allowable pressure drop at a given flow across the strainer element and body when free of solid particulate loading.

(c) Strainers shall have field tagging (e.g., ID tag, engraving) to ensure external visual identification post-installation.

(d) The installed strainer shall allow for removal of the element for inspection or cleaning.

(e) Strainers shall be drainable when free of solid particulate loading and installed in the recommended orientation.

(f) The design or installation of the strainer within the system should enable detection and removal of captured solid particulates (e.g., visual inspection or pressure differential monitoring).

SD-3.18 Chromatography Columns

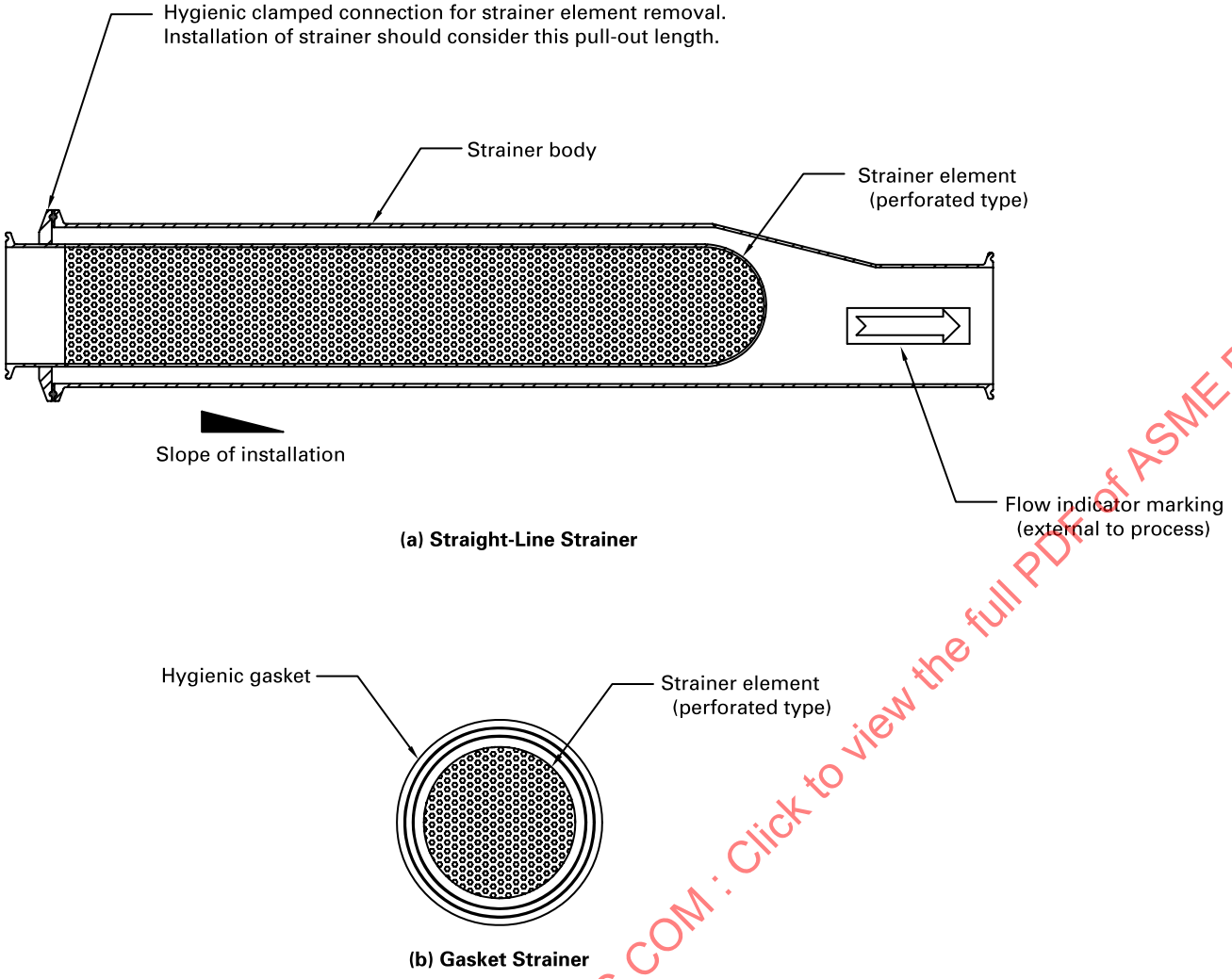
SD-3.18.1 General. This section defines typical design elements related to large-scale chromatography columns and includes columns that are intended for repeated use in processing. Although chromatography processes are not typically aseptic, design features for cleaning and/or sanitization should be considered. More information on chromatography columns can be found in Nonmandatory Appendix T.

SD-3.18.2 Pressure-Retaining Parts. The column tube is both a product contact surface and a pressure-retaining component. Chromatography columns are vessels operating under pressure and should meet the requirements of ASME BPVC, Section VIII, as referred to in GR-1, as applicable. If the column tube is acrylic, it shall comply with ASME PVHO-1, Case 14, Low UV. The owner/user is responsible for informing the manufacturer of the normal and abnormal operating conditions to which the column may be exposed. The manufacturer is responsible for ensuring the column will operate safely under said conditions.

SD-3.18.3 Design for Cleaning and Sanitization

SD-3.18.3.1 Cleaning. Columns should be designed in accordance with SD-2.4.2 with the exception of the bed supports and flow distributor. Cleaning of chromatography columns is achieved by control of contact time and concentration of the appropriate cleaning agents.

Figure SD-3.17.1-1
Example Strainer Types



GENERAL NOTE: Gasket strainers do not have a stand-alone strainer body. When installed, the gasket strainer is integral to the hygienic piping, which acts as the strainer body.

SD-3.18.3.1.1 Seals. All seals shall conform to Part MC.

SD-3.18.3.1.2 Exterior Surfaces. Exterior surfaces of columns shall be nonabsorbent and compatible with cleaning agents. Columns shall be designed to allow effective removal of cleaning agents from surfaces.

SD-3.18.3.1.3 Hygienic Connections. Hygienic connections shall conform to other Parts of this Standard.

SD-3.18.3.2 Sanitization

SD-3.18.3.2.1 Chemical Sanitization. All product contact surfaces within the system shall be compatible with the sanitization agents selected.

SD-3.18.3.2.2 Thermal Sanitization. When thermal sanitization is used, all column product contact surfaces shall be designed to accommodate expansion and contraction during exposure and cooldown stages.

SD-3.18.4 Column Materials. Column materials for all product contact surface wetted parts shall conform to application sections of Parts SD, PM, and SF.

SD-3.18.5 Column Performance. The owner/user shall be responsible for informing the manufacturer of the conditions under which the column may be expected to operate. This shall include the methods, frequency, and duration of cleaning and sanitization procedures. In addition to the service temperature and pressure, any

parameters that may affect the column performance shall be provided.

SD-3.18.5.1 Service Temperature and Pressure. Columns shall be capable of withstanding thermal and pressure cycling between the rated upper and lower temperature and pressure limits.

SD-3.18.5.2 Routine Maintenance. To ensure continued column performance, the accessibility of all column components for routine maintenance shall be considered.

SD-3.18.6 Conformance Requirements

SD-3.18.6.1 General Requirements. A unique identifier shall be indelibly marked on the column or the column's support structure. The unique identifier shall enable the owner/user to identify the supplier and the supplier to identify the raw material and processing conditions used to fabricate the article.

SD-3.18.6.2 Certificate of Conformance. A Certificate of Conformance shall be issued by the column manufacturer to certify conformance to this Standard when required by the owner/user.

The Certificate of Conformance shall contain the following information:

(a) manufacturer's name

(b) unique identifier of the column

(c) material of process contact items

(d) compliance to USP <87> Class VI (or ISO 10993-5) and USP <88> (or ISO 10993-6, -10, and -11)

Also see Table PM-2.2.1-1.

(24) SD-3.19 Multiuse Rigid Polymeric Vessels

SD-3.19.1 General. This subsection defines requirements for the design, fabrication, and use of multiuse rigid polymeric pressure and non-pressure rated vessels in process contact applications.

(a) Design and fabrication of polymeric vessels shall conform to the requirements of SD-3.4.1.

(b) Polymeric vessels are fabricated using weldless technologies (e.g., molding) or material joining methods. The manufacturer shall select a material joining method that meets the specified design criteria. The acceptance criteria for polymeric vessel welds shall be agreed on by the manufacturer and the owner/user.

SD-3.19.2 Polymeric Materials. Thermoplastic polymeric materials are described in PM-2.1.1. Examples of thermoplastic polymers commonly used in bioprocessing applications are listed in Table O-1.1-1.

The polymeric material shall be selected with consideration for operating temperature, composition of all fluids in contact with the polymer including cleaning agents, purity requirements, sanitization, and sterilization techniques.

Polymeric vessels shall be constructed of materials that

(a) provide adequate strength and durability to withstand continuous or cyclic stressors (e.g., thermal, pressure) as specified for design.

(b) do not directly or indirectly affect the purity or integrity of the product.

(c) conform to the biocompatibility requirements described in PM-3.1.

The owner/user should assess the intended use of process contact materials, as outlined in PM-2.2.

SD-3.19.3 Operating Conditions. Polymeric vessels shall be designed with consideration for

(a) extractables and leachables, in accordance with PM-3.2

(b) chemical compatibility, in accordance with PM-3.3

(c) operating conditions of all applicable processes, including CIP and SIP

(d) physical and mechanical properties, in accordance with PM-3.3

SD-3.19.4 Surface Finish. The surface finishes for the process contact surface of the vessel, tubing, and internal components shall be measured as required by Part SF and conform to values designated in Table SF-3.4-1. Acceptance criteria shall conform to Part SF.

The non-process contact surface finishes of the vessels located in clean areas shall meet the requirements of SD-2.4.4.2.

SD-4 PROCESS UTILITY SYSTEMS

SD-4.1 Compendial Water Systems

(a) Compendial water systems, such as USP Grade Water-for-Injection (WFI), USP Grade Purified Water (PW), and Highly Purified Water (HPW), shall be designed as looped circulatory systems, rather than noncirculating, dead-ended, branched systems.

(b) Loops shall be designed to provide fully developed turbulent flow in the circulating sections and to prevent stagnation up to the weir of each point-of-use valve.

SD-4.1.1 Compendial Water Generation

(a) All surfaces that shall come into direct contact with the compendial water, feed water, or condensate/blowdown produced by the units shall be constructed of 316- or 316L-type stainless steel or other material as specified by the owner/user.

(b) Connections to the compendial water, feed water, or condensate/blowdown compendial water by the units shall be made by the use of hygienic design fittings. All fittings should be constructed in such a manner as to avoid dead legs and crevices.

(c) Units should be drainable and should not contain areas where agents used to clean, descale, or passivate the units are trapped or not easily flushed during rinsing operations.

SD-4.1.2 Compendial Water Distribution Systems

SD-4.1.2.1 Point-of-Use Piping Design for Compendial Water Systems. Point-of-use (POU) can be defined as a location in a compendial water loop where water is accessed for processing or sampling. Typically, the point-of-use assemblies are composed of the following elements:

(a) piping associated with a compendial water loop at the physical POU

(b) POU valves, equipment, and instruments

Additional process components and equipment may be added to satisfy any application or system requirements and will be discussed further in this Part (see Figure SD-4.1.2.1-1).

SD-4.1.2.2 Critical Design Criteria for Point-of-Use Assemblies

(a) All point-of-use assemblies should be designed to enable draining through the POU valve.

(b) Assemblies shall be designed for sanitization (e.g., hot flush, SIP).

(c) Valves used in POU applications should be welded into the water distribution loop where possible. Current industry designs are available to achieve an L/d of 2 or less (see SD-3.1.2.2).

(d) Sample valves should be integral to the design of the primary valve and should not constitute dead legs.

(e) Sample valves should be installed only as needed on the main loop.

(f) Sample valves should be installed where water is used for the process to demonstrate water quality compliance to compendial monographs.

(g) Any valve used to provide clean utility services to the POU assembly (e.g., steam or clean gas) should be fabricated in such a manner as to achieve an L/d of 2 or less downstream from the primary POU valve [see Figure SD-4.1.2.1-1, illustrations (a) and (c)].

(h) The length of tubing from POU valves to process equipment should be minimized [see Figure SD-4.1.2.1-1, illustrations (a) and (b)].

(i) If evacuating the system is not possible, appropriate porting of the primary POU valve should be accomplished to facilitate sanitization.

(j) When heat exchangers are used as POU coolers [see Figure SD-4.1.2.1-1, illustration (c)], the design shall conform to SD-3.6.

(k) Physical breaks shall be employed between hoses, drain valves, or any other component leading to drains or sinks to avoid back-siphoning into the POU assembly [see Figure SD-4.1.2.1-1, illustrations (d) and (e)]. The distance H of the physical break should be at least twice the inner diameter of the hoses, drain valves, or any other component leading to drains or sinks to avoid back-siphoning into the POU assembly. The break shall be at least 1 in. (25 mm) for hoses, drain valves, or other components with internal diameters less than or equal to $\frac{1}{2}$ in. (13 mm) (see Figure SD-4.1.2.2-1).

(l) Tubing and other piping materials should be a minimum of $\frac{3}{4}$ in. (19 mm) in diameter to enable draining of water after use.

(m) POU assemblies shall be drainable as indicated in SD-2.4.3.

(n) A POU may include a venturi or orifice plate, if the restriction of water flow is required. Where used, the additions of these components will require a blowdown to enable drainability.

(o) When compendial water systems are constructed of metallic materials, the surface finish should be less than or equal to 25 µin. R_a or 0.6 µm (see Part SF) and may be internally electropolished. All 316L-type internal surfaces shall be passivated.

(p) When compendial water systems are constructed of polymer materials, the surface finish should be less than or equal to 25 µin. R_a or 0.6 µm.

SD-4.2 Clean/Pure Steam Systems

This section is applicable to both clean and pure steam systems.

SD-4.2.1 Clean/Pure Steam Generation

(a) All surfaces that come into direct contact with the clean/pure steam, feed water, or condensate/blowdown produced by the units shall be constructed of 316- or 316L-type stainless steel or other material as specified by the owner/user.

(b) Connections to the clean/pure steam, feed water, or condensate/blowdown produced by the units shall be made by the use of hygienic design fittings. All fittings should be constructed to be free of dead legs and crevices.

(c) Units should be drainable and should not contain areas where agents used to clean, de-scale, or passivate the units are trapped or not easily flushed during rinsing operations.

SD-4.2.2 Clean/Pure Steam Distribution System

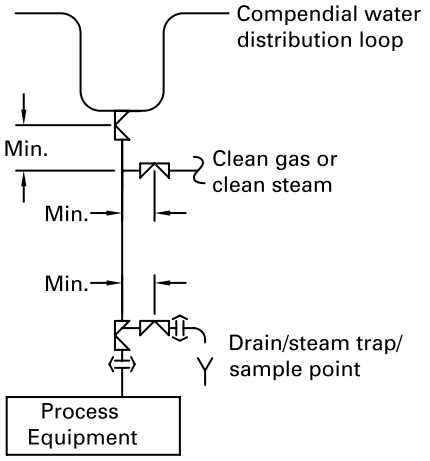
(a) The distribution system shall have adequate provision to remove air during start-up and normal operations. The use of air vents installed at locations where air is likely to be trapped, such as at the ends of steam headers, can assist in this requirement.

(b) The horizontal distribution lines should be sloped in the direction of flow as indicated in SD-2.4.3. Where necessary, increases in height should be achieved by vertical risers (see Figure SD-4.2.2-1).

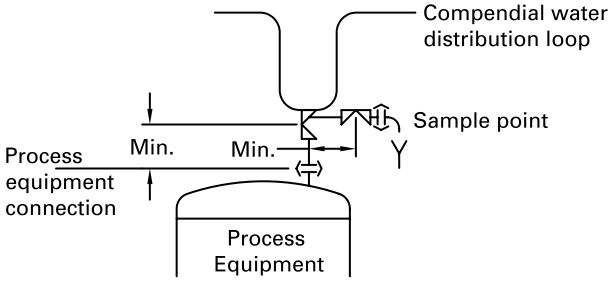
(c) Adequate provision should be made to allow for line expansion and to prevent sagging of the distribution lines, so that lines are drainable.

(d) Distribution systems shall not be directly connected to any nonhygienic steam systems (e.g., plant steam systems).

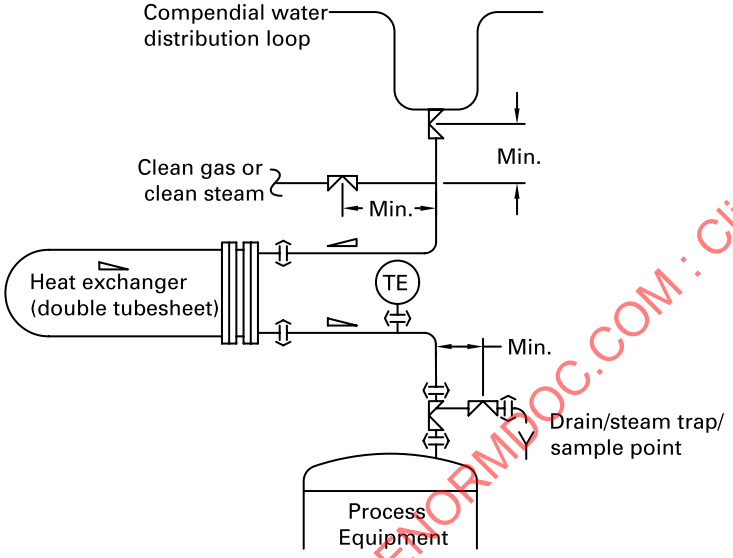
Figure SD-4.1.2.1-1
Point-of-Use Piping



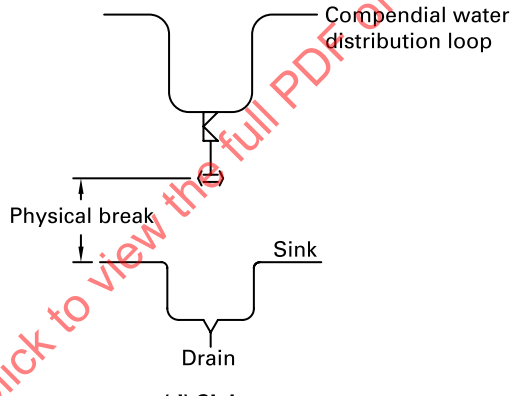
(a) Hard Piped to Equipment



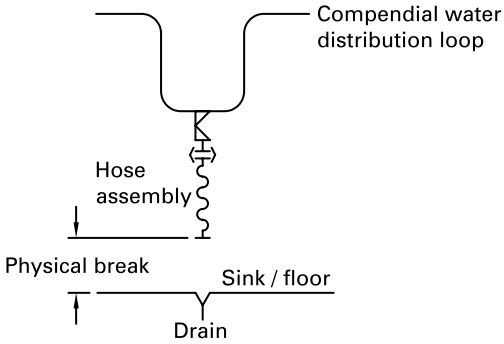
(b) Direct Connect to Equipment



(c) Integral Heat Exchanger

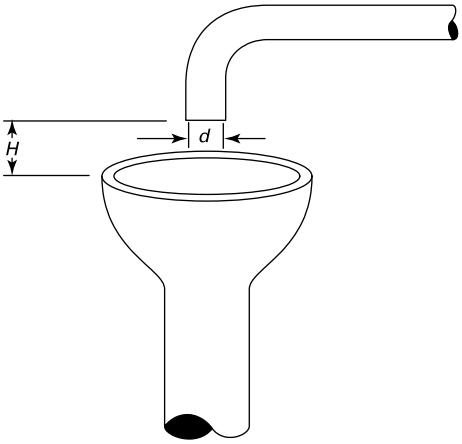


(d) Sink



(e) Hose

Figure SD-4.1.2.2-1
Physical Break in Point-of-Use Piping



GENERAL NOTE: $H = 2d$ or $H = 1$ in. (25 mm) if $d < \frac{1}{2}$ in. (13 mm).

(e) Trap legs for the collection of condensate from the steam distribution system should be of equal size to the distribution line for sizes up to 4 in. (100 mm), and one or two line sizes smaller for lines of 6 in. (150 mm) or larger. These shall be trapped at the bottom. The line size reduction can be made after the branch to the trap leg (see Figure SD-4.2.2-2).

(f) Trap legs should be installed at least every 100 ft (approximately 30 m), upstream of control and isolation valves, at the bottom of vertical risers, and at any other low points.

(g) Condensate systems shall be designed to drain to and from steam traps. The use of overhead, direct-coupled, pressurized condensate return systems should be avoided (see Figure SD-4.2.2-2).

(h) Where possible, all components within the distribution system should be drainable.

(i) Dead legs should be avoided by design of runs and the use of steam traps to remove condensate (see Figures SD-4.2.2-1 and SD-4.2.2-2).

(j) Branches and points-of-use should be routed from the top of the steam header to avoid excessive condensate loads at the branch (see Figure SD-4.2.2-2).

(k) Sampling points for clean/pure steam should be located to collect representative sample(s) of the system (e.g., generator outlet, distribution header ends, critical points-of-use, autoclaves, or SIP stations).

SD-4.2.3 Clean/Pure Steam Valves. This paragraph covers isolation, regulation, and control valves that are part of the steam system and are subject to continuous steam service.

(a) Valves for steam service shall be drainable.

(b) Ball valves are an acceptable industry standard for isolation purposes on continuous steam service. Three-piece-body ball valves should be used instead of single-body designs for both cleanability and maintainability. The bore of the ball valve assembly shall match the inside diameter of the tube (see Figure MC-2.3.1.3-1).

(c) All components shall be suitable for continuous steam service at the temperatures and pressures specified by the owner/user.

(d) Requirements for operation under CIP and SIP conditions [see MC-3.3.2.3(a)(10) and MC-3.3.2.3(a)(12)] can be relaxed when agreed to by the owner/user.

(e) Secondary stem seals with telltale connections are not required for steam service.

(f) Valves shall be accessible for maintenance.

SD-4.3 Process Gases

SD-4.3.1 Process Gas Distribution Systems. For this section, a process gas distribution system is one that extends from the bulk supply source (including cylinders) to the points of use as defined by the owner/user.

(a) The installation of process gas delivery and distribution systems for use within the scope of this Standard requires appropriate selection of piping materials. All components shall be supplied or rendered both hydrocarbon free (e.g., oil free) and particulate free prior to installation and use.

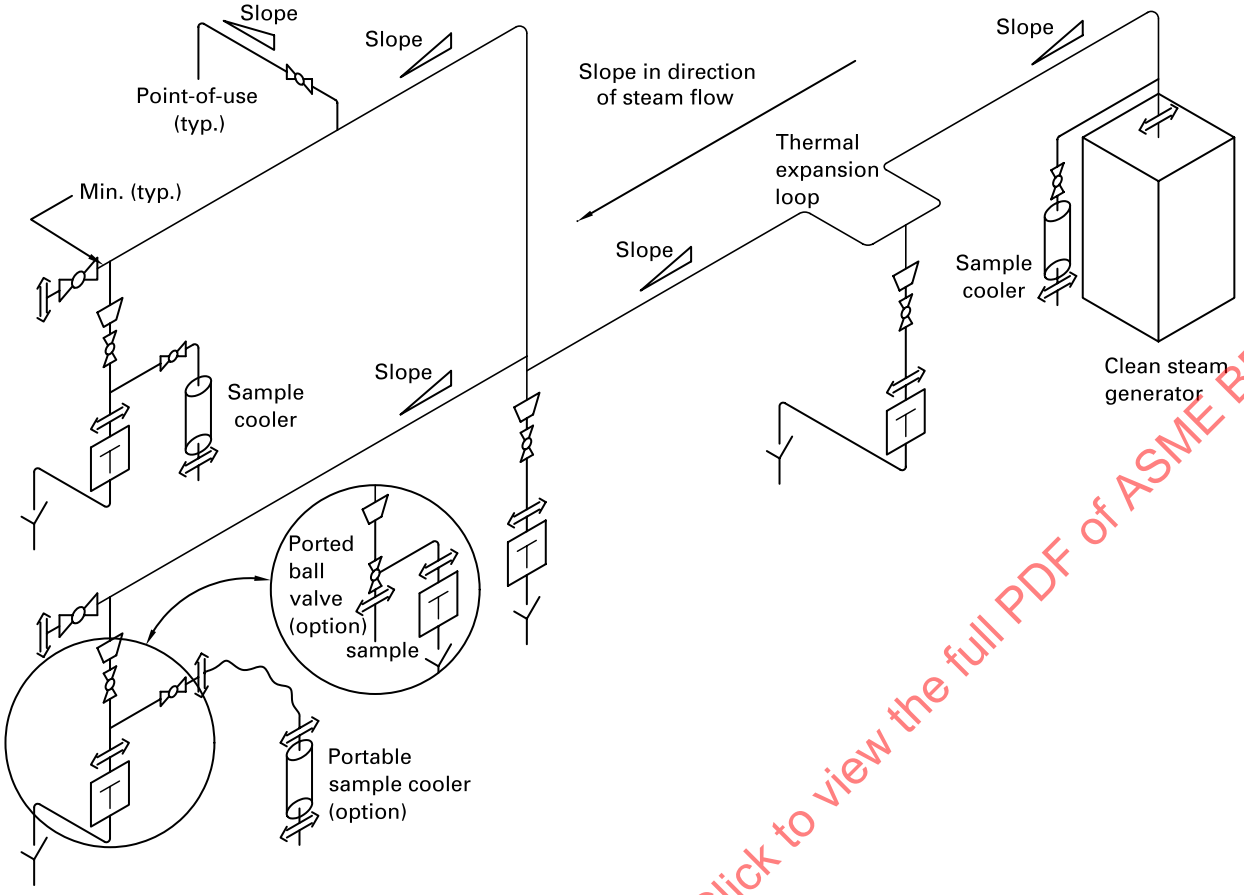
(b) For materials of construction, the owner/user shall specify all materials. When copper is used, it should be hard drawn and installed in accordance with the current edition of NFPA 99, Chapter 5. When copper is specified in a clean room or area, the owner/user shall confirm that all planned cleaning and sanitizing agents are compatible with copper and all materials of construction. When stainless steel tubing is specified, the materials of choice are 304L-type or 316L-type alloys. Orbital welding is the recommended joining method. Inside clean rooms, the materials of choice are 304L-type or 316L-type stainless steel tubing and fittings. The owner/user and manufacturer shall agree on all joining methods, levels of inspection, and acceptance criteria for all joints prior to installation.

(c) Compression fittings may be used for valves, regulators, mass flow controllers, and other instrumentation systems at the source and within system boundaries.

(d) Gas systems are not designed or configured with the intent or provisions to be cleaned, passivated, or chemically treated after installation. Features such as slope, high-point vents, and low-point drains need not be incorporated into these systems.

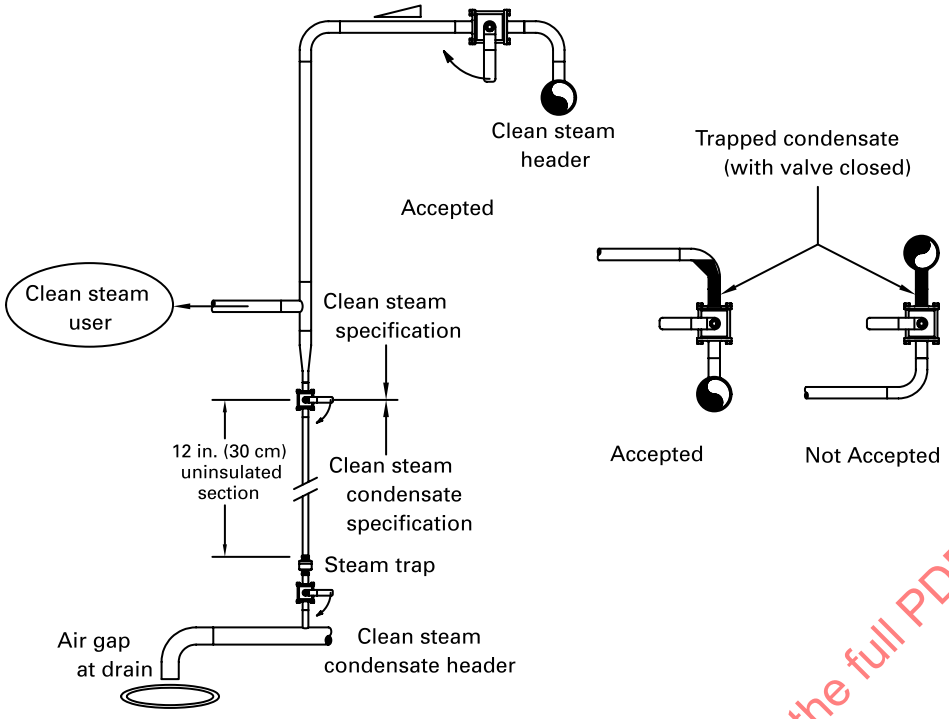
(e) There shall be no nonvolatile residue. The system design shall ensure that gas will remain pure throughout its delivery.

Figure SD-4.2.2-1
Typical Clean Steam System Isometric



GENERAL NOTE: Provide steam traps
(a) where line transitions from horizontal to vertical (at the bottom of the vertical riser)
(b) at least every 100 ft (30 m)
(c) at end of each header or branch
(d) at thermal expansion loops or transitions
(e) where steam is sampled

Figure SD-4.2.2-2
Clean Steam Point-of-Use Design



(f) It is important to select appropriate prefilters and final system filters. The final point-of-use gas purity shall conform to the process requirements.

(g) Gas systems testing and sampling shall conform to 21 CFR 211 and ICH Q7 (International Conference on Harmonization, Good Manufacturing Practice Guidance for Active Pharmaceutical Ingredients).

SD-4.4 Process Waste Systems

This section addresses process waste systems because the reliable function of the waste system can reduce the risk of contamination to the process. By designing systems that can be cleaned and rendered safe for access and preventive maintenance, reliable operation may be achieved.

SD-4.4.1 General. The manufacturing of biologics generates liquid waste in various quantities that may or may not contain viable microorganisms. The liquid waste comes directly from the process fluids and may include cleaning solutions mixed with product components, buffers, or media.

The performance of process waste treatment systems may benefit from the sanitary design requirements of Part SD. The design of the process waste transfer line(s) shall prevent process waste backflow to the process system(s), reducing the risk of contamination.

The effectiveness and safety of process waste treatment systems have been shown to benefit from incorporating the design principles of Part SD. This is true of bio-inactivation systems where heat or chemical dosing is used, or where biosafety containment is required.

SD-4.4.2 Bio-Inactivation Systems. Depending on the type of waste, the treatment method is chosen based on effectiveness, efficiency, and jurisdictional requirements. The owner/user shall define the inactivation conditions and verify the effectiveness of the system with respect to these requirements. Bio-inactivation may be designed to be continuous or batch type and is achieved using one or more of the following methods:

(a) thermal
(b) chemical
(c) radiation

The system design should minimize fouling and buildup of solids and films. Bio-inactivation systems should be cleanable to allow safe disassembly and maintenance. Where biosafety containment is a requirement, the system shall be sanitizable.

In bio-inactivation systems, piping design features specified in SD-2 and SD-3 may help in achieving proper and repeatable operation of these process waste systems.

SD-5 PROCESS SYSTEMS

SD-5.1 Bioreactors and Fermentors

SD-5.1.1 General. For this section, the terms "fermentors" and "bioreactors" are interchangeable. A bioreactor or fermentor shall be defined as a vessel-based system used in the growth of microorganisms or plant, mammalian, or insect cells.

(24) **SD-5.1.4 System Design**

SD-5.1.4.1 Inlet Gas Assembly. The inlet gas assembly shall be defined as a piping assembly that has the ability to deliver controlled amounts of filtered gases into a bioreactor vessel. The assembly shall include but is not limited to the items in SD-5.1.4.1.1 through SD-5.1.4.1.4.

SD-5.1.4.1.1 Flow Control Devices

(a) Flow control devices (e.g., rotameters, mass flow controllers, and modulating control valves) shall be installed outside of the sterile boundary; therefore, piping requirements within this section may not apply. However, provisions shall be included within the design to prevent instrumentation damage due to SIP procedures and backflow.

(b) Flow control devices should be sized to prevent a vacuum condition, or a provision to bypass the flow control device shall be provided to maintain positive pressure in the vessel.

SD-5.1.4.1.2 Inlet Filter Assembly

(a) For this section, an inlet filter shall be defined as a filter element installed in a housing of suitable material. The inlet filter assembly shall be defined as the filter(s) local to the bioreactor.

(b) Inlet filter assemblies shall be designed for SIP with provisions to remove entrapped air and condensate.

(c) If multiple inlet filters are used in series, then the filter assembly closest to the bioreactor shall be a sterilizing filter.

(d) Provisions shall be made for integrity testing of the inlet filter assembly in situ or out of place.

(e) If one or more inlet housings are included in a cleaning circuit, the filter element or elements shall be removed prior to introduction of cleaning solutions.

(f) Gas filters should be installed above the bioreactor liquid level.

SD-5.1.4.1.3 Gas Sparging Assemblies

(a) Spargers shall be defined as mechanical devices normally located below an impeller used to disperse gases within a charged bioreactor. This section applies to sparge lances, wands, rings, and other devices (see Figures SD-5.1.4.1.3-1 through SD-5.1.4.1.3-4) that may be mounted in the bioreactor vessel to introduce various gas streams for process operations. Sparge device assemblies shall meet the requirements of SD-3.4.2.

(b) Spargers shall be designed for SIP with the vessel.

(c) Spargers should be designed for CIP. If the sparge element cannot be CIP'd, provisions shall be made to remove the sparge assembly from the bioreactor for replacement or cleaning out of place.

(d) The removable sparger shall be supplied with the means to ensure that the installation orientation is in conformance to design intent.

(e) If a check valve is installed in the sparge line within the sterile envelope, it shall be designed for CIP and SIP.

SD-5.1.4.1.4 Inlet Gas Piping

(a) Overlay piping is defined as piping that directs filtered gases to the vessel headspace.

(b) Inlet gas assembly piping (sparge and overlay) within the sterile envelope shall meet the requirements as defined in SD-3.1.2.

SD-5.1.4.2 Exhaust Gas Assembly. The exhaust gas assembly is defined as a piping assembly that maintains the integrity of the sterile boundary with respect to sterility and pressure. The assembly shall include but is not limited to the items in SD-5.1.4.2.1 through SD-5.1.4.2.4.

SD-5.1.4.2.1 Exhaust Filter

(a) For this section, an exhaust filter shall be defined as a filter element (as described in Nonmandatory Appendix T) installed in a housing of suitable material.

(b) Exhaust filters shall be designed for SIP. The housings shall be installed in such a way as to prevent the collection of condensate in the elements due to SIP.

(c) If redundant sterilizing-grade exhaust filters are used in series, then the filter farthest from the bioreactor shall have a maximum rating of 0.2 μm absolute. In addition, provisions shall be included for draining condensate from the piping between the filters.

(d) Consideration should be made for CIP or removal in the case of cleaning out of place.

(e) Provisions shall be made for integrity testing of the exhaust filter assembly.

(f) If one or more exhaust filter housings are included in a cleaning circuit, the filter element or elements shall be removed prior to introduction of a cleaning solution

(g) To prevent the exhaust filters from becoming blinded by condensate saturation during operation, the exhaust gas assembly may include exhaust condensers (see Figure SD-5.1.4.2.1-1), exhaust heaters (see Figure SD-5.1.4.2.1-2), or steam jacketed or electrically heat traced filter housings (see Figure SD-5.1.4.2.1-3). These items shall be designed for SIP and CIP.

SD-5.1.4.2.2 Exhaust Gas Heat Exchangers. [Reserved for future content]

Figure SD-5.1.4.1.3-1
Gas Sparging Assembly — Lance

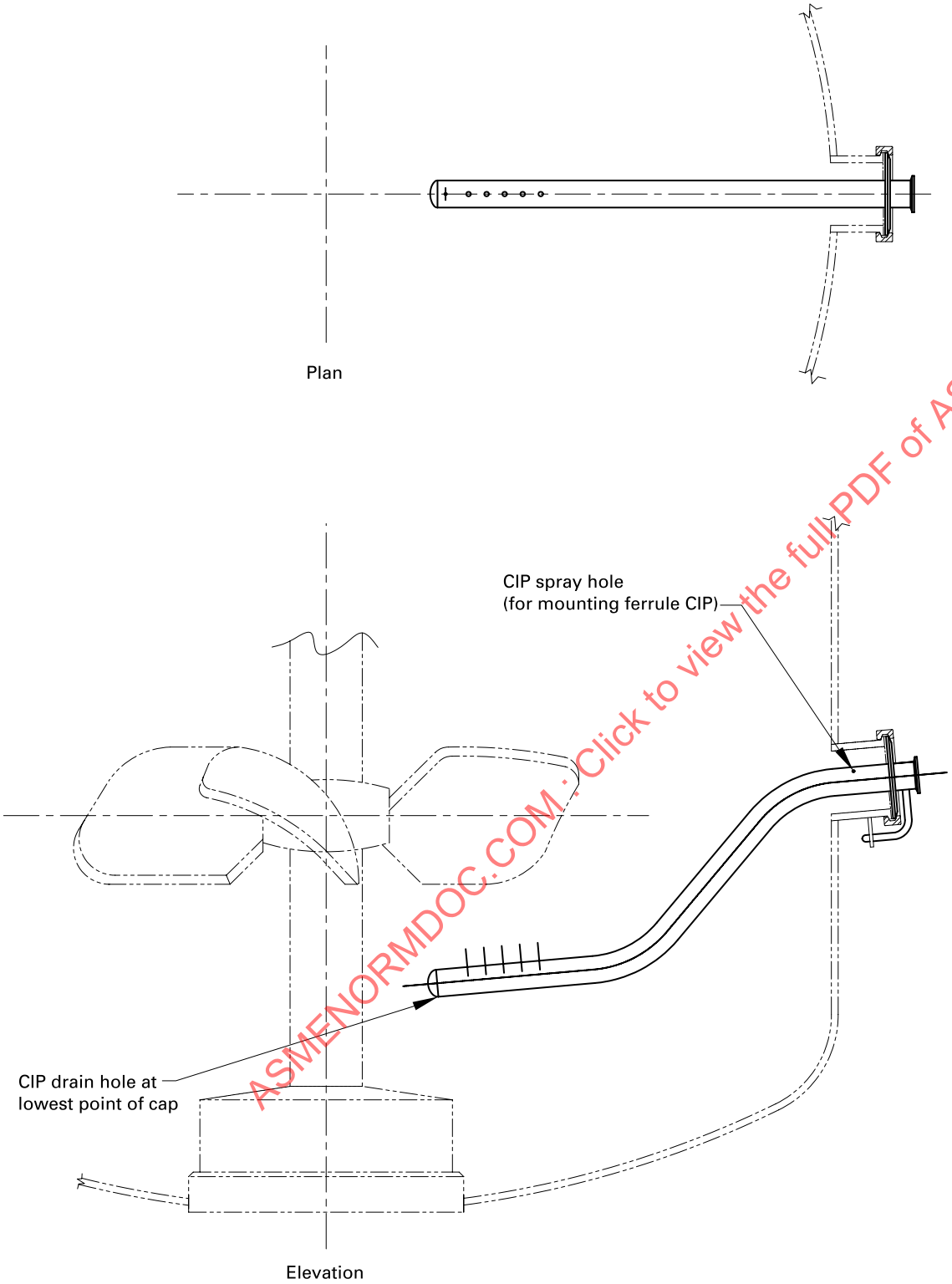


Figure SD-5.1.4.1.3-2
Gas Sparging Assembly — Sintered

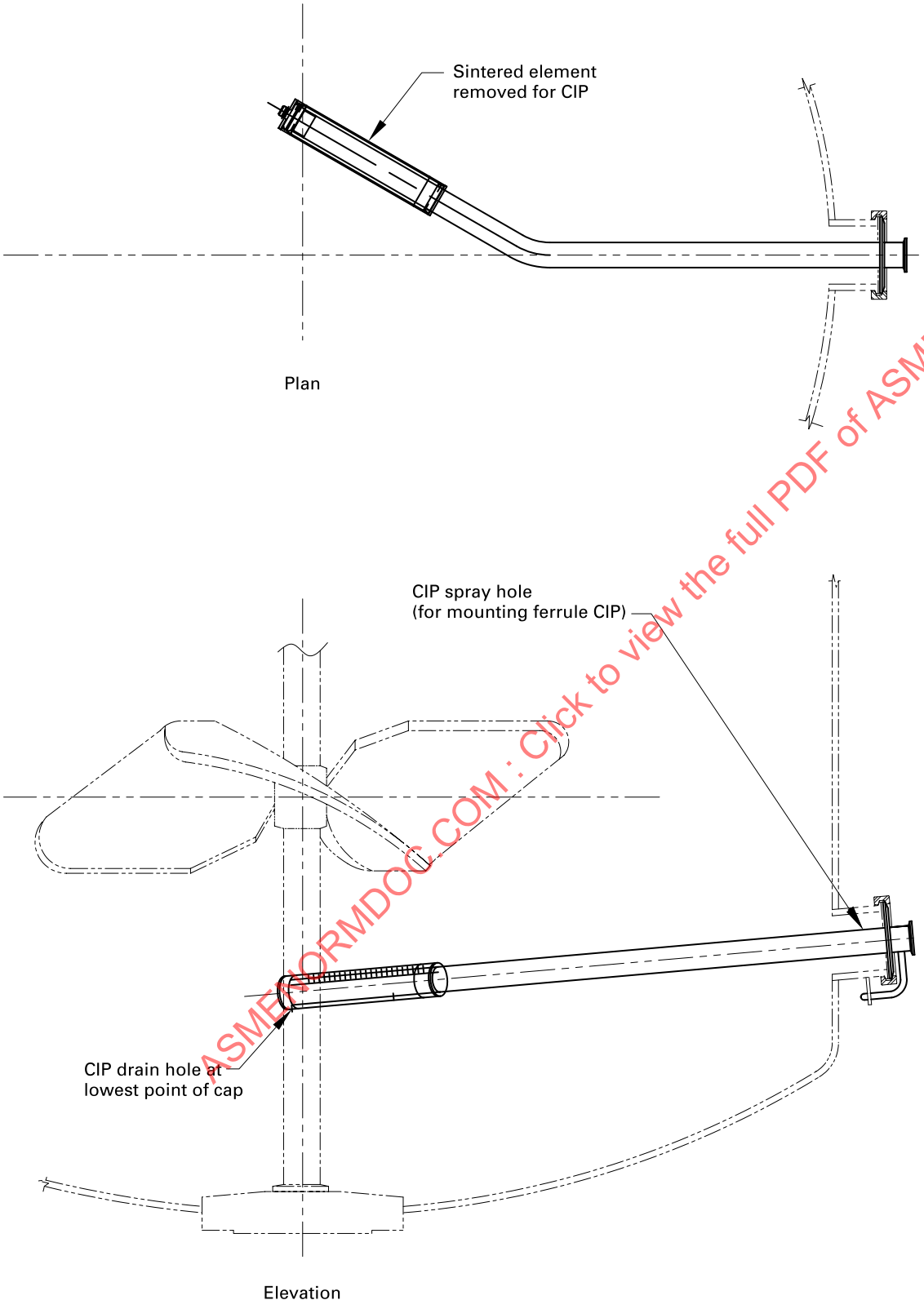


Figure SD-5.1.4.1.3-3
Gas Sparging Assembly — Ring

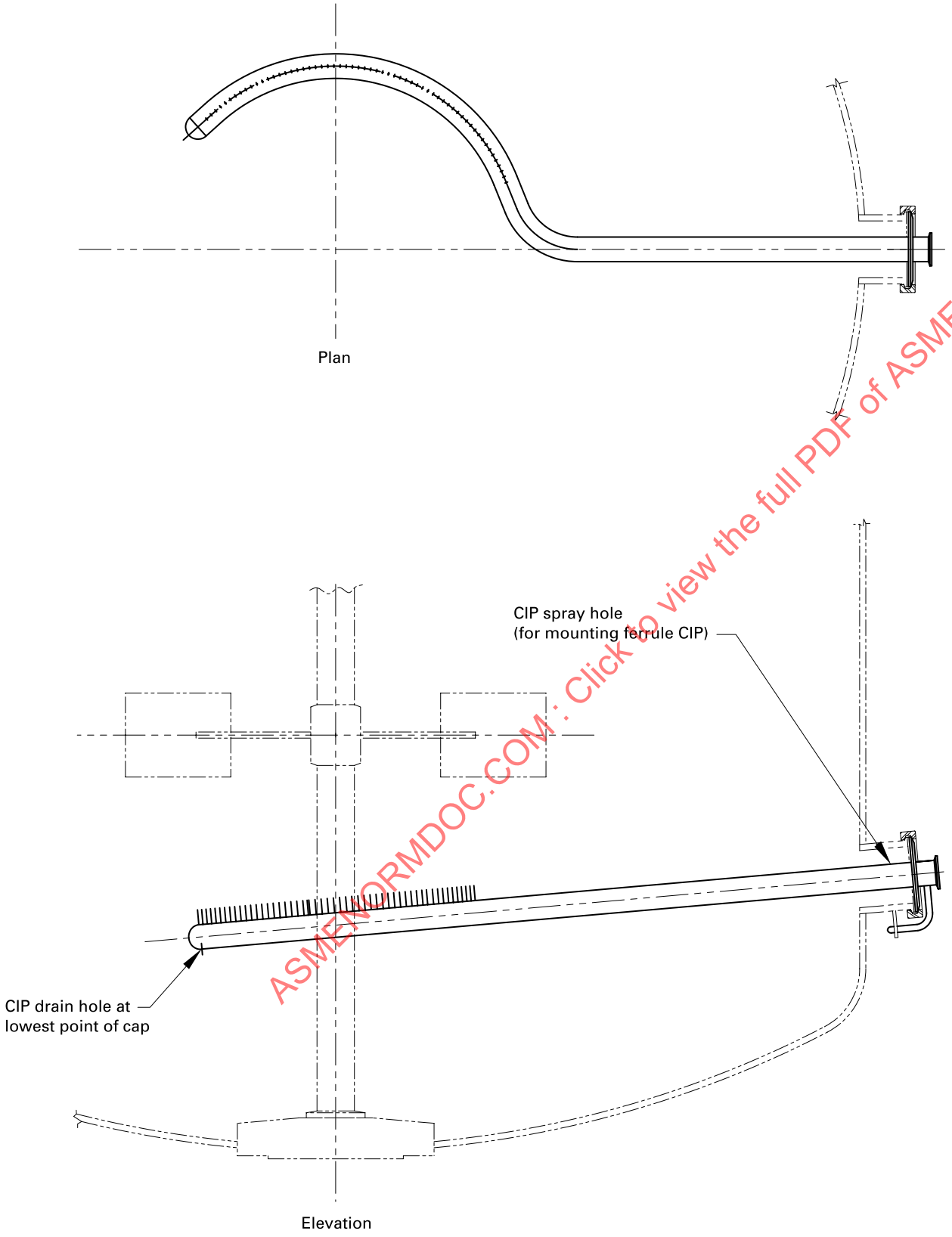


Figure SD-5.1.4.1.3-4
Gas Sparging Assembly — Single Orifice

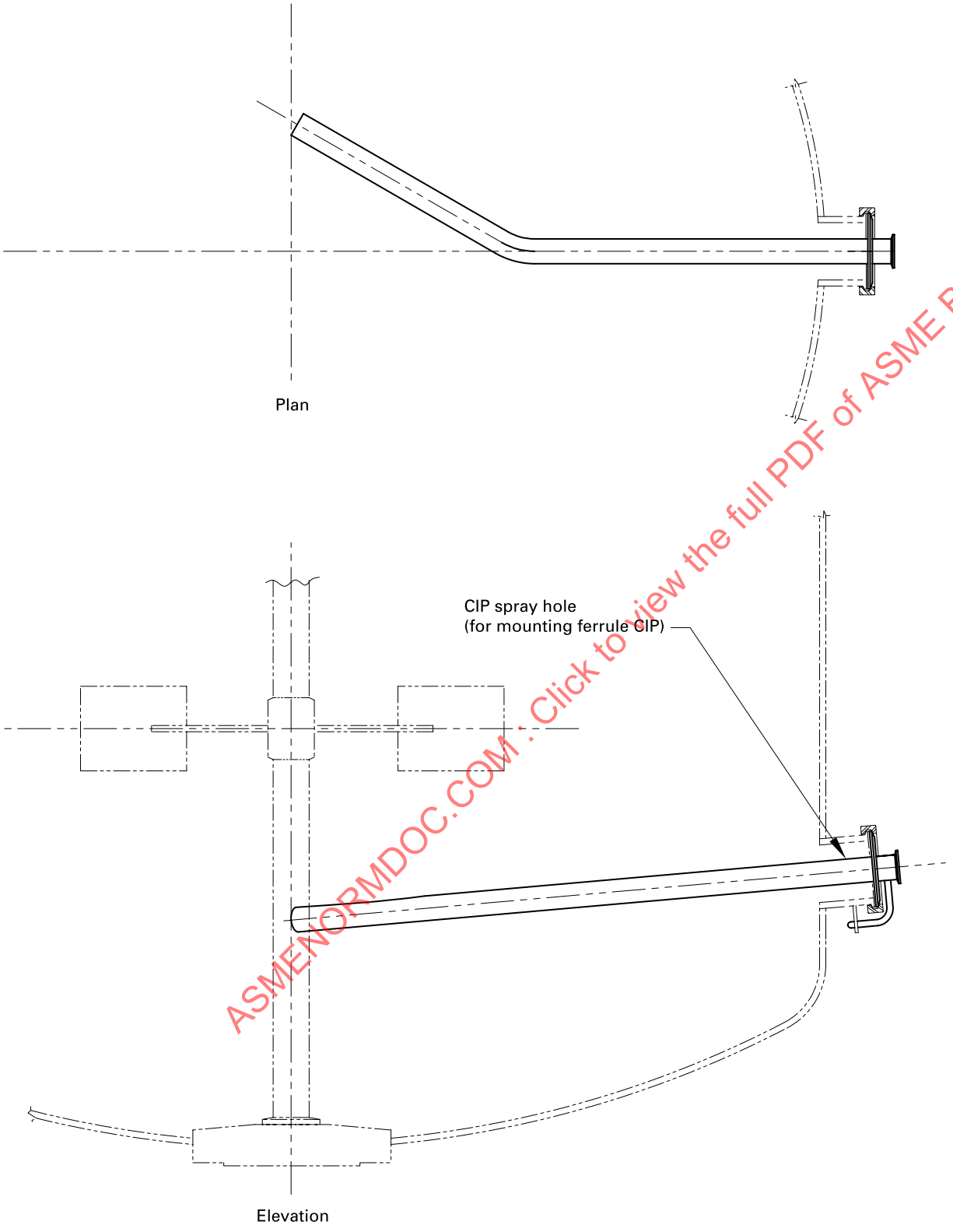


Figure SD-5.1.4.2.1-1
Exhaust Gas Condenser

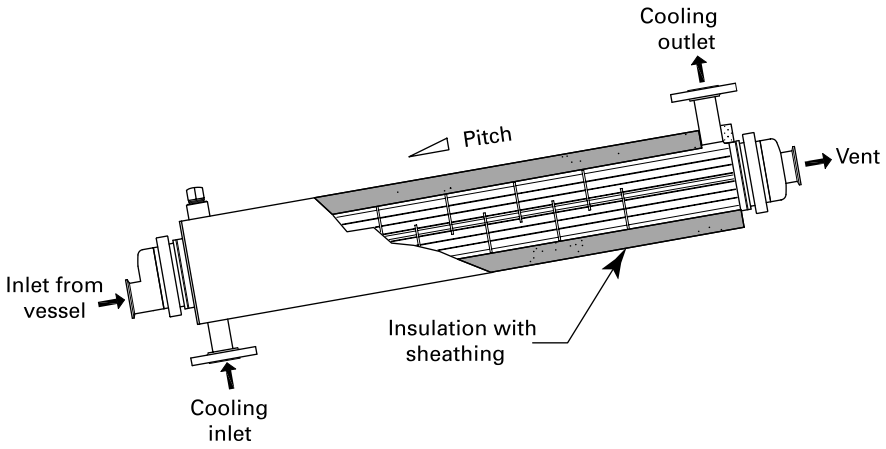


Figure SD-5.1.4.2.1-2
Exhaust Gas Heater

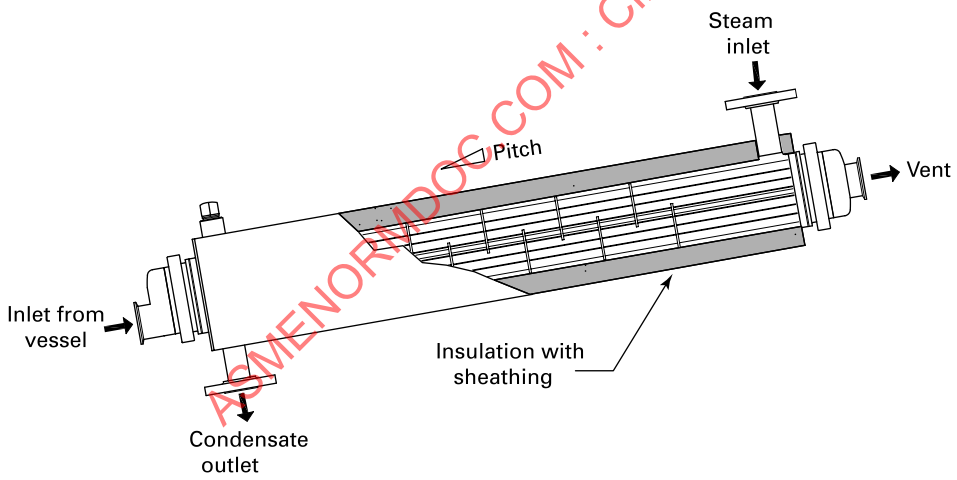
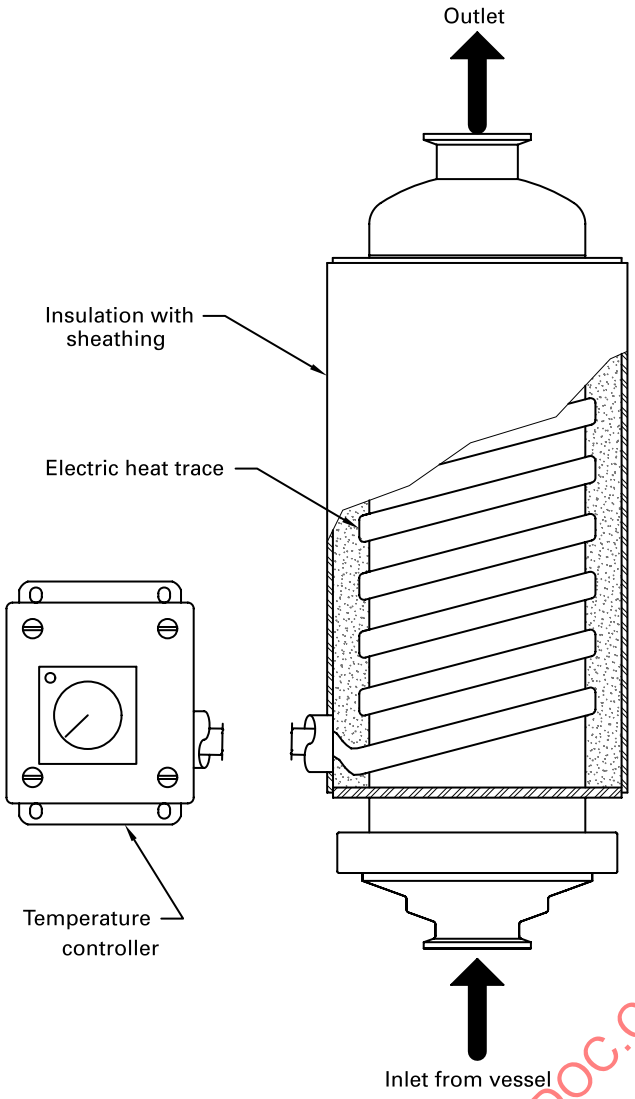


Figure SD-5.1.4.2.1-3
Electrically Heat Traced Filter Housing



SD-5.1.4.2.3 Exhaust Gas Piping

(a) The exhaust gas assembly within the sterile envelope shall meet the requirements as defined in SD-3.1.2.

(b) The design of exhaust gas piping from the bioreactor should ensure that there is no condensate accumulation in the line downstream of the system.

SD-5.1.4.2.4 Back Pressure Control Devices

(a) If required, back pressure control devices (e.g., modulating control valves or regulators) should be installed outside of the sterile boundary.

(b) Back pressure control devices shall not hinder the bioreactor's capability of being SIP'd and CIP'd.

(c) If a vapor-liquid separator is used in the exhaust within the sterile envelope, it shall be designed for CIP and SIP.

SD-5.1.4.3 Feed Lines. This section applies to bioreactor piping systems used to feed liquid ingredients (e.g., pH control reagents, antifoam reagents, media, nutrient, and inoculum). Feed lines shall be designed with the appropriate piping system to allow CIP and SIP of the bioreactor vessel and the feed line itself. CIP and SIP of the feed line may be done independently or simultaneously with the bioreactor.

SD-5.1.4.3.1 Dip Tubes. This section applies to all bioreactor port tube-extensions within the vessel.

(a) Bioreactor dip tubes shall meet the requirements of SD-3.4.2.

(b) Removable dip tubes (see Figure SD-3.4.3-1) shall be inserted through a hygienic fitting. The removable dip tube shall be supplied with the means to ensure that the installation orientation is in conformance to design intent.

(c) Bioreactor dip tubes shall be designed for CIP or cleaning out of place (COP).

SD-5.1.4.4 Harvest Valves/Bottom Outlet Valves. This section applies to all valves installed in the vessel bottom head.

(a) Harvest valves shall meet the requirements of MC-3.3.2.3.

(b) Bioreactor harvest valves shall be designed for SIP and CIP or COP.

SD-5.1.4.5 Agitation Assemblies. This section applies to mechanical agitator assemblies mounted in the bioreactor for achieving one or more mixing-related unit operations (e.g., blending, mass transfer, heat transfer, and solids suspension).

(a) Agitators shall meet the requirements of SD-3.5.

(b) Agitators with dual mechanical seals (see Figure MC-2.3.2.3-2) or magnetic couplings (see Figure SD-3.5.5-2) are recommended to isolate bioreactor contents from the environment.

(c) Agitator seal or magnetic coupling components shall be designed for CIP and SIP.

SD-5.1.4.6 Mechanical Foam Breaker Assemblies. This section applies to mechanical foam breaker assemblies that may be mounted in the bioreactor for reducing or eliminating foam accumulation in the vapor space of the bioreactor.

(a) Foam breaker assemblies shall meet the requirements of SD-3.5.

(b) Foam breakers with either dual mechanical seals (see Figure MC-2.3.2.3-2) or magnetic couplings (see Figure SD-3.5.5-2) are recommended to isolate bioreactor contents from the environment.

(c) Foam breaker seal or magnetic coupling components shall be designed for either CIP or for both CIP and SIP as appropriate.

SD-5.1.4.7 Internal Coils

(a) Internal coils should be avoided where possible.

(b) Product contact surfaces of internal coils require provisions for CIP and SIP.

SD-5.1.4.8 Baffles. Baffle assemblies shall meet the requirements of SD-3.4.

SD-5.1.4.9 Spray Devices. This section applies to sprayballs, wands, and other devices (see Figure SD-3.9.2.1-1) that may be mounted in the bioreactor vessel for distributing cleaning solution during CIP operations.

(a) Spray device assemblies shall meet the requirements of SD-3.4.2 and SD-3.9.

(b) If not removed during processing, spray device assemblies shall be designed for SIP.

SD-5.1.4.10 Instrumentation

(a) Instruments installed within the sterile envelope or boundary shall be designed for SIP. Consideration should be made in the design for instrument removal for calibration.

(b) Instruments installed within the sterile envelope or boundary shall be designed for CIP or removed for COP.

(c) Temperature-sensing elements should be installed in thermowells. Piping associated with in-line thermowells shall be sized to allow sufficient steam and condensate flow.

SD-5.1.4.11 Cell Retention Devices (Perfusion Bioreactors/Fermenters). [Reserved for future content]

SD-5.1.5 Design for Bioburden Control

(a) The area within the bioreactor sterile envelope or boundary shall be designed for cleanability and bioburden control. As a minimum, the bioreactor sterile envelope or boundary shall include the following (see Figures SD-5.1.5-1 and SD-5.1.5-2):

(1) vessel internals

(2) inlet gas piping from the filter element(s) to the vessel and any installed isolation valving (If redundant sterilizing-grade filters are used in series, the inlet filter element farthest from the reactor vessel shall define the sterile boundary.)

(3) exhaust gas piping from the vessel side of the exhaust filter(s) to the vessel and any installed isolation valving (If redundant sterilizing-grade filters are used in series, the exhaust filter farthest from the reactor vessel shall define the sterile boundary.)

(4) agitation assembly including all internal surfaces of the impellers and the shaft up to the mechanical shaft seal in contact with the product

(5) feed systems from the vessel to the seat of the isolation valve nearest to the bioreactor vessel or if the feed stream is being filter sterilized, the sterilizing-grade filter element

(6) sampling system

(7) product harvesting system from the vessel to the seat of the isolation valve nearest to the bioreactor vessel

(b) A bioreactor is made up of a number of subassemblies. Process-contacting subassemblies require special design consideration for cleaning and bioburden control.

(c) The bioreactor design for cleanability and sterility shall take into consideration the biosafety level requirement for the system. A bioreactor shall be designed in accordance with a biosafety level requirement as defined by the National Institutes of Health or equivalent organization (e.g., BSL-1, BSL-2, BSL-3, or BSL-4). The biosafety level requirement should be determined based on the organism, the process, the product being produced, and the owner/user's preferences. To meet a specific biosafety level requirement, special operational considerations (e.g., steam blocks) may have to be addressed within the bioreactors' subassembly designs. If the bioreactor has been used to grow an organism that requires biohazard containment, provision shall be made to decontaminate all surfaces that may have come in contact with the product prior to CIP, or to contain and decontaminate the fluids used for CIP.

SD-5.1.5.1 Drainability

(a) Inlet gas piping within the sterile envelope shall meet slope requirements as defined for GSD3 in Table SD-2.4.3.1-1.

(b) Exhaust gas piping within the sterile envelope shall meet slope requirements as defined for GSD3 in Table SD-2.4.3.1-1.

(c) All wetted surfaces of sparge devices shall be sloped into the vessel for drainability.

(d) Feed line valves and piping orientation shall be designed for drainability during CIP and SIP.

(e) All wetted surfaces of dip tube(s) shall be sloped into the vessel for drainability.

(f) Bottom outlet valves shall be designed, sized, and installed to be drainable and to enable draining of the bioreactor contents for all operations.

(g) Bottom-mounted agitators shall not interfere with the draining of bioreactor contents.

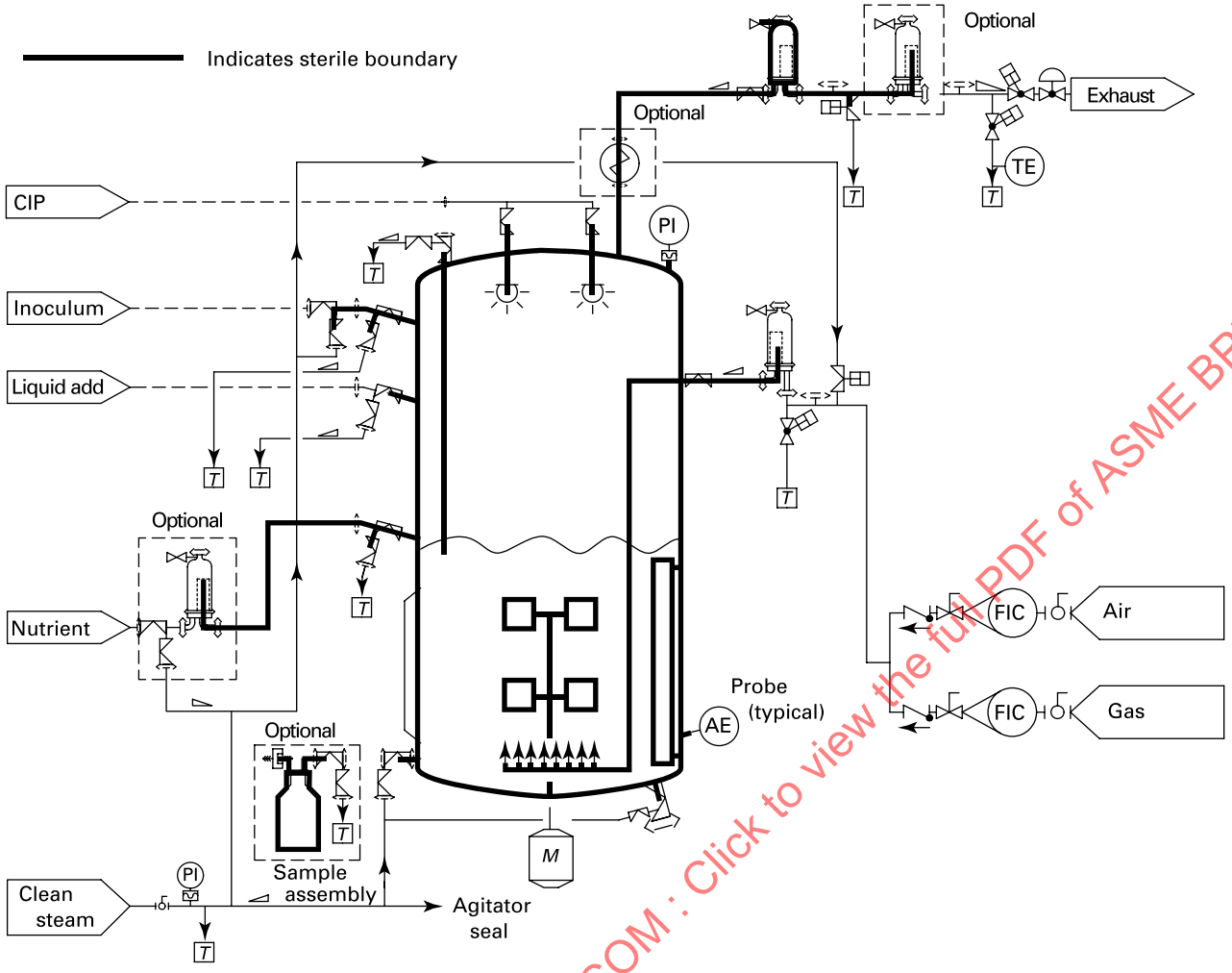
SD-5.1.5.2 Cleaning

(a) The area within the sterile envelope should be designed for CIP. For components that cannot be CIP'd, the design shall allow removal for replacement or manual cleaning out of place.

(b) If instruments will be cleaned out of place, blind caps or plugs should be provided to maintain the integrity of the bioreactor system.

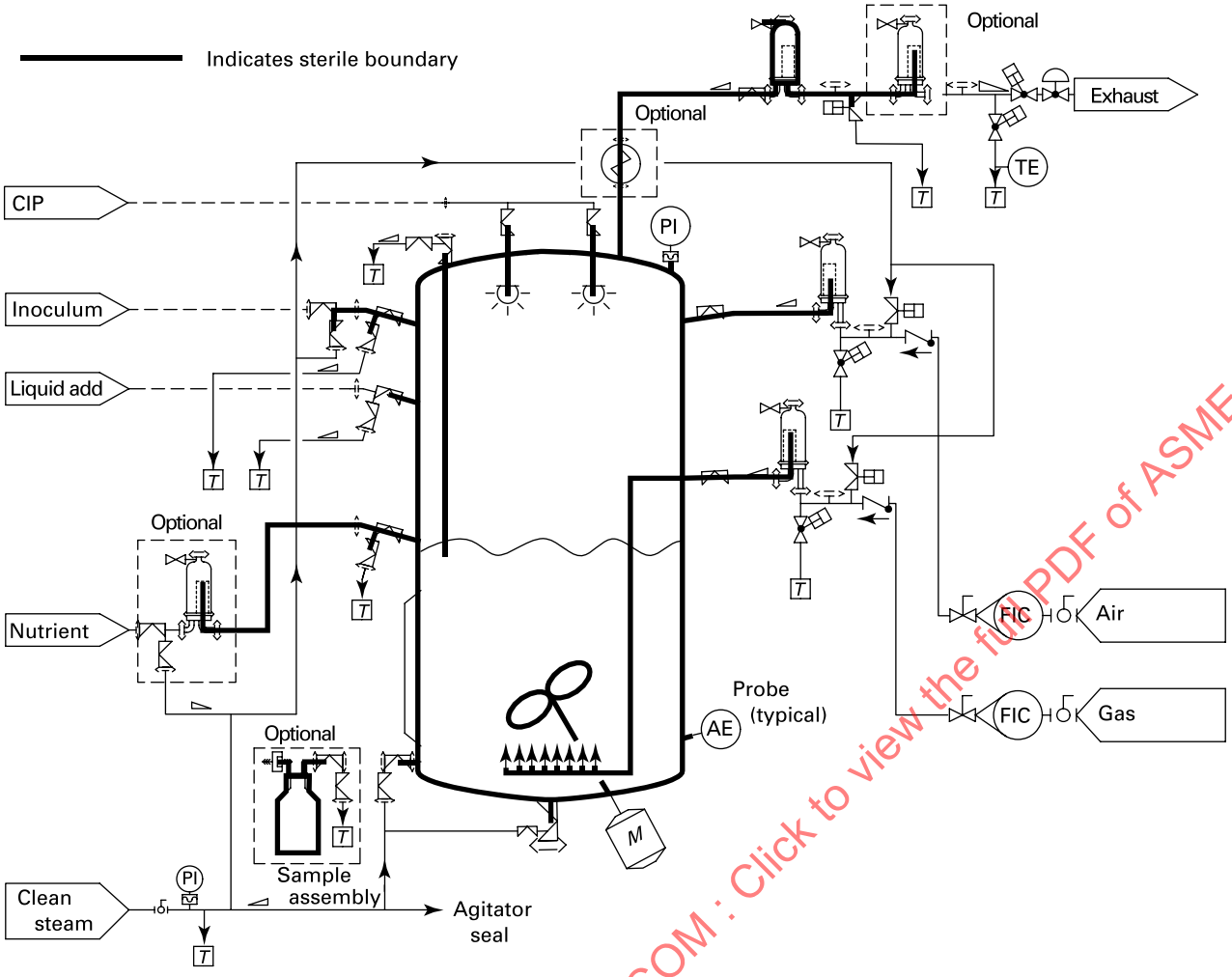
(c) If CIP of the ingredient feed system is performed during active culture operations, then the design should include provisions to prevent cross-contamination between CIP solutions and product.

Figure SD-5.1.5-1
Fermentor Sterile Envelope



GENERAL NOTE: Design may vary.

Figure SD-5.1.5-2
Bioreactor Sterile Envelope



GENERAL NOTE: Design may vary.

(d) If one or more dip tubes are cleaned in place with the vessel, both the inside and outside of the dip tubes shall be cleaned.

(e) Provisions shall be included in the design to clean the product contact surfaces of impellers. Additional spray elements may be required to achieve coverage.

(f) CIP for sparge devices that use porous material for gas distribution requires particular attention. These devices should be evaluated for CIP cleanability and should be removed from the bioreactor for external cleaning or replacement when CIP is not feasible.

SD-5.1.5.4 Thermal Sanitization/Sterilization

(a) The area within the sterile envelope should be designed for SIP. For those components or assemblies that cannot be SIP'd, the design shall allow removal for steam sterilization using an autoclave as long as additional provisions are provided for sterilizing the interface (e.g., steam block) once the components or assemblies are reconnected to the remainder of the bioreactor system. Autoclaved components or assemblies shall be capable of being steam sterilized without degradation to any of the elastomers or polymers that make up the components or assemblies.

(b) If the bioreactor is sterilized with media in the vessel, the SIP operation shall direct steam flow through the sparge device.

(c) If the bioreactor is sterilized with media in the vessel, and one or more dip tubes extend below the working level of the media, the SIP operation shall direct steam flow through the dip tube into the vessel.

(d) For dip tube(s), the SIP operation shall direct or balance steam distribution to establish and maintain sterilization temperature within the tube(s) during the sterilization hold period.

(e) Special considerations for spray devices are as follows:

(1) The SIP operation shall direct or balance steam distribution to establish and maintain sterilization temperature within the spray device during the sterilization hold period.

(2) With the exception of a combination sparger/spray device, internal spray devices should be located above the bioreactor operating liquid level.

(3) If the bioreactor is sterilized with media in the vessel, and the spray device assembly extends or is located beneath the working level of the media, the SIP operation shall direct steam flow through the device into the vessel.

(f) For systems with a dual mechanical agitator seal, the following requirements apply:

(1) The mechanical seal and the barrier fluid system, bounded by the nearest upstream valve(s) or filter(s) and the downstream outlet port(s) on the seal, shall be SIP'd.

(2) The design shall prevent the differential pressure between the vessel and the barrier fluid system from exceeding the manufacturer's recommendations. The barrier fluid system should indicate if operating conditions fall outside the design range.

(3) During post-SIP cooldown, the design shall prevent vacuum in the barrier fluid system.

SD-5.1.7 Testing. The bioreactor vessel should be pressure/vacuum and temperature rated per the owner/user's design criteria. The vessel shall be constructed, tested, inspected, and stamped in accordance with local ordinances, regulations, and codes.

SD-5.2 Cell Disruptors

SD-5.2.1 General. Homogenizers and high-shear fluid processors disrupt cells by sudden cavitation, high shear, or impingement of a highly pressurized process fluid.

Homogenizer systems consist of a variable-speed positive displacement pump and an adjustable orifice. The system may also include a feed pump and a cooling heat exchanger.

High-shear fluid processors are a variation of the homogenizer operating at higher pressure ranges. High-shear fluid processors include a fixed-speed positive displacement pump and a fixed orifice.

See Figure SD-5.2.1-1 for a typical cell disruptor process flow schematic diagram.

SD-5.2.2 System Performance Requirements. The following system performance requirements and operating parameters shall be defined:

(a) process fluid properties (e.g., cell mass concentration, shear sensitivity, density, viscosity)

(b) operating pressure range

(c) process fluid flow rate

(d) process temperature range

(e) required cell disruption efficiency

SD-5.2.3 System Design. The manufacturer shall disclose when ASME BPE nonconforming materials, connections, or seals are required for product contact areas in high-pressure applications.

SD-5.2.3.1 Inlet

(a) Continuous flow and pressure shall be present to prevent damage to the cell disruptor. Pulsations or fluctuations of the process flow should be minimized.

(b) The system should be capable of priming/purging air from the system during start-up.

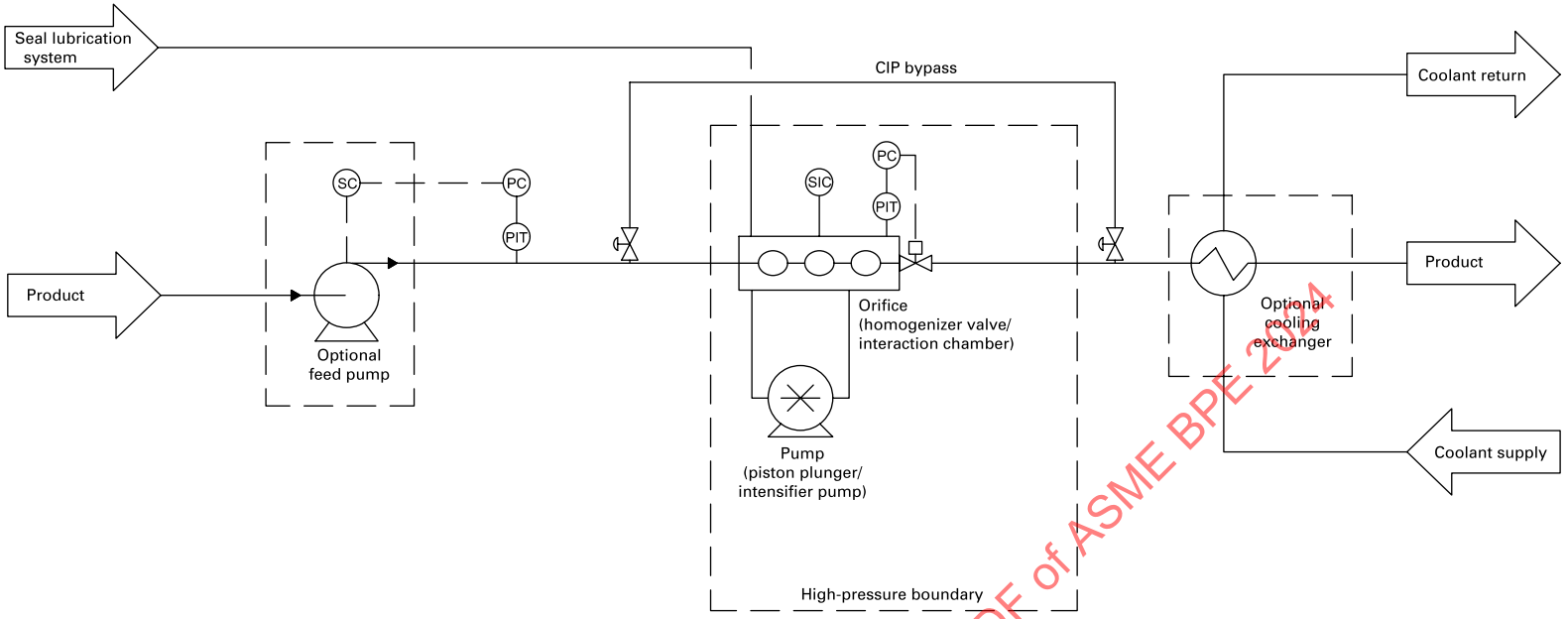
(c) The system should be capable of maintaining an environment free of air entrainment during operation.

SD-5.2.3.2 Pump and Orifice

(a) The manufacturer shall disclose if seal materials in contact with process fluids do not meet the requirements of SD-2.4.1.1 (e.g., USP Section <88> Class VI).

(b) When high containment is specified, the cell disruptor shall be designed as a closed system (e.g., homogenizer with double packed cylinder seal design,

Figure SD-5.2.1-1
Cell Disruptor Process Flow Schematic Diagram



GENERAL NOTES:
(a) Only major piping and instruments are shown.
(b) Additional or alternative piping, valves, instruments, and equipment may be required for the following purposes:
(1) pressure safety
(2) CIP requirements
(3) SIP requirements
(4) multiple-stage/pass unit

containment of seal quench fluid, containment of components with the isolator).

SD-5.2.3.3 Outlet. If required by the process, the system shall be designed to remove heat generated by the cell disruptor.

SD-5.2.3.4 Instrumentation. The system should be designed to enable high-pressure seal integrity monitoring (e.g., viewing through a sight glass, conductivity monitoring, or turbidity monitoring).

SD-5.2.4 Design for Bioburden Control. The bioburden control strategies (e.g., CIP, COP, water rinses, SIP, hot or superheated water sanitization, chemical sanitization) for product contact surfaces shall be defined by the owner/user. The preferred mode of equipment storage (e.g., flooded or dry) shall be defined.

SD-5.2.4.1 Drainability. The design shall accommodate forced expulsion for the removal of liquid when the system is specified to be stored dry.

SD-5.2.4.2 Cleaning

(a) The following are recommendations for cell disruptors designed for CIP:

(1) The manufacturer should recommend CIP flow rate and pressure.

(2) The equipment should be designed to enable cleaning verification/validation of all process contact surfaces.

(3) CIP bypasses should be provided parallel to flow restrictions for hydraulic balancing. Means of flow verification should be provided for cleaning circuits that employ parallel cleaning paths.

(4) The cell disruptor should be operated during cleaning, typically at the highest flow rate available.

(5) If present, seal lubrication systems should be designed to be cleaned or flushed.

(b) Portions of cell disruptors that are not designed for CIP shall be identified. Those identified portions shall be designed for disassembly and reassembly for COP and examination.

SD-5.2.4.3 Chemical Sanitization

(a) Where chemical sanitization is specified, the components within the sanitization boundary shall be designed for exposure to and removal of sanitizing agent while maintaining the sanitized state.

(b) The manufacturer should recommend the chemical sanitization flow rate and pressure.

SD-5.2.4.4 Thermal Sanitization. Where thermal sanitization is specified, the surfaces within the sanitization boundary shall be designed for SIP or hot liquid sanitization.

SD-5.2.5 Design for Serviceability, Examination, and Operation. The high-pressure zone shall be capable of disassembly for periodic cleaning and inspection.

SD-5.3 Centrifuges

SD-5.3.1 General. Centrifugation is a process used to separate suspended materials of different densities using centrifugal force. Centrifuges may be used for collection of solids such as harvest of cells or inclusion bodies of precipitated protein, or for clarification of bioprocess solutions. Different types of centrifuges include disk stack centrifuges, tubular bowl centrifuges, single-use centrifuges, and ultracentrifuges.

In bioprocessing, the centrifuge is typically used to separate cells from cell broth or cell debris or precipitates from liquid, or to recover inclusion bodies after homogenization of microbial cells.

SD-5.3.1.1 Disk Stack Centrifuge. A disk stack centrifuge consists of a cylindrical bowl containing a stack of conical disks separated by spacers, which reduce the distance and increase the surface area for particulate settling when under centrifugal force.

SD-5.3.2 System Performance Requirements. The following system performance capabilities should be defined at the beginning of design:

(a) whether the centrifuge is intended for open, closed, or briefly exposed operations

(b) product to be separated

(1) solid concentration [e.g., packed cell volume (PCV)]

(2) solids cell type or particle size and distribution

(3) recovered product phase: supernatant, solids, or both

(4) density difference between solvent and suspended solids, if available

(5) viscosity and surface tension of liquid, if available

(6) product shear sensitivity

(c) multipurpose or dedicated to a single product

(d) batch or continuous operation

(e) batch size

(f) process liquid feed flow rate

(g) process temperature

(h) description of owner/user's processes immediately upstream and downstream of the centrifuge

(i) requirements for processing volatile flammable materials

SD-5.3.2.1 Process Parameters. The following additional process parameters required to confirm system capabilities should be defined:

(a) cleaning requirements (e.g., CIP or manual cleaning)

(b) sanitization requirements (e.g., SIP)

(c) maximum allowable processing and cleaning/sanitization times

(d) requirements associated with the biosafety level and room classification of the process and system

(e) required feed and discharge pressure

(f) purity criteria (e.g., solids in supernatant, turbidity, yield, based on prior product tests or experience)

SD-5.3.3 Operating Capabilities and System Function. The system should be designed with an alternative liquid feed source (e.g., purified water, buffer) for priming of the centrifuge.

SD-5.3.4 System Design

SD-5.3.4.1 Feed. For intermittent discharge systems, the centrifuge system shall control and monitor the feed flow rate and pressure.

SD-5.3.4.2 Bowl

(a) If a cyclone is present in intermittent solids-discharging centrifuges, it shall be capable of containing and decelerating the discharged bowl contents. The cyclone should be cleanable.

(b) Nozzles at the periphery, top, or bottom of the bowl in continuous solids-discharging centrifuges should allow for continuous discharge of settled contents.

(c) Process compatibility, cleaning, and sanitization requirements shall be considered when selecting materials. Components in the centrifuge that are subject to high dynamic stresses (e.g., peripheral rotating components) may require high strength materials.

SD-5.3.4.3 Disk Stack

(a) Disks shall be removable for visual inspection.

(b) Disk Spacing

(1) Spacers between disks should be drainable.

(2) Spacers should not interfere with system cleanability.

(c) The disk stack shall be designed with a material that can withstand the mechanical stresses that the centrifuge will undergo during operation.

SD-5.3.4.4 Instrumentation

(a) Instrumentation should be installed to detect a failure in the bowl discharge or flooding of the cyclone, if present.

(b) Centrifuge instrumentation shall monitor abnormal machine vibrations that may result in a safety hazard and unit failure.

(c) The system should be capable of regulating bowl speed to control the centrifugal forces that separate the product.

(d) The quality of the supernatant should be monitored through a sight glass or instrument such as a turbidity meter.

SD-5.3.4.4.1 Supernatant Outlet Pressure Control Valve. The supernatant outlet on centrifuges that are not hermetically sealed should have a pressure control valve to keep the bowl flooded.

SD-5.3.4.5 Compendial Water Separation. The compendial water system shall be isolated from potential process contamination (e.g., by use of a break tank or double block and bleed valve).

SD-5.3.4.6 Interfaces. [Reserved for future content]

SD-5.3.5 Design for Bioburden Control. The bioburden control strategies (e.g., CIP, SIP, chemical sanitization) and associated conditions (e.g., temperature, pressure, chemistry) for product contact surfaces shall be defined.

SD-5.3.5.1 Drainability. Centrifuges that are not designed to be drainable may require additional means for liquid removal (e.g., air blow). The centrifuge shall be designed to facilitate liquid removal under dynamic bowl conditions.

The solids catcher inside the centrifuge and the solids discharge connection to the cyclone are typically horizontal. Provisions for liquid removal from these surfaces shall be provided in accordance with SD-2.4.3.1.

SD-5.3.5.2 Cleaning

SD-5.3.5.2.1 Disk Stack Centrifuges. Disk stack centrifuges should be designed for CIP. Additional requirements for disk stack centrifuges subject to CIP include the following:

(a) Product contact surfaces (e.g., bowl, hood, solids catcher, cyclone) shall be compatible with the cleaning solutions.

(b) Sampling points for representative cleaning verification/validation of product contact surfaces shall be defined.

(c) The manufacturer should recommend the CIP supply flow rates, pressures, and cleaning step times required to clean the centrifuge.

(d) The recovery, sampling, or monitoring of the various cleaning streams shall be defined.

SD-5.3.5.2.2 Other Centrifuges

(a) Centrifuges that are not designed for CIP shall be capable of disassembly and reassembly for cleaning and examination.

(b) Areas of primary and incidental product contact that require manual cleaning or cleaning out of place (COP) in addition to CIP shall be defined.

SD-5.3.5.3 Chemical Sanitization/Sterilization. [Reserved for future content]

SD-5.3.5.4 Thermal Sanitization/Sterilization. Centrifuges subject to SIP shall be designed in accordance with SD-2.3.1.1 and, in certain jurisdictions, may be

considered pressure vessels (see GR-1). Saturated steam penetration across components that define the SIP boundary of the system shall be demonstrated.

(24) **SD-5.3.5.5 Post-Use Storage.** Multiuse centrifuges shall be cleaned and sanitized for storage (e.g., by CIP, COP, SIP).

Centrifuges shall be stored under the condition (e.g., flooded or dry) specified for bioburden control. Systems that are to be stored dry shall have design features (e.g., blowdown, venting) that maintain the bacteriostatic state.

When used in aseptic applications, centrifuges should be stored under positive pressure post-sterilization.

SD-5.3.6 Design for Serviceability, Examination, and Operation. [Reserved for future content]

SD-5.3.7 Testing. [Reserved for future content]

SD-5.4 Filtration

SD-5.4.1 General. Filtration systems are used for the purposes of product purification, product concentration, and reduction of bioburden. Filtration systems include the filter elements (see Part PM) and filter housings/holders, and may include pumps, vessels, piping, tubing, fittings, valves, and instrumentation.

The following sections describe the general design requirements for the operation, cleaning, and sanitization of a multiuse filtration system.

SD-5.4.2 System Performance Requirements. The conditions and performance parameters under which the system will operate shall be defined. Typical items to consider include the following:

(a) type and mode of filtration
(b) inlet/outlet streams
(1) inlet and outlet physical and chemical properties
(2) flow rates required
(3) pressure conditions
(4) number of feed and outlet streams
(5) recirculation streams for tangential flow filtration (TFF) systems
(c) operation
(1) in-line dilution or formulation
(2) diafiltration
(3) measurement of fluid characteristics
(4) control strategy [e.g., for TFF – transmembrane pressure (TMP) control, permeate flux control, permeate pressure control, retentate flow control]
(5) percent volume reduction and final volume
(d) filtration element
(1) preparation for operation
(2) expected pressure drop at the indicated flow rates
(e) system
(1) the fluids to which the system may be exposed
(2) acceptable holdup volumes
(3) temperature of operating area and process fluids
(4) room classification
(f) automation
(1) control system requirements
(2) sensors and monitors for detection of system performance
(g) cleaning and sanitization requirements, including the following:
(1) methods
(2) frequency
(3) duration

SD-5.4.3 Operating Capabilities and System Function. Filtration systems shall be designed to control and monitor filtrate (or tangential and permeate flow) according to process requirements. Multiuse systems shall be designed to allow for process cleaning and sanitization.

SD-5.4.4 System Design. The system should be designed to promote recovery of product (e.g., drainable branches and path-by-path air blows to recover product retained in lines and filter elements) and meet cleaning and sanitization requirements. The system should be designed to mitigate the risk of crossover of feed solutions, which could contaminate the process.

Filtration system designs should conform to SD-3.1. Where multiuse systems are not drainable, see SD-2.4.3.

When required by system function, components present in direct flow and tangential flow filtration systems shall include the following:

(a) feed and filtrate for direct flow; permeate and retentate for tangential flow
(b) valves
(c) pumps
(d) vessels (feed and filtrate collection)
(e) instruments (process monitoring and control)
(f) one or more filtration elements and element holders

The system design should mitigate the risk of leakage and carryover of residual solutions to subsequent steps.

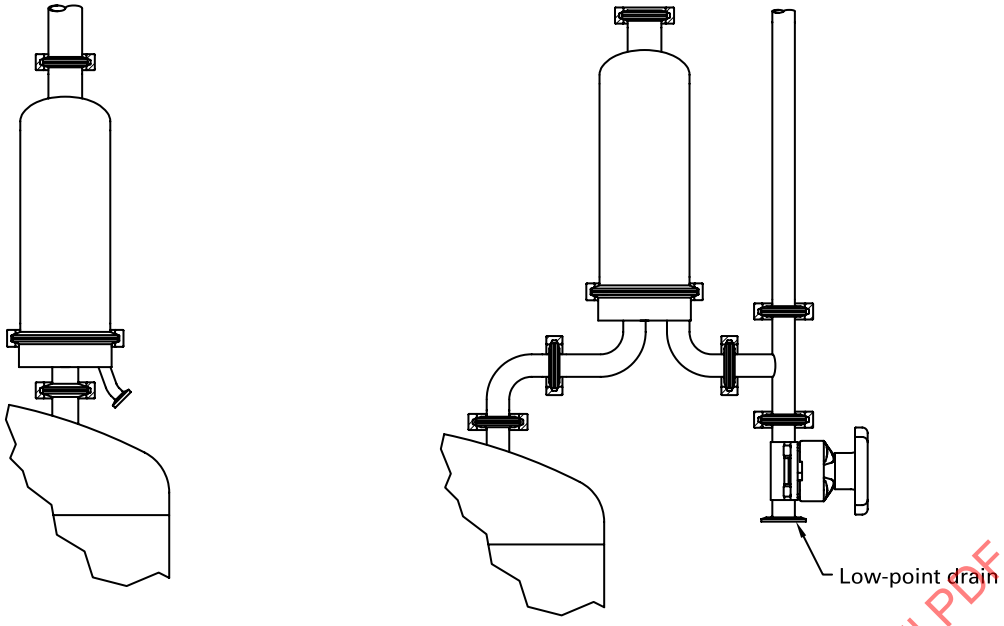
SD-5.4.4.1 Materials. The process contact materials shall be compatible with process fluids, including those used for cleaning and sanitization.

SD-5.4.4.2 Pumps. Pumps designed for both process and CIP shall meet the required duty points (i.e., flow rate and pressure) for each operation.

SD-5.4.4.3 Instruments for Feedback Control of Process Liquids. When multiple liquids are combined, the flow rate of the feed solutions (and retentate for tangential flow systems) to the filter element should be monitored.

SD-5.4.4.4 Multiple Connections. Where required, the system shall be designed to enable isolation of the filter at its connection points (e.g., for removal of the filter, to shut off permeate, or to bypass the filter

Figure SD-5.4.5.1-1
Tank/Vessel Vent Fillers



(a) In-Line Design
(Accepted)

(b) T-Type Design
(Accepted)

element) or to control the direction of flow through the filter (e.g., top to bottom versus bottom to top).

SD-5.4.4.5 Air Entrapment. The system should be designed to minimize the introduction into and accumulation of air in the filter housings. The system shall be designed to relieve trapped gases from the filter housings. Sight glasses or instrumentation should be installed when required to facilitate air detection.

SD-5.4.4.6 Filter Element Housing Design

(a) Parts forming internal crevices should be easily disassembled to enable access for cleaning.

(b) All wetted surfaces should be accessible for cleaning and examination.

(c) All nozzle connections shall be of a hygienic design.

(d) Baffle plates, when used, should be cleanable and designed for SIP.

(e) The housing assembly, end plates, and connections should be designed to prevent bypassing of process fluid around the element.

(f) Vent filters for hot liquid processes should be heat traced or steam jacketed. Other methods for preventing excessive moisture accumulation in vent filters, such as oversizing filters, vent heaters, or condensers, may be considered.

SD-5.4.5 Design for Bioburden Reduction. This section covers drainability, cleaning, and chemical and thermal sanitization/sterilization for the purpose of bioburden reduction.

SD-5.4.5.1 Drainability. Filtration systems should be designed to minimize holdup volume. Piping systems and components of filtration systems that are designed to be drainable shall be sloped to enable draining. Drain valves shall be installed at low points. Where liquid removal is required but drainability is not possible or practical, a method of forced expulsion of liquids (e.g., by air) shall be provided. Drain points shall not create dead legs. A common drain port on the skid is preferred.

Direct flow filtration housings shall include a low port drain to facilitate cleaning and removal of liquid from the system as well as filtration element changeouts. Liquid tee-style filter housings should be installed vertically for drainability. In-line vent filter housings subject to SIP should be installed vertically with the condensate/drain port directed downward (see Figure SD-5.4.5.1-1).

Tangential flow cartridge housings subject to CIP or SIP shall be designed with connections and covers that will allow the unit to drain.

SD-5.4.5.2 Cleaning. Where direct flow filtration housings are CIP'd, provision for draining or forced expulsion of liquid shall be included to facilitate cleaning of the

system. Cleaning of filtration systems is achieved using the CIP TACT principles (see SD-6.3.1).

Direct flow filtration elements are typically not reused and are not installed during the cleaning process.

Tangential flow filtration elements may be designed for multiuse and cleaned along with the system. When multiuse elements are CIP'd, the system shall be designed to be hydraulically balanced to ensure suitable conditions (e.g., flow rates) to properly clean the filtration elements.

SD-5.4.5.3 Chemical Sanitization/Sterilization. Process contact components within the system shall be exposed to the chemical solution for a specified duration. The components shall be compatible with the sanitization agents and conditions selected.

If a system subject to chemical sanitization/sterilization includes elements not compatible with the chemical conditions required, those elements shall be isolated or removed during the cleaning process without compromising the system integrity.

SD-5.4.5.4 Thermal Sanitization/Sterilization. Systems shall be compatible with the thermal conditions to which the system will be exposed.

If a system subject to SIP includes elements not compatible with the thermal conditions required, those elements shall be isolated or removed during SIP without compromising the system integrity.

SD-5.4.6 Design for Serviceability and Inspection. Multiuse systems shall be designed to facilitate service and inspection including removal and replacement of the filter elements.

SD-5.4.7 Testing. Selection of filtration integrity and performance test methods should be based on evaluation of process risks.

When the filter is used as a sterilizing or viral removal filter, provisions for integrity testing should be provided.

Acceptable test methods include the following:

(a) pressure hold test to identify system leaks for direct and tangential flow systems

(b) transmembrane test to confirm absence of membrane fouling in tangential flow filtration systems

(c) salt rejection testing to confirm system integrity in reverse osmosis applications

(d) bubble point or forward flow diffusion tests in sterilizing-grade direct flow filtration systems used to verify bioburden control

(e) particle tests in viral filter systems employed to confirm specific viral removal

SD-5.5 Chromatography Systems

SD-5.5.1 General. Chromatography systems are used for product purification, concentration, and viral load reduction. Chromatography systems include pumps, piping, valves, instrumentation, and a stationary medium that is contained in a column, cartridge, or capsule. The stationary medium/phase may be a membrane adsorber or resin.

The chromatography system shall not contribute to the contamination of the product. This section describes operational, cleaning, and sanitization requirements of multiuse chromatography systems. This section does not address the requirements of systems intended for single-use. Chromatography systems used for analytical testing are not included in the scope of this section.

For the purposes of this section, "column" shall refer to any component (e.g., column, cartridge, capsule, membrane adsorber) housing the stationary medium.

A chromatography system may also include provisions for

(a) assisting with the packing of a column with the stationary phase

(b) evaluating the performance of a packed column

(c) performing in-line dilution and in-line formulation operations

For the purposes of this section, "gradient operation" refers to flow rates of two or more liquids to be adjusted such that the physical and chemical characteristics of the resulting chromatography feed solution change over time.

SD-5.5.2 System Performance Requirements. The following operating conditions and performance parameters shall be specified to ensure proper design and function of a chromatography system: (24)

(a) mode of operation (e.g., isocratic versus gradient, inline dilution or inline formulation)

(b) inlet and outlet streams

(1) physical and chemical properties of feeds and effluents

(2) flow rate range

(3) pressure conditions

(4) number of feed and outlet streams

(5) direction of flow

(c) operation

(1) measurement of fluid characteristics

(2) control strategy (e.g., gradients, product collection, flow rate control, inline dilution and formulation)

(d) chromatography column

(1) preparation for operation

(2) expected pressure drop at the indicated flow rates

(e) system

(1) control of axial dispersion

(2) acceptable holdup volumes

(3) temperature of operating area and process fluids

(4) room classification

(f) instrumentation and controls

(1) control system requirements

(2) sensors and monitors for detection of system performance

(g) cleaning and sanitization requirements

(1) methods

(2) frequency

(3) duration

SD-5.5.3 Operating Capabilities and System Function. The chromatography system shall be capable of delivering a consistent flow of liquids through the stationary phase and mitigating the risk of introducing gas onto the column. Multiuse systems shall be designed to be cleaned and sanitized. If columns are stored packed with stationary phase, the systems shall be capable of maintaining a flooded bacteriostatic condition.

When gradient chromatography operations are required, gradient accuracy capability shall be defined. The chromatography system should be designed to provide an elution buffer flow path that minimizes axial dispersion.

(24) **SD-5.5.4 System Design.** Chromatography systems may include the following components, as required by system function:

(a) product feed, buffer feeds, eluate, and waste connections
(b) valves
(c) pumps
(d) filters
(e) vessels (feeds, eluate, and other collection)
(f) instruments (process monitoring and control)
(g) one or more chromatography columns
(h) air trap

The system should prevent leakage and minimize carryover of residual product, cleaning solution, and buffer solution to subsequent steps.

SD-5.5.4.1 Flow Control. A pump, a control valve, or both shall be provided to control the process stream flow rate. The system should control the flow rate to the required set point at the expected operating pressure. The equipment should be selected so the turndown range meets process requirements including holding pulsation to within an acceptable limit when applicable.

If the chromatography system has integral pumps, they shall be selected to support CIP flow requirements.

SD-5.5.4.2 Mobile Phase Composition. When multiple liquid streams are blended into a feed solution, properties that confirm the composition should be monitored.

SD-5.5.4.3 Air Entrapment. The system should be designed to prevent the introduction of air into the chromatography column or columns. The use of air traps upstream of the columns is acceptable.

SD-5.5.4.4 Instruments for Column Effluent Analysis. Instrumentation shall be provided to monitor properties of the column effluent. The properties monitored should be chosen to enable the system to monitor and control the performance of the chromatography process.

SD-5.5.4.5 Chromatography System Outlet. The system shall control the eluate flow path. The product outlet shall interface with downstream collection vessels or other unit operations and shall be of hygienic design.

SD-5.5.4.6 Additional System Components and Equipment. A chromatography process may require inclusion of additional components. Typical components often include the following:

(a) a static or dynamic mixer to ensure homogeneity of the system feeds
(b) one or more filter assemblies to allow liquid components to be filtered prior to entering the column
(c) a heat exchanger to regulate the temperature of the process liquids

SD-5.5.4.7 Seals. Seal design should facilitate routine and nonroutine operations (e.g., recovery from upset conditions, restarting equipment after maintenance).

SD-5.5.5 Design for Bioburden Control. This subsection provides requirements for the drainability, cleaning, and chemical and thermal sanitization or sterilization of chromatography systems for the purpose of bioburden reduction. (24)

SD-5.5.5.1 Drainability. The chromatography system should have a low-point drain to facilitate cleaning of the system and for chromatography column change-outs. Components, equipment, and systems that are not drained for storage shall be stored under bacteriostatic conditions.

Process piping systems that require draining shall be sloped to drain. Drain valves shall be installed at low points. Liquid holdup volume should be minimized in components, equipment, and piping when drained. Where liquid removal is required but draining is not possible or practical, a method of forced explusion of liquids (e.g,. by clean compressed air) shall be provided. Drain points shall not create dead legs. A common drain port on the system is preferred.

SD-5.5.5.2 Cleaning. Chromatography systems requiring nonmanual cleaning operations shall be designed for CIP using TACT criteria (see SD-6.3.1) to mitigate the risk of contamination from the environment, from product-to-product carryover, or from cross-contamination.

SD-5.5.5.3 Chemical Sanitization/Sterilization. Process contact surfaces shall be compatible with the sanitization agents selected.

SD-5.5.5.4 Thermal Sanitization/Sterilization. Where a system is designed for thermal sanitization, components that are not capable of withstanding the specific conditions shall be removed or isolated prior to the

sanitization process. Typically, chromatography columns are not designed for thermal sanitization.

(24) **SD-5.5.6 Design for Serviceability and Inspection.** Components that require service or inspection shall be accessible. When required for packing and unpacking of the resin, the system shall be designed to allow access to service the columns.

(24) **SD-5.5.7 Testing.** Pre-use integrity and performance tests are often required in a cGMP environment. Chromatography system testing should be based on evaluation of process risks and may include verification of the following:

(a) feed delivery performance (e.g., gradient, inline dilution or formulation)

(b) column packing quality

(c) system integrity

Where integrity and performance tests are required, the system shall be designed to enable performance of these tests.

SD-5.6 Lyophilizers/Freeze Dryers

SD-5.6.1 General. For the purpose of this section, the terms "lyophilizer" and "freeze dryer" may be used synonymously. This section describes the requirements for cleanability and bioburden control of lyophilizers that are used for biopharmaceutical processing. This section applies to lyophilizers in which product is loaded onto shelves. Other designs that use methods and components not described in this section should be evaluated and agreed on by the owner/user. A lyophilizer comprises a number of interconnected components. Components with process contact surfaces shall be designed for cleanability and bioburden control.

Lyophilizer surfaces of components, piping, equipment, or systems that are isolated by design from both product and process fluids are not process contact surfaces and are not required to be designed for cleanability or bioburden control. Examples of surfaces that are not process contact surfaces include the exterior surfaces of equipment, drain lines, vacuum lines, and systems containing hydronic or hydraulic fluids.

SD-5.6.2 System Performance Requirements. The following system performance requirements shall be defined:

(a) vacuum integrity requirements

(b) product capacity (vial quantity or required product shelf area)

(c) condensing capacity (liters)

(d) minimum shelf temperature

(e) shelf heating and cooling rate (clean, dry, and empty)

(f) shelf temperature uniformity requirements

(g) evacuation rate

(h) minimum vacuum level

SD-5.6.3 Operating Capabilities and System Function. The lyophilizer should be capable of the following functions:

(a) shelf and condenser temperature control

(b) vacuum pressure control

(c) condenser defrost

(d) loading and unloading (when specified)

(e) stoppering (when specified)

(f) vacuum integrity testing

(g) filter integrity testing

(h) cleaning

(i) sterilization/sanitization

SD-5.6.4 System Design. A lyophilizer is comprised of functional components/systems, as shown in Figure SD-5.6.4-1, which are designed for isolation, cleanability, and bioburden control.

All components shall be specified for the applicable pressure, vacuum, temperature range, thermal shock, and exposure to sanitizing agents [e.g., vaporized hydrogen peroxide (VHP)] when applicable.

Process contact surfaces made from nonmetallic material should conform to SD-2.4.1.1, SD-2.4.1.2, SD-2.4.1.4, and Part PM.

SD-5.6.4.1 Lyophilizer Chamber

(a) The interior surfaces of the lyophilizer chamber (chamber vessel) are considered process contact surfaces.

(b) The lyophilizer chamber includes all necessary fittings and closures (e.g., doors, bellows, isolation valves). The chamber floor shall be drainable.

(c) The surface finishes of the chamber internal surfaces (i.e., door, walls, ceiling, floor) shall be specified by the owner/user using the designations in Table SF-2.4.1-1.

(d) Where the chamber interfaces with the clean room or isolator, the surfaces shall meet the owner/user's specified requirements.

SD-5.6.4.2 Condenser Vessel

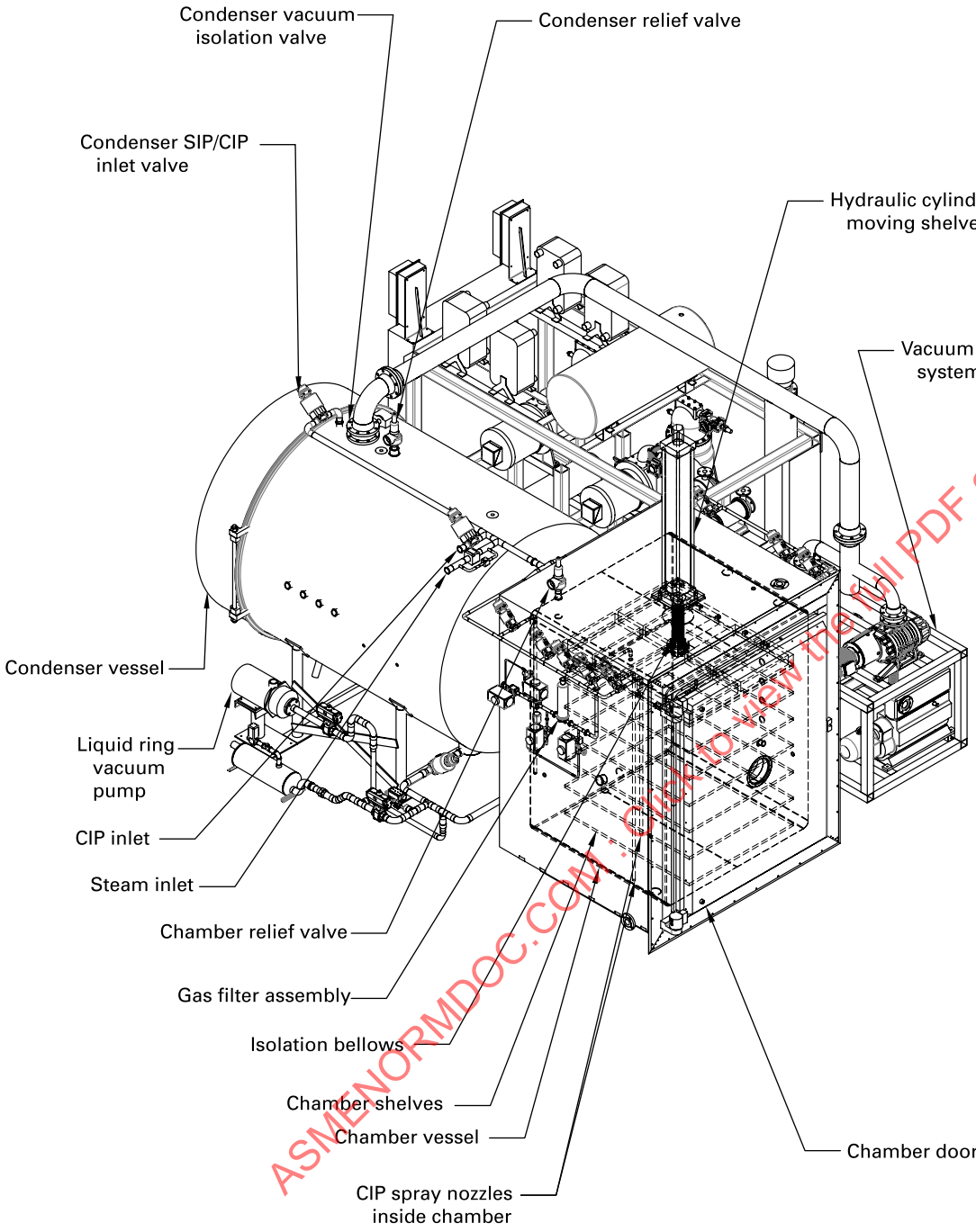
(a) The condenser vessel, used to contain the condenser heat exchanger, is connected to the chamber vessel and may be separated by a main isolation valve.

(b) All surfaces shall be drainable.

(c) In systems designed with backstreaming prevention (i.e., prevention of reverse flow from the vacuum pumps), the condenser vessel is downstream of the chamber. The condenser vessel surfaces are not process contact surfaces and do not have surface finish requirements.

(d) In systems not designed with backstreaming prevention, the condenser vessel surfaces are process contact surfaces. The surface finishes of the condenser vessel shall be specified by the owner/user using the designations in Table SF-2.4.1-1.

Figure SD-5.6.4-1
Typical Lyophilizer Component Assembly



SD-5.6.4.3 Lyophilizer Shelves

(a) The flat surfaces of shelves supporting containers of product (e.g., vials containing product) are considered process contact surfaces.

(b) The flat surfaces of shelves are considered product contact surfaces if product without containers is placed directly on the shelves.

(c) Surfaces of the structural components of the shelves are considered process contact surfaces.

(d) The shelf heat transfer performance depends on shelf flatness. The loading/unloading and initial container closure performance require the shelves to be level. Therefore, shelves are not required to be sloped and may not be drainable. Methods may be required to remove residual CIP liquid (e.g., collapsible shelves may be contracted to remove residual CIP liquid from shelf surfaces followed by a process that facilitates drying, such as SIP followed by a vacuum hold).

(e) The surface finishes of shelves shall be specified by the owner/user using the designations in Table SF-2.4.1-1. A rougher surface may be specified for the bottom side of the shelves by the owner/user to meet process requirements (e.g., stopper adhesion prevention).

SD-5.6.4.4 Vacuum Systems

(a) The lyophilizer vacuum pumps and condenser cooler establish a pressure gradient during lyophilization from the chamber vessel through the condenser vessel resulting in single-direction flow toward the lyophilizer vacuum pumps. To maintain an environment appropriate for aseptic processing in the chamber vessel, the vacuum system shall prevent reverse flow (backstreaming).

(b) The lyophilizer vacuum pumps are not hygienic components and should be designed to be outside the sterile boundary.

(c) Where vacuum pumps for wet service (e.g., liquid ring vacuum pumps) are used to evacuate air/vapor from the chamber and condenser vessels, they should be located outside the sterile boundary.

SD-5.6.4.5 Isolation Bellows

(a) Isolation bellows are employed to isolate nonhygienic moving components from the lyophilizer sterile boundary.

(b) The surfaces of the bellows and its mounting connections exposed to the inside of the lyophilizer are considered process contact surfaces and should be assessed for cleanability. The bellows shall be extended during the cleaning cycle to provide access to all exposed process contact surfaces.

(c) The bellows shall be sealed at each end to isolate the inside of the lyophilizer from external conditions. Bellows may be bolted or welded into place. A bellows sealed by a bolted flange connection with an O-ring seal within the chamber vessel facilitates replacement and maintenance. The inside of the bellows may be evacuated, vented, or pressurized to facilitate retraction or extension of the bellows. The lyophilizer may be provided with a leak-test system to ensure the bellows is intact.

(d) When specified, the bellows shall be suitable for sterilization and shall allow for full penetration of the sterilizing agent at all surfaces inside the sterile boundary.

SD-5.6.4.6 Internal Moving Parts. The following should be considered in the design of moving parts (e.g., the raising and lowering of the shelves) within the chamber or condenser vessel:

(a) Nonmetallic material may be used for moving parts to reduce friction (e.g., PTFE, PEEK, UHMWPE). The selection of the material should consider minimizing particle generation.

(b) Contact surfaces between moving parts shall be exposed to solutions used for cleaning and bioburden control.

(c) A bellows may be used to isolate the chamber or condenser from moving parts that are not of hygienic design.

SD-5.6.4.7 Spray Devices

(a) Spray devices are used in lyophilizers to facilitate the cleaning of surfaces inside the chamber and condenser vessels. Spray devices in the condenser vessel may also be used for directing spray at the condenser cooler to facilitate defrosting of the condenser cooler.

(b) Spray devices designed for cleaning should provide sufficient flow and force to clean flat surfaces (e.g., shelves) by direct spray. Cleaning the internal surfaces of a lyophilizer by direct spray may require a supply pressure and flow rate that are substantially higher than are typical for cleaning an empty vessel. The supply pressure and flow rate should meet the manufacturer's recommendation for these spray devices.

(c) Both static and dynamic spray devices are acceptable for use in lyophilizers. The use and application of a particular spray device design should be agreed on among the owner/user, lyophilizer manufacturer, and CIP system integrator. The number of spray devices may be reduced if the shelves are allowed to move during cleaning. Spraying of shelves should be designed to avoid the interference of spray streams of opposing directions.

(d) The use of threaded connections for spray devices should be avoided.

(e) Spray devices shall meet the provisions of SD-3.9.2.

(f) Spray device design, location, and orientation shall ensure appurtenances (e.g., nozzles, bellows, shelf supports, hoses) are exposed to complete spray coverage.

SD-5.6.4.8 Gas Filter Assemblies

(a) For the purpose of this paragraph, the gas filter assembly is defined as those filters installed for the purpose of filtering process gases supplied by the

lyophilizer. The filter assembly includes the filter media, seals, housing, and connected tubing.

(b) The last filter in the path of the gas to the lyophilizer (proximal filter) shall be part of the sterile boundary and be designed for the chosen means of bioburden reduction (e.g., SIP or VHP). This filter shall be a sterilizing-grade filter. If a redundant sterilizing filter is used, both filters shall be included within the sterile boundary.

(c) Filter assemblies that are steamed in place shall be designed to

(1) limit the pressure drop across the filter to within the manufacturer's specifications in the specified flow direction

(2) permit temperature monitoring in a location representative of the coldest location

(3) accommodate the integrity testing of the proximal filter, either in situ or out of place

(d) If CIP of the gas filter assembly is specified, provisions shall be made in the design for removal of the filter element or elements prior to the CIP. Filter elements shall be reinstalled prior to sterilization of the filter assembly.

SD-5.6.4.9 Doors and Door Seals

(a) Lyophilizer doors and door seals shall be designed to withstand vacuum, cleaning, and sterilization conditions.

(b) Lyophilizer doors shall be accessible, cleanable, and replaceable and should be capable of undergoing inspection without dismantling.

(c) For multiple-door systems, the doors shall be interlocked to allow the opening of only one door at a time during normal operation.

(d) Doors and locking hardware that interface with the clean room should not be retracted to uncontrolled space.

(e) Both sliding and swing door designs are acceptable.

(f) Door seals can be made with either static or inflatable seals. Static seal grooves that hold the seal may be on either the door or the chamber.

(g) The seal groove may be set back from the chamber flange edge to keep the seal in position during vacuum conditions.

(h) Compression of a single static seal to achieve a metal-to-metal contact is preferred to avoid a gap between the door and chamber vessel.

(i) The door static-seal design shall provide access for manual sanitization as the seal face under compression does not permit penetration of sterilizing agents.

(j) A combination (static and inflatable) seal design with the static seal circumscribing the inflatable seal provides for penetration of sterilizing agents across the sealing face of the inflatable seal.

(k) Door seal lubricants shall not be used in aseptic processing applications.

(l) See Part MC for specifications of seals used in bioprocessing.

SD-5.6.4.10 Valves

(a) Valve design and selection for service shall follow MC-3.3.2.3(a) and Part SD as appropriate. The application of a specific valve type for a given service should be agreed on by the manufacturer and owner/user.

(b) Hygienic valves shall be used inside the sterile boundary.

(c) Diaphragm valves are acceptable for hygienic fluid service.

(d) Butterfly valves may be used as part of the sterile boundary when piping/tubing is larger than 2 in. in diameter.

(e) Ball valves may be used outside the sterile boundary to establish positive isolation.

(f) Pressure relief devices or rupture disks of hygienic design may be used as part of the sterile boundary.

(g) If the lyophilizer is designed for isolation between the chamber and condenser, the isolation valve may take the form of a mushroom valve, butterfly valve, or other proprietary valve design.

SD-5.6.4.11 Instruments

(a) All instruments within the sterile boundary should conform to all applicable sections of Part PI, including PI-2.1, PI-2.1.2(c), PI-2.1.2(f), and PI-2.2.2.

(b) Instruments in process contact should be of hygienic design.

(c) Instrument probe surfaces and side port penetrations shall be oriented for drainability.

(d) Instruments installed within the sterile boundary should be designed for CIP and sterilization. Instruments not designed for CIP should be removed for cleaning and reinstalled for sterilization.

(e) Locations with product-sensing instruments (e.g., thermocouples and RTDs) and wire lead-throughs should be considered when designing for cleaning and sterilization.

(f) Instrumentation with integral seals or diaphragm seals is preferred within the sterile boundary. The risk of using instrumentation without integral seals or diaphragm seals (e.g., Pirani gauges) should be assessed based on the risk to product quality as determined by the owner/user.

SD-5.6.5 Design for Bioburden Control. Lyophilizers designed for bioburden control should consider the following:

(a) pressure or vacuum hold testing in preparation for the bioburden reduction process. See SD-5.6.7 for vacuum integrity testing.

(b) evacuation of air from the chamber and condenser vessels to reduce the potential for air to be trapped during the bioburden reduction process. Effective air evacuation may be achieved through the use of a liquid ring vacuum pump or similar.

(c) for the purpose of identifying areas that should be exposed to sterilizing agents, the following areas within the chamber and condenser vessels define the sterile boundary as indicated in Figure SD-5.6.5-1:

(1) the inside surfaces of the chamber vessel to the chamber door isolation seal.

(2) the inside surface of the condenser vessel to the condenser door isolation seal.

(3) the chamber and condenser drains to the first isolation drain valve.

(4) the vacuum pump inlet connection in the condenser vessel to the first isolation vacuum valve closest to the condenser vessel.

(5) the vacuum break/gas inlet line to the sterile gas filter. If redundant sterilizing filters in series are used, the sterile boundary ends at the membrane of the filter farthest from the chamber vessel.

(6) the CIP/SIP inlet lines to the first CIP/SIP isolation valve that is closed during the lyophilization process.

(7) the sealing surface on all instruments connected to the chamber and condenser vessels.

(8) thermocouple/RTD seals connected directly to the chamber and condenser vessels.

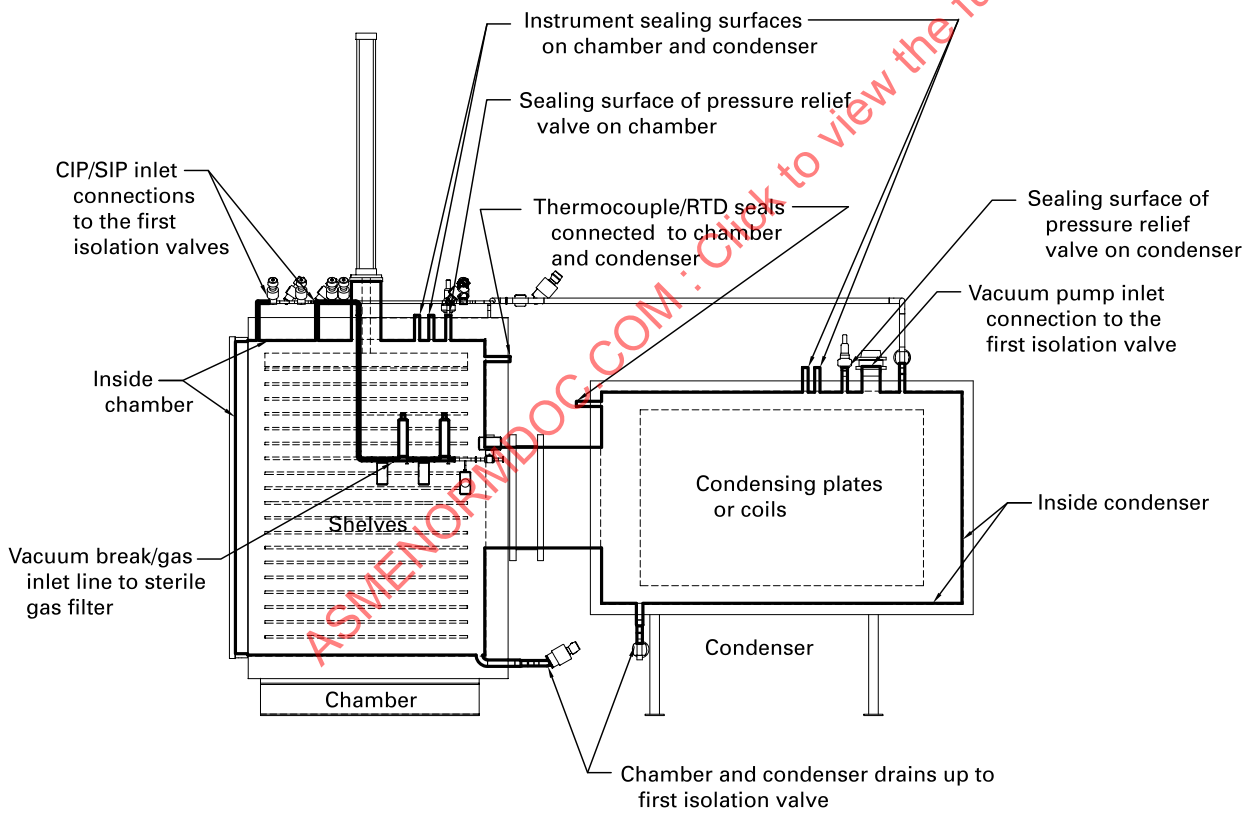
(9) the exposed surface of the pressure relief valve or rupture disk.

(d) Internal Connections and Fasteners

(1) Threads sealed by an O-ring or hygienic gasket are acceptable. The use of exposed threads within the lyophilizer sterile boundary should be avoided. If other means of fastening are not practical, the use of exposed threads may be permitted with the agreement of the owner/user. The surfaces of exposed threads should be among those assessed for cleaning and penetration of sterilizing agents.

(2) For process contact surfaces, the use of pins, clevis rods, snap rings, and clips may be required to mount hardware inside the sterile boundary but should be minimized and agreed on by the owner/user. The surfaces of these fasteners should be among those assessed for cleaning and penetration of sterilizing agents.

Figure SD-5.6.5-1
Lyophilizer Sterile Boundary



(3) Socket head cap screws and counterbored holes inside the sterile boundary shall only be used with the agreement of the owner/user.

(e) Branch Connections

(1) The provisions of SD-3.1.2.2 are applicable to liquid-service process contact piping, leading to the lyophilizer.

(2) Nozzles within the sterile boundary should be designed to allow for full exposure to the sterilizing agent.

(3) Nozzles and other appurtenances that are cleaned by liquid spraying should allow complete coverage.

(4) Lyophilizer internals should be designed to avoid low points where fluid can be trapped.

SD-5.6.5.1 Drainability

(a) Internal liquid distribution piping shall be sloped to meet the requirements of GSD2 for drainability.

(b) External liquid distribution piping shall be designed with valve actions that facilitate draining. The pipe slope shall meet the requirements of GSD2.

(c) The liquid level in the chamber and condenser vessels should be minimized during once-through CIP by correct sizing of the drain and by providing slope to the respective drain. A CIP drain pump may be used to assist draining of the chamber and condenser vessels.

(d) When recirculated CIP is used, recirculated systems shall be drainable, including pump casings.

(e) The chamber and condenser vessels shall be drainable.

(1) Process contact surfaces shall be sloped to meet the requirements of GSD3 for drainability of CIP fluids and to prevent the collection of condensate during the steaming processes.

(2) Interior surfaces of nozzles penetrating the vertical walls of the vessel shall be sloped to meet the requirements of GSD3.

(3) The floor of the vessel shall be sloped toward the drain connection to meet the requirements of GSD3, unless otherwise agreed to by the manufacturer and owner/user.

SD-5.6.5.2 Cleaning. The following requirements are for CIP of lyophilizers:

(a) Systems used to clean lyophilizers shall conform to SD-6.3.3. Cleanability requirements of SD-2.4.2 are applicable to lyophilizers except for SD-2.4.2(b)(1), which does not apply to lyophilizer shelves.

(b) It is accepted practice to use water as the CIP fluid for cleaning water-soluble compounds. Water for injection shall be used for the final rinse in aseptic processing applications.

(c) The chamber vessel, which includes internal shelves, should be cleaned via internal spray devices designed to provide coverage of targeted surfaces. Risk to product quality should be considered when determining the required coverage. The acceptance criteria for coverage shall be agreed to by the manufacturer and owner/user. Nonmandatory Appendix L provides an acceptable procedure for spray device coverage testing.

(d) The process contact surfaces within the condenser vessel may be cleaned via internal spray devices to provide the coverage agreed on between the manufacturer and owner/user.

(e) When recirculated CIP is used, recirculated systems shall be capable of removing residual chemicals and debris during the final rinse.

SD-5.6.5.3 Thermal Sanitization/Sterilization. When designing lyophilizers for SIP

(a) steam should enter the lyophilizer at only one point at a time to minimize the potential to trap air or condensate. If steam needs to enter through multiple locations simultaneously, the design should create flow paths that avoid air entrapment. The design should ensure that condensate will freely flow toward low-point drains.

(b) a dual control design may be used to deliver high steam flow rates that are often required during the heating phase and to maintain tight control of temperature and pressure during the exposure phase. For example, one regulator or control valve may be used for the heating phase and a separate regulator or control valve may be used for tight control during the exposure phase.

(c) a vacuum drying phase should be used to eliminate any condensate remaining within the sterile boundary following SIP.

(d) if cooling and drying are accomplished with the introduction of a process gas with open drains, a positive pressure differential shall be maintained to preserve the sterile boundary during this operation.

(e) temperature monitored throughout the SIP cycle should include coldest (worst-case) locations. If routine monitoring of worst-case locations is not practical, the temperature of locations that have been correlated to the actual worst-case locations may be monitored instead.

(f) to minimize cold locations during SIP, horizontal penetrations should be sloped to allow condensate to drain.

SD-5.6.5.4 Chemical Sanitization/Sterilization. When designing lyophilizers for sterilization with hydrogen peroxide gas under vacuum

(a) the system should be designed to be dried and have a surface temperature that meets the supplier specification for the hydrogen peroxide supply system [typically between 59°F (15°C) and 176°F (80°C)] prior to the start of the sterilization process.

(b) the system should be designed to verify that the residual hydrogen peroxide levels are below the established thresholds, after the sterilization process has been completed. Threshold levels should be agreed on by the owner/user for both operator's safety and the potential impact on the product quality.

SD-5.6.7 Testing. The following requirements are for leak-rate (vacuum integrity) testing:

(a) Lyophilizers designed for aseptic lyophilization processes shall be designed to meet leak-rate testing criteria as agreed to by the owner/user. The sterile boundary should be leak tested before aseptic operations begin. The leak rate is calculated as follows:

$$Q = \frac{\Delta PV}{\Delta t}$$

where

Q = leak rate, mbar-L/s
V = the lyophilizer system volume subject to the vacuum, adjusted to exclude the volume occupied by internal hardware, L
ΔP = the absolute pressure rise during the test, mbar
Δt = the test duration, sec

(b) Leak-rate testing should be performed on a clean, dry, and fully assembled and insulated system with the condenser cooler in operation to capture residual vapor. Typically, leak rates less than 0.02 mbar-L/s are acceptable for new installations. Leak-rate testing is intended to confirm vacuum integrity of the system.

(c) Leak-rate tests are performed at high vacuum conditions with an absolute pressure typically on the order of 0.01 mbar.

(d) Sufficient stabilization time will avoid misinterpretation of the vacuum leak rate due to virtual leaks. Virtual leaks are identified by a leak rate that stabilizes over time.

(e) Individual component assemblies that are subjected to vacuum conditions should be helium leak tested prior to final installation.

SD-5.7 Solution Preparation Systems

Solution preparation systems are used for the preparation, storage, and distribution of buffer solutions, media solutions, and other reagents used in bioprocessing, formulation, and filling operations. Systems may include components for transfer and mixing of solids and liquids (e.g., agitators, in-line mixers, vacuum transfer equipment, intermediate bulk containers). The systems may also include tanks/vessels for solution preparation and for solution storage. Systems may also include components designed specifically for bioburden reduction or solution conditioning. Examples of these include filtration systems and thermal conditioning systems such as ultra-high-temperature/high-temperature short-time (UHT/HTST) systems.

SD-5.7.1 Operating Capabilities and System Function. The owner/user shall define which process contact surfaces require cleaning and sanitization (e.g., vessel internals, solids transfer equipment, solution transfer lines, vent lines) and which cleaning methods (e.g., CIP, COP, water rinses) and sanitization methods (e.g., chemical sanitization, SIP, hot-water flush) are to be used. When a solution sterilizing-grade filter is SIP'd with the system, the sterile envelope shall include the filter membrane. In practice, this requires a design that achieves sterilization conditions across the filter membrane.

For systems that require closure, controls to achieve and maintain a functionally closed system after mixing may include

(a) equipment to achieve required bioburden reduction in prepared solutions (e.g., sterilizing-grade filters, HTST, sterilization vessels)

(b) technologies that prepare equipment for use (e.g., CIP, SIP, use of gamma-irradiated single-use components)

(c) procedures and designs to maintain control during processing and holds after bioburden reduction (e.g., system closure after sanitization, drying equipment for holds, and hold and processing time limits)

SD-5.7.2 System Design

SD-5.7.2.1 Contamination Control. Measures should be taken to contain powders that are added to mixing tanks and to contain aerosols that may be generated during solution preparation to mitigate the risk of cross-contamination between operations. The owner/user shall assess the risk of cross-contamination between operations. Controls to mitigate the risk of cross-contamination may include

(a) physical separation (e.g., separate rooms, isolators)

(b) airflow controls (e.g., dust collection systems, filtration of circulated air, flow direction)

(c) use of closed-process systems

(d) temporal separation

(e) procedural separation

The owner/user shall specify requirements for mitigation of risks from environmental contamination and growth of adventitious agents such as bacteria, fungi, and viruses in solutions during processing and hold times.

SD-5.7.3 Design for Bioburden Reduction

SD-5.7.3.1 Filters. Systems used for buffer distribution may require a filter to reduce bioburden during transfers to downstream systems, particularly when the buffer is growth-promoting or is transferred to a holding system before use.

SD-5.7.3.2 Preparation Tanks. Preparation tanks may be designed for operations that are briefly exposed to the room environment (e.g., addition of reagents through an open port) when appropriate measures are exercised for bioburden control and other particulate contamination (e.g., filtration to reduce bioburden after reagents are dissolved).

SD-5.7.3.3 Tanks for Long-Term Storage. Tanks used for long-term storage of solutions should be designed to be sterilized unless the intended solution is bactericidal or bacteriostatic.

SD-5.7.3.4 Thermal Sanitization/Sterilization. Systems used for aseptic processing shall have all surfaces that contact sterile process streams downstream of the bioburden control device capable of being sterilized. This includes interfaces between components that are sterilized separately.

SD-6 PROCESS SUPPORT SYSTEMS

SD-6.1 Cabinet Washers

SD-6.1.1 General. This section describes the requirements for washers that are designed to clean various materials and components such as glassware, drums, containers, hoses, pallets, and accessories (washable items) that are not cleaned in place. Requirements in this section are intended to be applied to cabinet washers, but may be applied to other types of washers as appropriate.

(a) Cabinet washers shall be fully automatic and should be capable of multiple cycle types for various load conditions. Cabinet washers may be designed with an integrated chemical addition system or receive cleaning solutions from a CIP system.

(b) Cabinet washers shall include racks or holding systems designed to enable repeatable exposure of washable items to cleaning solutions.

(c) The documentation requirements of GR-5 are applicable to process contact components/instruments of cabinet washers.

SD-6.1.3 Operating Capabilities and System Function

(a) Cabinet washers shall be capable of delivering cleaning solutions and of the subsequent rinsing of cleaning solutions from washed surfaces.

(b) Cabinet washers should have the ability to perform the following general phases during the cycle:

(1) prewashing
(2) washing
(3) rinsing
(4) final rinsing
(5) drying with heated filtered air
(6) cooling with filtered air

SD-6.1.3.1 Rinse Requirements

(a) The final rinse step may be performed using recirculated water integrated with drain steps or as a single-pass rinse (or series of single-pass rinses) to remove residual cleaning solutions. The final rinse water at the outlet of the washer shall meet the owner/user's acceptance criteria (e.g., conductivity, total organic carbon, cycle time).

(b) The ways of providing a single-pass rinse include

(1) direct connection supply from a utility water system with hygienic safeguards to prevent backflow. If a direct utility connection is used, the design should mitigate the effect of variation in supply pressure (e.g., due to draw by other users) and its impact on the flow rate.

(2) use of a water break-tank. The break-tank shall be drainable and vented. Rinse water from the break-tank shall not contribute to the soiling or bioburden load in the cabinet.

(c) The hydraulic conditions (i.e., pressure and flow rate) for the rinsing phases shall be consistent with those established for washing phases to ensure consistent rinsing of the washable items, the chamber interior, and the complete hydraulic circuit.

SD-6.1.4 System Design

(a) Materials of Construction

(1) Process contact surfaces shall conform to the requirements of SD-2.4.1.

(2) All welded metallic process contact surfaces shall be passivated in accordance with SF-2.6.

(3) External surfaces of the washer cabinet shall be fabricated with material that is resistant to cleaning and sanitizing agents as specified by the owner/user.

(4) Process contact polymeric materials shall conform to Parts MC and PM.

(5) Process contact metallic materials shall conform to Part MM.

(b) Surface Finish. The surface finishes for the interior surfaces of the chamber, wetted process contact tubing, and exterior surfaces exposed to cleaning solutions shall be specified by the owner/user using designations provided in Table SF-2.4.1-1. Electropolishing is not required.

SD-6.1.4.1 Wash Chamber

(a) The interior surfaces of the chamber are considered process contact surfaces. These surfaces, which have the potential to drip onto washed items, shall have complete spray coverage (see SD-6.1).

(b) The interior of the chamber shall conform to SD-2.4.2. Internal surfaces that may be difficult to clean (e.g., wheels, cabling, external surfaces of exposed hygienic-clamp connections) should be minimized and assessed for the risk to product quality.

(c) All internal surfaces shall be sloped for drainability with a slope agreed on between the owner/user and fabricator. Where possible, a slope of not less than $\frac{1}{8}$ in./ft (10 mm/m) is recommended.

(d) External surfaces should be insulated to minimize heat transmission and promote cleaning and drying.

(e) Breastplates, reinforcing pads, doubler plates, poison pads, etc., which are required for welding dissimilar material to the chamber, should be of the same material as the chamber.

(f) Lubricants shall not be used where they may come in contact with cleaning solutions or washable items.

SD-6.1.4.2 Chamber Openings

(a) Nozzles that are designed to be cleaned by a spray device should have the smallest L/d ratio practical. For non-flow through nozzles, an L/d of less than 2 is recommended (see Figure SD-3.4.2-1).

(b) Sidewalls and chamber-ceiling nozzles should be flush with the interior of the chamber (see Figure SD-3.4.2-5).

(c) Blank covers shall have the same surface finish as the chamber internals.

(d) Process valves shall meet the requirements of MC-3.3.2.3.

(e) Sample valves shall meet the requirements of SD-3.11.2.1.

(f) Sight glasses on the chamber shall meet the requirements of Figure SD-3.4.6-1. Sight glasses should be designed with the smallest L/d practical and should incorporate cleanable seal designs.

SD-6.1.4.3 Washer Door and Door Seals

(a) Washer doors and door seals shall be designed to prevent wash fluid leakage during the entire wash cycle.

(b) For multiple-door systems, the doors shall be interlocked to allow the opening of only one door at a time for loading and unloading.

(c) Both sliding and swing door designs are acceptable.

(d) Doors that interface with classified clean rooms should not be retracted to an uncontrolled space.

(e) Construction of the door shall meet SD-2.4.1.

(f) The internal surface finish of the door shall be the same as specified for the chamber internal surfaces.

(g) Solid or inflatable door seals shall meet the requirements of SD-2.4.1.1 (e.g., conforming to FDA 21 CFR 177 and USP Section <88> Class VI).

(h) See Part MC for specifications of seals.

SD-6.1.4.4 Internal Components

(a) Washer cabinet internal components include loading racks and supports, thermowells, spray manifolds, etc.

(b) Weld-in thermowells [see Figure SD-3.4.3-2, illustrations (e) and (f)] shall have the same finish as the chamber internals.

(c) Loading racks/accessories

(1) The racks are designed to support the cleaning of specific washable items. The rack design should be verified to provide complete spray coverage for washable items defined by the owner/user in an arrangement for which the loading rack is designed.

(2) Loading racks shall secure the washable items during the wash cycle.

(3) Loading racks may be designed to distribute rinse and cleaning solutions to interior and exterior surfaces of the washable items.

(4) Loading racks should have a surface finish that meets the surface finish requirements of the chamber. Surface finish verification may not be possible for all components of the loading rack.

(5) The loading rack manifold fabrication shall conform to SD-3.1.2.3.

(6) Loading rack design considerations should include the disassembly required for inspection and maintenance.

SD-6.1.4.5 Air Drying, Intake, and Exhaust Systems. Where specified by the owner/user to dry washed items, the following provisions are applicable:

(a) The air intake system shall be filtered. A prefilter and HEPA filter system are recommended to protect the washed items.

(b) The drying system shall provide heated, filtered air to the chamber, the hydraulic circuit, and in-line components.

(c) The filtered air used for drying may be supplied from a controlled or uncontrolled environment.

(d) Temperature and humidity variability of intake air should be considered in system design.

(e) The exhaust ducting should be designed to direct condensate to a drain.

SD-6.1.4.6 Spray Systems. Design of spray systems in cabinet washers requires the integration of manifolded spray devices in the chamber with those installed in loading racks. Spray systems in cabinet washers may use both static and dynamic spray devices that conform to SD-3.9.

(a) Loading-rack spray systems may have interchangeable spray devices to accommodate a variety of washable items in a single rack.

(b) Translational/reciprocating spray devices in the cabinet using mechanical devices (e.g., pulleys and PTFE sheathed cables) should be designed for ease of disassembly for inspection and maintenance.

(c) Mechanical devices used in the chamber shall be compatible with the process fluids and shall be cleanable.

SD-6.1.4.7 Chemical Addition Systems. When cleaning solutions are not provided by a CIP system, the following provisions are applicable:

(a) A number of chemicals that function as pH adjusters, emulsifying agents, or soil removers may be added during the cabinet washer cycles. The design considerations should include positive identification of each chemical delivery and connection.

(b) Concentrated chemicals may be delivered to the washer from bulk distribution systems or from local holding containers. The design of concentrated chemical delivery and storage systems should consider minimizing human contact.

(c) Design of concentrated chemical storage and distribution components should consider safety provisions.

(d) The design should include monitoring of adequate bulk chemical supply (e.g., level) for the entire wash cycle.

SD-6.1.4.8 Recirculation Pumps

(a) The pump shall have sufficient capacity (flow rate and pressure) for all spray configurations used in the washer.

(b) Pumps shall conform to SD-3.3.2.

(c) Pump seals shall conform to Part MC.

SD-6.1.4.9 Heat Exchangers

(a) Heat exchangers included in cabinet washers to heat cleaning solutions, rinse water, etc., shall conform to SD-3.6.

(b) Heat exchangers using steam or a thermal liquid may include shell-and-tube, coil, or tube types.

(c) Electric heat exchangers may be direct or indirect immersion type heaters.

SD-6.1.4.10 Instrumentation

(a) All process contact instruments should conform to the applicable sections of Part PI.

(b) The design should enable operators to monitor process parameters without having to pass through changes in room classifications.

SD-6.1.4.11 Interfaces. Where the chamber interfaces with the clean room, the external surfaces shall meet the owner/user's specified requirements.

SD-6.1.5 Design for Bioburden Control

(a) Cabinet washers shall conform to the fabrication requirements of SD-2.4.1.

(b) Tubing within the process contact boundary should be orbital-welded tubing where possible and shall conform to Part MJ.

(c) All wetted process contact surfaces shall be of hygienic design per the applicable sections of this Standard.

SD-6.1.5.1 Branch Connections

(a) The provisions of SD-3.1.2.2 are applicable to liquid-service process contact piping leading to the chamber and delivering cleaning solutions to the spray manifolds.

(b) Liquid-service branch connections with an L/d greater than 2 shall be provided with low-point drains that are opened between each phase of the washing cycle to avoid cross-contamination.

SD-6.1.5.2 Drainability

(a) The chamber drainability should be verified during fabrication. Verification methods and acceptance criteria for drainability shall be agreed on in advance by all the parties.

(b) Instrument probes and sidewall penetrations (see Figure SD-3.4.2-2) shall be sloped for drainability, unless the instruments used require horizontal mounting (see Figure SD-3.4.2-3).

(c) Loading racks shall be drainable.

SD-6.1.5.3 Cleaning

(a) The design should enable multiple chemical additions during the prewashing and washing processes.

(b) Cleaning solution temperature shall be controlled and monitored during washing and rinsing phases.

(c) The pressure and flow rates of cleaning solutions supplied to dynamic and static spray devices within the chamber or loading racks should be monitored.

(d) If cleaning solutions are recirculated during the cycle, the recirculation pump shall meet the requirements of SD-3.3.2.

(e) The design should provide final rinse water at an elevated temperature [e.g., >149°F (65°C)] for sanitization and improved drying efficiency.

(f) The system shall be designed to provide analytical verification of final rinse water quality (e.g., conductivity, total organic carbon).

SD-6.1.6 Design for Serviceability, Examination, and Operation

(a) Cabinet washers should be designed to enable access for inspection and service of components that are subject to wear and to allow periodic calibration of instruments.

(b) Mechanical components and instruments that require maintenance may be located in an unclassified space where the maintenance can be performed.

(c) The washer design considerations should include integration with the space where maintenance is performed (e.g., minimizing moisture due to condensation).

(d) Pumps should be designed and configured to enable access for removal, inspection, and maintenance.

SD-6.1.7 Testing. The test requirements shall be defined by the owner/user and agreed to by the manufacturer, and may include tests beyond those described in this section. These tests apply to newly installed systems and to modifications of existing systems (e.g., the addition of a loading rack to an existing system).

SD-6.1.7.1 Spray Device Coverage Test. Cabinet washers should be tested to confirm complete spray coverage of the specified washable items and the interior process contact surfaces of the washer chamber. The

spray device coverage testing described in SD-7.1 is applicable to cabinet washers. The spray device coverage test procedure described in Nonmandatory Appendix M may be used for cabinet washers with the following additional considerations:

(a) Testing should include empty configurations (i.e., loading rack only).

(b) Testing should include racks loaded to capacity.

(c) It is acceptable to bypass the drying phase of the cycle to examine the wet conditions. If parts are dry when inspected, they should be gently rewetted with ambient or cold water to observe any residual riboflavin fluorescence.

(d) The sequence in which parts are examined should be documented to prevent false positive results due to transfer of residual riboflavin from one washable item to a clean washable item.

SD-6.1.7.2 Drainability Test. The proposed drainability test procedure in SD-7.4 for vessels may be applied to cabinet washers with the following exceptions/considerations:

(a) It is not necessary to fill the chamber with the outlet closed. The chamber should be wetted by liquid delivered through the spray system.

(b) The chamber drainability test should be performed without drain pump assistance.

SD-6.1.7.3 Cycle Performance Test. The performance test should demonstrate the ability to clean loaded items based on an identified list of washable items. The test should verify removal of residue from surfaces and that the final rinse meets the specified water quality (e.g., an acceptable compendial water requirement) at the drain within a specified period of time. The test should verify that the process contact surfaces within the washer are also cleaned to the same specifications used for the washable items.

SD-6.2 Steam Sterilizers/Autoclaves

SD-6.2.1 General. For this section, "autoclaves" and "steam sterilizers" shall be used synonymously. This section describes the requirements of autoclaves that are used in bioprocessing for the steam sterilization of hard, dry-wrapped, and liquid materials.

This section does not pertain to pasteurizers, ETO (ethylene oxide), VHP (vaporized hydrogen peroxide), or ClO_2 (chlorine dioxide) type sterilization equipment. The manufacturer shall define the sterile boundary of the system.

SD-6.2.3 Operating Capabilities and System Function. Autoclaves should be capable of multiple cycle types for various load conditions. Autoclaves shall only be used to sterilize the types of goods for which they are designed. The most common load types are specified in SD-6.2.3.1 through SD-6.2.3.3.

SD-6.2.3.1 Hard Goods Cycles. "Hard goods" refers to goods such as metallic instruments, containers, and glassware. Effective removal of noncondensable gases is required for effective autoclaving of hard goods. Hard goods may be wrapped or unwrapped. Unwrapped goods can often be effectively autoclaved using either a single vacuum pull or gravity air displacement. These goods can sometimes be autoclaved at higher temperatures. Multiple vacuum pulse preconditioning is required for wrapped goods to ensure proper evacuation of noncondensable gases from both the autoclave chamber and autoclaved goods. Steam sterilizers used for the processing of wrapped or porous goods shall be able to pull vacuum to levels below 1 psia [69 mbar] and maintain the vacuum with a maximum leak rate of 0.1 psi/5 min (6.9 mbar/5 min). Cooling, drying (pulse, vacuum) is an optional cycle step used to dry goods at the end of the autoclave cycle. Heated pulse drying is also recommended for the drying of porous goods such as rubber stoppers. Exhaust rates and heating rates should be adjustable for pressure-sensitive materials.

SD-6.2.3.2 Liquid Cycles. Forced air removal preconditioning is an optional cycle used to evacuate the noncondensable gases from the autoclave chamber. Liquid cooling cycles should be provided to efficiently cool the autoclave chamber. Providing the chamber with overpressure helps prevent the liquid goods from boiling over during the cooldown phase. Liquids can also be cooled by slow-rate exhaust. Heating rates should be adjustable to help compensate for differences in heating profiles of items in mixed loads.

SD-6.2.3.3 Air Filter Sterilization. An independent air filter SIP sterilization cycle should be provided for the in situ sterilization of the chamber vent filters ensuring supply of sterile air for cooldown phases of autoclave loads.

SD-6.2.4 System Design. Materials in contact with steam shall resist corrosion from steam and steam condensate. The materials shall not affect steam quality and shall not release any substances known to be toxic or that could adulterate the product. Piping/tubing and fittings shall be pressure and vacuum tight. The piping/tubing layout should be designed to eliminate dead legs within the sterile boundary. Tubing within the sterile boundary should be orbital-welded stainless steel tubing where possible and shall conform to Part MJ (Table MJ-8.4-1) acceptance criteria. All process contact surfaces within the sterile boundary including tubing, chamber, and components shall be passivated.

The autoclave shall be enclosed with paneling that is resistant to corrosion and is cleanable.

The surface finish within the sterile boundary need not exceed 35 µin. R_a (0.89 µm). Electropolishing is not required for steam sterilization systems.

Elastomers shall conform to MC-3.1 through MC-3.3. Elastomers shall be resistant to corrosion and to chemical and thermal degradation. Elastomers used in autoclave applications shall be capable of withstanding pressures of a minimum of 25 psig at 266°F (1.7 barg at 130°C). Seals should meet the testing requirements specified in MC-4.2.

SD-6.2.4.1 Chamber. Autoclave chambers are pressure vessels and shall be pressure and temperature rated per the owner/user's design criteria with a minimum pressure rating of 25 psig at 266°F (1.7 barg at 130°C). The chambers shall also be vacuum rated.

For systems used in the processing of materials used in the European market, autoclaves may also be required to comply with relevant EU codes [e.g., Pressure Equipment Directive (PED) and EN-285].

SD-6.2.4.2 Doors. Autoclave door(s) shall be accessible, cleanable, and replaceable, and should be capable of undergoing inspection without dismantling. The door seal shall be resistant to clean steam and clean steam condensate. The door on the nonsterile side shall be capable of reopening after closing without undergoing a cycle. The door(s) shall not be capable of opening during a sterilization cycle. The doors shall be constructed of materials that are resistant to clean steam and clean steam condensate. For multiple-door systems, the doors shall be interlocked to allow the opening of only one door at a time. The unloading ("sterile-side") door shall remain sealed in standby mode. See Part MC for specifications of seals used in bioprocessing.

SD-6.2.4.3 Sterile Air/Vent Filters. Where the sterilization cycle requires admission of air into the chamber, the air should be filtered with a sterilizing filter (0.22 µm or less). The filter element shall be replaceable. Provisions for the steam in place of the vent filter elements should be provided.

SD-6.2.4.4 Steam Traps. See SD-3.12 for requirements of steam traps.

SD-6.2.4.5 Loading Carts/Trays. Carts and trays exposed to clean steam shall be constructed of materials resistant to clean steam and clean steam condensate. Carts, trays, and chamber shall be accessible or removable and cleanable.

SD-6.2.4.6 Valves. Valves and sealing materials located within the sterile boundary shall conform to MC-3.3.2.3. Valves within the sterile boundary are typically only exposed to clean steam service and chemical (s) used during passivation. Exposure to these conditions should be considered when selecting a valve type for this application.

(24) **SD-6.2.4.7 Backflow Prevention.** Provisions to prevent back-siphoning into the service feed systems (e.g., check valves) should be considered.

SD-6.2.4.8 Jacket. The jacket shall be constructed using materials that are resistant to corrosion and degradation from steam or clean steam and clean steam condensate, as applicable.

SD-6.2.4.9 Instrumentation. Autoclave pressure and temperature shall be displayed at all doors. All instruments within the sterile boundary should be of hygienic design. Instruments shall be capable of being calibrated and replaced. The instrumentation shall include the following:

(a) Temperature. Independent temperature elements (one or two for monitoring and recording and an independent one for controlling temperature) shall be provided. The chamber temperature recording element should be located in the chamber drain. Each temperature element shall be accurate to ±0.18°F (0.1°C) with a sensor response time <5 sec. The element installation shall not affect the maximum leak rate. The temperature elements shall be temperature and clean steam resistant.

(b) Pressure/Vacuum. Pressure/vacuum instruments shall be provided. The pressure instruments shall monitor the chamber and jacket pressures. Provisions for recording chamber pressure during active autoclave cycles shall be included.

(c) Date/Time. Provisions for recording the date and time during an autoclave cycle shall be included.

(d) Recording. Recording may be achieved by paper or 21 CFR Part 11–compliant electronic means.

SD-6.2.4.10 Interfaces

(a) Drain Temperature. Waste to drain temperature shall conform to owner/user specifications. The owner/user shall specify discharge temperature requirements to the manufacturer.

(b) Insulation. External surfaces should be insulated to minimize heat transmission.

(c) Biocontainment. Special conditions such as bioseals may be required for autoclaves used in BSL-3 and BSL-4 applications. Please refer to the Biosafety in Microbiological and Medical Labs (BMBL) and Centers for Disease Control (CDC) guidelines for these special conditions.

SD-6.3 CIP Systems

SD-6.3.1 General. This section addresses CIP systems used to clean and reduce bioburden on process contact surfaces. CIP systems include the CIP skid and the CIP distribution system. The system shall be self-cleaning and capable of distributing CIP fluids (e.g., cleaning solutions, rinse water, compressed air) to the targeted process contact surfaces of a CIP client.

The following terms are defined for this section:

(a) CIP path: the specific route contacted with CIP fluids during a CIP cycle (e.g., spray device path, inoculum line path, addition line path). Multiple paths within a circuit may be cleaned simultaneously or sequentially.

(b) CIP client: system or equipment (e.g., bioreactor, buffer hold vessel) targeted for cleaning by a CIP system.

(c) CIP circuit: the sum of CIP paths within CIP clients that are cleaned as part of a CIP cycle, as well as the CIP skid, CIP supply, and return distribution system.

(d) CIP phase: a process-oriented action within a CIP cycle, such as a rinse, wash, or air blow, that can be subdivided into steps and transitions.

(e) CIP cycle: the executed recipe of sequential CIP phases established to provide CIP fluids to the CIP circuit, e.g., rinses, washes, and air blows.

(f) TACT: an acronym for the cleaning process parameters time, action, chemistry, and temperature. The term "action" refers to kinetic energy that drives breakdown and suspension of residues from the process contact surface.

SD-6.3.2 System Performance Requirements. The following technical requirements or parameters that are essential for design development shall be defined:

(a) rinse and wash duration range

(b) flow rate and pressure ranges

(c) cleaning agents and their wash concentration ranges

(d) rinse and wash temperature ranges

(e) final rinse water quality (e.g., TOC, conductivity)

(f) air blow requirements

(g) sampling locations

(h) drain limitations

See SD-5 for CIP client cleaning requirements.

SD-6.3.3 Operating Capabilities and System Function. The CIP system shall be capable of controlling the following:

(a) TACT

(b) multiple water/solution feeds when required

SD-6.3.3.1 Rinse. The CIP system shall be designed with the capability to provide rinse solutions at the specified flow, pressure, and temperature to the CIP client.

SD-6.3.3.2 Wash. When a formulated wash step is required, the CIP system shall be designed to dose and mix cleaning agents to prepare wash solutions. The CIP system shall be capable of supplying the wash solution at the specified cleaning agent concentration and temperature.

(24) **SD-6.3.3.3 Drain.** The CIP system shall be drainable. The CIP system should support the use of multiple drain paths if required (e.g., biowaste inactivation system, waste neutralization system). CIP circuit piping should be designed with low point drain valves that can be opened between each phase of the CIP cycle. Where the CIP client cannot be drained, provisions for a motive force such as a pump or pressurized gas (air blow) shall be included for removal of residual liquid.

SD-6.3.3.4 Air Blow. The CIP system should be designed to provide pressurized air as a motive force, if required, to assist in removing liquid from the CIP circuit. Air blows should be sequenced through the individual CIP paths of a CIP circuit.

SD-6.3.3.5 Surface Treatment Cycles. If the CIP system is designed for surface treatment (e.g., derouging or passivation cycles) of CIP clients, the CIP system should have provisions to introduce and remove associated chemicals.

SD-6.3.3.6 Self-Cleaning Cycle. If a self-cleaning cycle of the CIP skid is required (e.g., to clean the CIP skid after maintenance), the skid design should have piping that meets recirculation/cleaning requirements.

SD-6.3.4 System Design

(a) Process contacting portions of the CIP system shall be of hygienic design and fabricated as per SD-3.1.2 and SD-2.4.3.

(b) Recirculating portions of the CIP system shall be considered process contact and may be considered product contact if used to clean product contact surfaces. Risks (e.g., cross contamination and containment) associated with recirculating CIP systems should be evaluated and addressed.

(c) CIP system materials of construction shall be compatible with the process and CIP fluids.

SD-6.3.4.1 CIP Skid. A CIP skid is a system that prepares, delivers, controls, and monitors CIP solutions.

(a) The following parameters shall be monitored and controlled:

(1) time: rinse, wash, air blow, or drain duration

(2) action: CIP supply flow rate

(3) chemistry: CIP wash solution concentration of cleaning agents (e.g., by conductivity)

(4) temperature: CIP supply temperature

(b) The following parameters shall be monitored:

(1) CIP return temperature

(2) final rinse water quality (e.g., conductivity, TOC)

(c) The following parameters should be monitored:

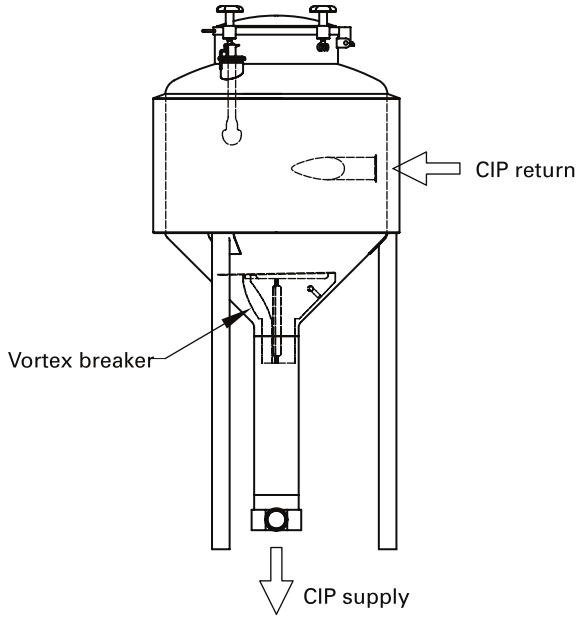
(1) CIP supply pressure

(2) CIP return flow verification

CIP skids may be located in a fixed, centralized location or may be portable and used adjacent to the CIP client. When the CIP skid is installed in or moved into a clean room, the clean room classification shall be addressed in the selections of both skid surfaces and materials of construction appropriate for the environmental requirements.

The CIP skid shall be provided with a physical separation between the water supply and the CIP solutions.

Figure SD-6.3.4.1.1-1
Conical Vessel With Reduced Bottom Outlet, or Tulip Tank



SD-6.3.4.1.1 Wash/Rinse Vessels

(a) A CIP system can include one or more vessels (e.g., separate wash and rinse vessels). Vessels can be used to provide a physical separation between the water supply and the CIP solutions.

(b) The rinse vessel should be sized to ensure uninterrupted delivery of rinse solution during the rinse phases of the CIP cycle.

(c) The wash vessel should be sized to provide adequate volume for the duration of the wash step. Sizing factors to consider are holdup volume for recirculation steps, total wash volume for once-through steps, and wash solution losses.

(d) Where recirculation of wash solutions is required, a no-foam inlet, tangential inlet, or dip tube should be used for the return of wash solutions to the wash vessel to reduce the risk of foaming.

(e) The vessels should be provided with vortex breakers and adequate outlet sizes. Vessels should also be located close to the CIP supply pump to ensure that the available net positive suction head (NPSH) is greater than required NPSH. If removable vortex breakers are installed, the design shall account for the effect of vibrations and forces on the vortex breaker and vessel wall.

(f) Air entrainment in the CIP return liquid can impact CIP supply pump performance. CIP return systems using eductors or liquid ring pumps often have a high percentage of air in the CIP liquid. Wash vessels should be designed to enhance gas/liquid separation and provide adequate NPSH, as well as to reduce CIP circuit volume. An example of a vessel having those features is a conical tank with a tangential inlet and cylindrical reduced diameter bottom section (i.e., tulip tank; see Figure SD-6.3.4.1.1-1).

(g) Vent filters on CIP skid vessels should be designed to mitigate the risk of foam or moisture blinding the filter element (e.g., heating the filter housing, bypassing the filter during filling).

(h) The CIP skid vessel used for final rinsing should be provided with a sterilizing-grade vent filter if the vessel is vented into unclassified space.

SD-6.3.4.1.2 Heat Exchanger. Heat exchangers shall be designed to meet the full range of CIP cycle duties.

SD-6.3.4.1.3 Supply Pump

(a) The CIP skid shall have flow control, either via pump output or by means of flow control valves.

(b) The pump and its associated piping (e.g., partial flow diversion) shall be designed to meet all flow rate and pressure requirements for all CIP circuits.

SD-6.3.4.1.4 CIP Return

(a) If CIP fluids are returned to the CIP skid, motive force is required (e.g., pumps, eductors, gravity, or top pressure).

(b) The CIP return sampling system should be designed for two-phase flow (i.e., liquid-gas mixtures) or vacuum conditions where applicable.

SD-6.3.4.1.5 CIP Return Eductors. A CIP return educator is a venturi device that provides motive force (i.e., vacuum) to assist CIP fluid return.

(a) CIP return eductors shall be drainable.

(b) Design factors that should be considered when using CIP return eductors include vapor pressure, return line size, elevation, viscosity, and flow rate.

(c) When CIP return eductors are used, the potential for foaming should be considered.

SD-6.3.4.1.6 Chemical Delivery. The CIP skid chemical delivery does not require sanitary design. Acceptable metering methods for chemical delivery include one or more of the following:

(a) weight
(b) flow totalization
(c) duration via metering pump or venturi
(d) conductivity

Typically one method is used for delivery, and a second method is used for confirmation or final control.

SD-6.3.4.1.7 Compressed Air Supply. The CIP skid may be provided with a clean compressed air supply to assist the removal of the rinse or wash solution. Compressed air shall meet the quality requirements for the applications (e.g., by installing a point-of-use

filter at the CIP skid). The supply pressure and flow rate shall meet the process requirements. Compressed air may be supplied at other locations in the CIP circuit to assist removal of rinse or wash solutions.

SD-6.3.4.1.8 Instrumentation

(a) The CIP supply flowmeter shall be specified and installed to measure the flow rates of CIP liquids.

(b) To address air in the CIP return, final rinse conductivity sensors should be located to ensure proper operation in both liquid and mixed-flow conditions (e.g., by providing a drainable instrumentation cup, compensated through instrument settings).

(24) **SD-6.3.4.2 CIP Distribution** A CIP distribution system consists of supply and return piping. The supply distribution piping delivers the CIP fluids from the CIP skid to the CIP clients. The return distribution piping delivers the CIP fluids from the CIP clients to the CIP skid. CIP return motive force should be provided, e.g., by one or more of the following:

- gas overlay pressure in the CIP client
- gravity
- eductor
- pump

Return distribution piping is not required for once-through cleaning or locally recirculated cleaning.

(a) General

(1) The CIP distribution system shall be sized to meet flow rate and pressure requirements of the associated CIP clients (e.g., as defined in SD-6.3.5.2).

(2) The distribution system shall be designed without dead legs under the flow conditions for each CIP circuit.

(3) CIP supply and return distribution should use piping, looped headers, transfer panels, hoses, removable spool pieces, or valves (e.g., divert, mix-proof, cluster, block-body, multiport, zero-static, diaphragm) to route the CIP fluids to or from CIP clients. If rising stem seal valves (e.g., divert valves, mix-proof valves) are used in the CIP distribution system, the risk of contamination or residue retention along the sliding stem should be assessed.

(4) The distribution piping and components, including sample points in a CIP circuit, shall meet design requirements per SD-2 and SD-3.

(5) The CIP distribution system shall be designed to prevent backflow from the drain (e.g., air breaks, check valves, sensor-activated valves, pressurization).

(6) The CIP circuit shall be designed to maintain hydraulic balance between supply and return flows to prevent liquid accumulation in the CIP client (e.g., vessel, filter housing).

(7) If the CIP client is cleaned by a once-through process, the piping downstream of a sample point or an instrument for final rinse measurement may be considered a process drain (non-process contact).

(b) Looped Headers (see Figure SD-6.3.4.2-1)

(1) The dimension from the looped header to the isolation valve weir or seat should conform to SD-3.1.2.2 (e.g., by use of short-outlet tees, mix-proof valves, zero-static valves).

(2) Spare connections on the looped header should use capped short-outlet tees or capped installed zero-static valves.

(3) A looped header and its connections shall be designed to be drainable.

(4) CIP header design should provide for adequate velocity to ensure flooding and cleaning of the entire looped header (e.g., line size reduction within the looped header).

(c) Multiport Valves. Cluster, block-body, and multiport valves should be designed and installed to prevent dead legs, reduce holdup areas, and enable draining.

(d) Zero-Static Manifolds. The manifolds shall be designed so any holdup can be flushed and drained during each CIP phase (see Figure SD-6.3.4.2-2).

(e) Swing Elbows and Piping Spools (see Figure SD-6.3.4.2-3). Swing elbows or piping spools shall be connected to adequately supported piping to maintain line slope and connection alignment.

(f) Mix-Proof Valves

(1) Mix-proof valves are double-seat valves with a drain path between the seats that allows for simultaneous processes in the two bodies of the valve. Mix-proof valves shall conform to the general design requirements in MC-3.3.2.3(a) and rising stem seal valves requirements in MC-3.3.2.3(c).

(2) If the process requires cleaning across a single seat, the valve shall be provided with individual seat lifts.

(3) Mix-proof valve arrays should be designed to accommodate draining from the leak chamber and provide sufficient access for maintenance of the valve internals.

(4) The mix-proof valve fitting-bound portion of looped header configurations should be installed to avoid low points where liquid may accumulate. Pitch of the mix-proof valve array may result in liquid retention in valve bodies and should be risk assessed (see Figure SD-6.3.4.2-4).

(5) When mix-proof valves are used in a non-looped manifold (similar to a zero-static manifold), the manifold shall be designed to be flushed and drained during each CIP phase (see Figure SD-6.3.4.2-2).

(6) If a mix-proof valve with exposed sliding stem is used to divert process fluids, it shall allow for cleaning of the stem surfaces prior to contacting the process fluids (e.g., by actuating the valve during CIP).

Figure SD-6.3.4.2-1
CIP Looped Header (Supply or Return)

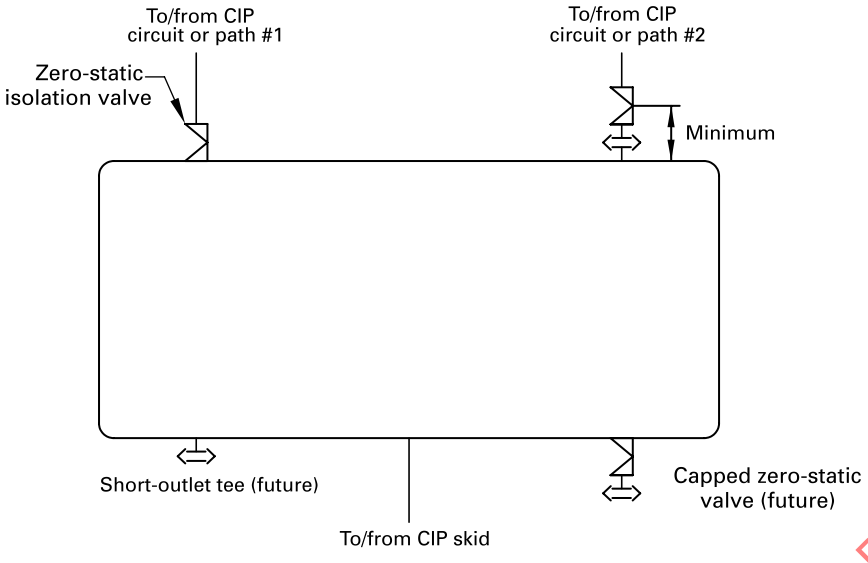


Figure SD-6.3.4.2-2
Zero-Static Chain

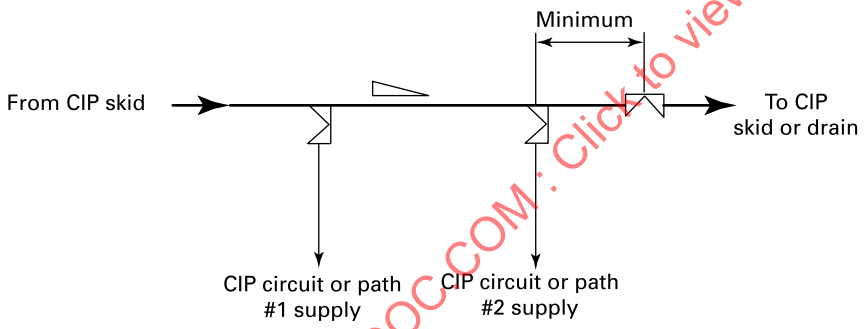


Figure SD-6.3.4.2-3
Swing Elbow Arrangement

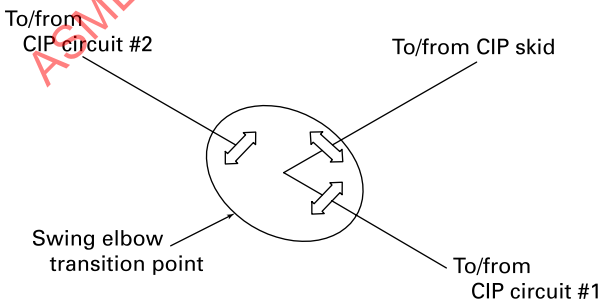
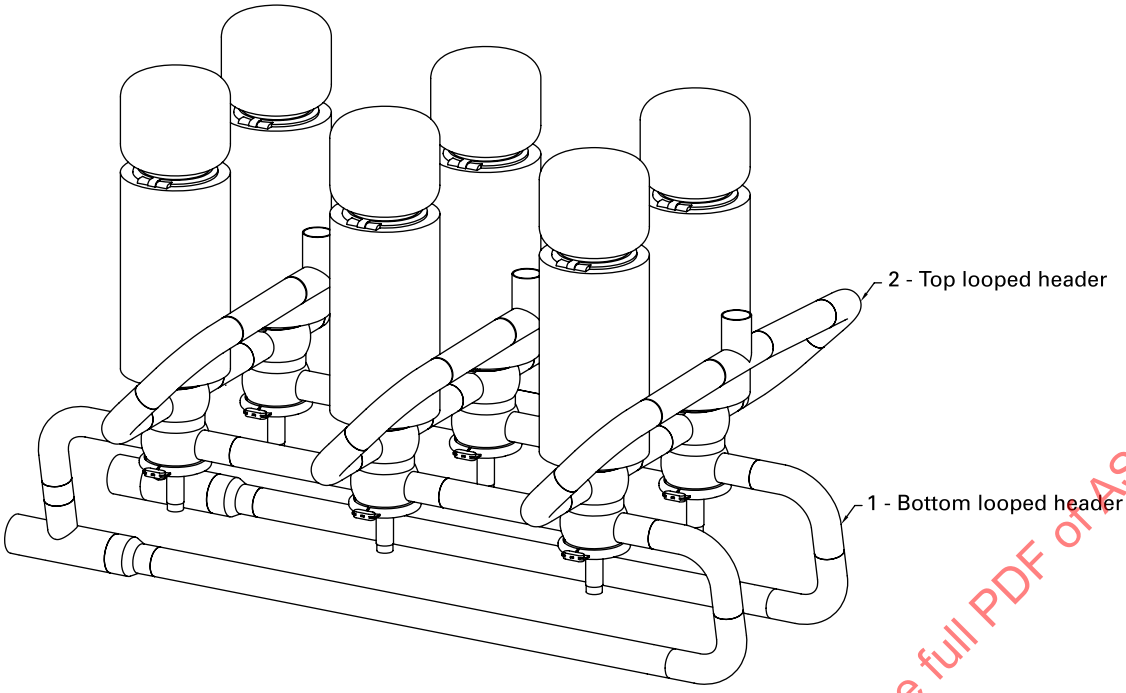
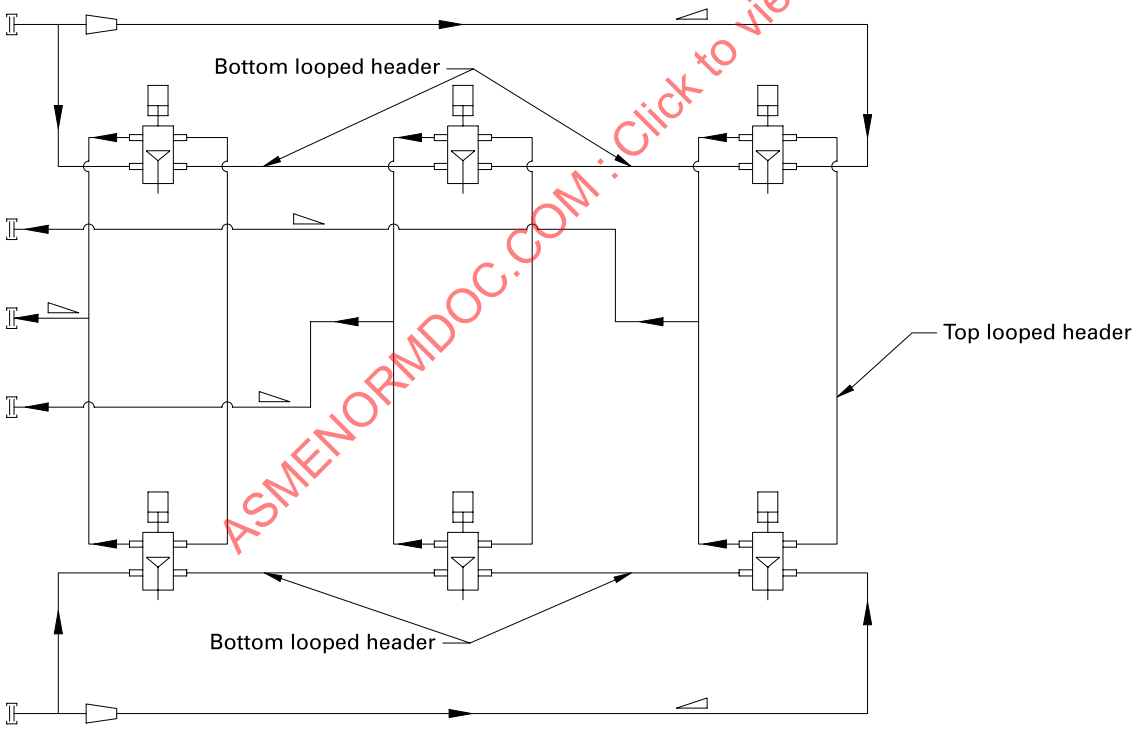


Figure SD-6.3.4.2-4
Mix-Proof Valve Array



(a) Isometric Representation



(b) Schematic Representation

GENERAL NOTE: Arrows on top and bottom looped headers point toward fitting-bound section.

(g) CIP Return Pumps

(1) Centrifugal pumps are preferred for CIP return applications when pumps are required. Self-priming pumps (e.g,. liquid ring pumps) should be used where gas/liquid mixtures are anticipated.

(2) When the CIP circuit has an air break, the CIP return pump should be placed at the low point of the circuit.

(3) CIP return pumps shall be drainable.

(4) CIP return pumps shall be sized to maintain hydraulic balance between supply and return flows.

(5) The suction-side piping shall be designed to meet hydraulic requirements for the pump, including liquid ring pumps that may not have published NPSH requirements.

(h) Instrumentation. For instrumentation in the CIP distribution system, see SD-6.3.4.1.8.

SD-6.3.5 Design for Bioburden Control

(24) **SD-6.3.5.1 Drainability.** CIP distribution piping shall be sloped for drainability as per SD-2.4.3. Slope designation GSD2 is recommended.

SD-6.3.5.2 Cleaning

(24) **SD-6.3.5.2.1 CIP Flow Rates for Process Lines**

(a) The CIP system shall meet the flow rate requirements of the CIP client for each path and during each phase of the CIP cycle.

(b) For effective cleaning, the CIP flow rate and pressure shall be sufficient to ensure that the cleaning agent and rinsing solutions wet targeted surfaces within the CIP circuit.

(c) The CIP system shall be designed to produce turbulent flow through process lines of the CIP client. Table SD-6.3.5.2.1-1 details flow rate guidelines for solution contact in straight horizontal and vertical lines for line sizes up to 2 in. (50 mm) without branches, fittings, and other in-line components. These flow rates correspond to a flow velocity of 5 ft/sec (1.5 m/s), which is well into the turbulent range and typical for CIP solutions.

(d) CIP flow rate requirements should be considered in conjunction with other CIP process variables (e.g., temperature, chemical concentration, and time).

(e) Air trapped in branches may inhibit full contact of cleaning agent and rinsing solution to those process contact surfaces. The flow direction, line orientation, line size, and presence and orientation of branches, fittings, and other equipment can have a significant influence on the flow rate required to remove air. Adequate solution contact may be achieved at a flow velocity of 5 ft/sec (1.5 m/s) with 1.5 in. (38 mm) and larger short-outlet tees (see Table DT-4.1.2-5). Smaller-diameter short-outlet tees and tees with longer branches may require velocities greater than 5 ft/sec (1.5 m/s) for adequate solution contact. Solution contact in branches can be enhanced in the design by

(1) strategic use of zero-static valves

(2) flow through branch or bleeding air from branch

(3) orienting blocked branches in the horizontal position

(4) use of flush-mounted instrument fittings, short-outlet tees, gauge tees, or minimum L/d "instrument cups" for small lines

(5) orienting branches so the flow of the liquid entering the tee is directed toward the blocked branch

(f) Branches with risk of incomplete solution contact should be considered worst-case locations that may require local cleaning verification.

NOTE: Factors that may mitigate the risk of insufficient cleaning due to incomplete air removal from branches include the following:

(a) CIP flow rates higher than process flow rates are likely to wet all surfaces that were soiled.

(b) Instruments or other devices protruding into the flow path may create additional local turbulence.

(c) Condensate generated during hot washes or hot rinses as part of a CIP cycle may provide some additional rinsing of surfaces.

(d) Dynamic flow conditions during route transitions and air blows may assist wetting.

SD-6.3.5.2.2 CIP of Process Vessels (24)

(a) Process vessels shall be designed to consistently enable exposure of the internal surfaces to the CIP liquids by spray device or flooding.

(b) Requirements for spray device design can be found in SD-3.9.2.

(c) Appurtenances (e.g., dip tubes) that have interior surfaces not reached by the spray device coverage shall be cleaned by other CIP paths or removed and cleaned out of place.

(d) If a vessel is cleaned with spray devices, the fluid level should be minimized in the process vessel during CIP. Proper hydraulic balance (supply and return flow) of the CIP circuit and sizing of the bottom outlet valve should be considered to minimize fluid level.

(e) A vortex breaker should be installed to prevent vortex formation that may adversely affect the CIP operation.

Table SD-6.3.5.2.1-1
Flow Rates to Achieve 5 ft/sec (1.5 m/s)

	I.D.		Flow Rate	
Nominal Size, in.	in.	mm	gpm	Lpm
½	0.370	9.40	1.7	6.3
¾	0.620	15.75	4.7	18
1	0.870	22.10	9.3	35
1½	1.370	34.80	23	87
2	1.870	47.50	43	162

(f) Vortex breaker surfaces shall be sloped to eliminate pooling during CIP and positioned to not adversely affect the hydraulic balance of the CIP circuit.

(g) For process vessels equipped with an agitator, the impeller should be rotated at an appropriate speed during the CIP cycle.

(24) **SD-6.3.5.3 Chemical Sanitization/Sterilization.** Chemical sterilization is generally not applicable to CIP systems. If liquid chemical sanitization of the CIP skid is required, recirculation should be provided within the skid.

(24) **SD-6.3.5.4 Thermal Sanitization/Sterilization.** Thermal sterilization is generally not applicable to CIP systems. If steam sanitization of the CIP skid is required, the skid shall include provisions for pure steam distribution and condensate removal.

If hot water sanitization of the CIP skid is required, recirculation should be provided within the skid.

(24) **SD-6.3.6 Design for Serviceability, Examination, and Operation.** CIP systems shall be designed to allow for examination and maintenance of components such as return eductors, strainers, and spray devices.

(24) **SD-6.3.7 Testing.** Spray coverage of process and CIP skid vessels shall be confirmed by coverage testing per SD-7.1. The spray coverage test should be performed before the vessel is received at the owner/user's site.

SD-6.4 Thermal Treatment Systems

SD-6.4.1 General

SD-6.4.1.1 Terminology. The following terms are used in this section:

average residence time: the volume of the retention tube divided by the volumetric flow rate. (Average residence time should always be greater than the required residence time.)

coil heat exchanger: a coiled tube for process liquid flow, inside a shell or a second tube containing heating/cooling medium.

cooling equipment: heat exchangers or a flash cooler used to cool the process liquid after the retention tube.

energy recovery heat exchange system: optional equipment that takes heat from the discharge of the retention tube and uses it to preheat the incoming process liquid. These systems may have process fluid on both sides of a heat exchanger.

heating equipment: heat exchangers or direct steam injection equipment. Direct steam injection refers to use of a steam injector valve (typical) or a steam infusion chamber.

high-temperature short time (HTST): processing at a combination of temperature and required residence time that is designed to achieve a desired level of bioburden reduction or viral inactivation. Treatment conditions (i.e., exposure temperatures and residence times) for HTST systems range broadly, depending on the performance goal of the system.

required residence time: the minimum exposure time required at the specified temperature to achieve desired results.

retention tube: a section of tubing used in HTST/UHT systems to retain the process liquid (typically an aqueous solution) at an elevated temperature for a specified time.

ultra-high temperature (UHT): processing at temperatures above 275°F (135°C) with rapid heating and cooling and short exposure times to achieve what is generally accepted as a sterile condition.

Thermal treatment system example configurations are shown in Figures SD-6.4.1.1-1 and SD-6.4.1.1-2.

SD-6.4.1.2 Scope and Purpose. This section addresses thermal treatment systems used in bioprocessing to reduce or eliminate viable microorganisms and viruses in a liquid under continuous flow conditions while minimizing degradation of the product or a product intermediate. Thermal systems may be designed to achieve goals that do not require sterilization of the process liquid, such as inactivation of viruses or a particular bacterial species. Bio-inactivation (waste treatment) systems (SD-4.4.2) and food pasteurization systems are not addressed in the scope of this section.

SD-6.4.2 System Performance Requirements. The following system performance capabilities shall be defined:

(a) treatment temperature range
(b) required residence time at treatment temperature
(c) process liquid flow rate
(d) discharge temperature range
(e) maximum heating surface temperature, heat transfer fluid temperature, or process liquid heating rate (°F/sec, °C/s)

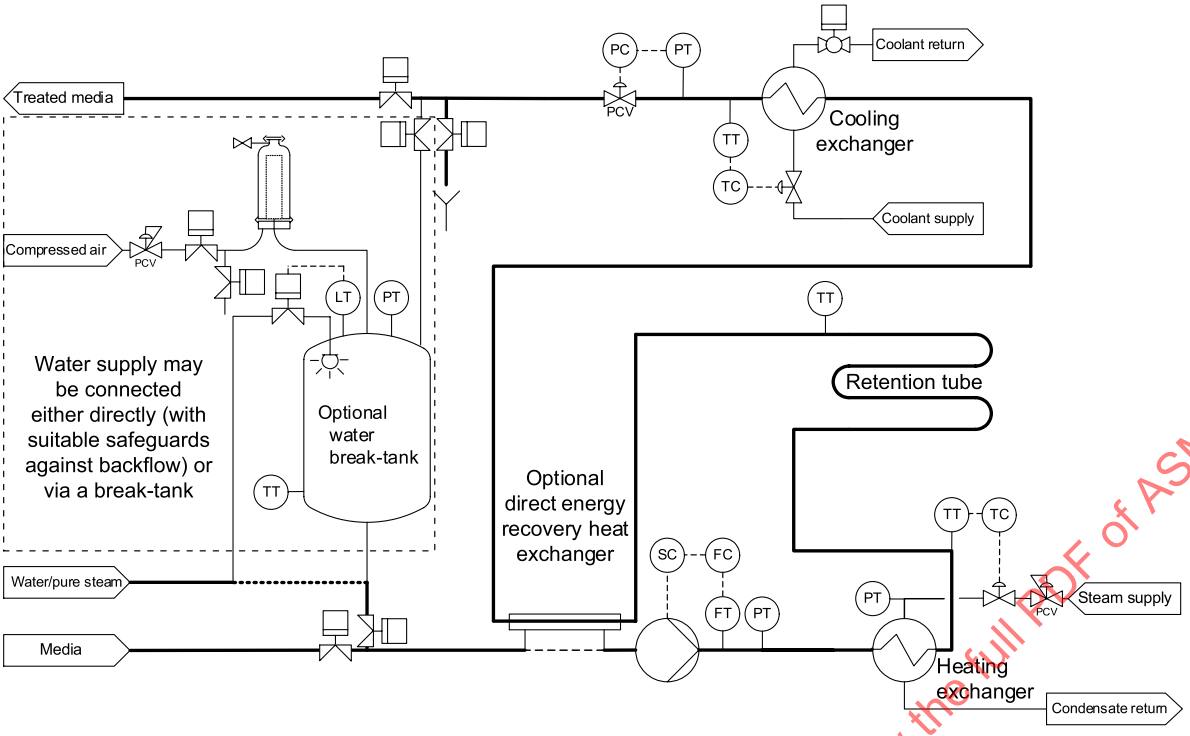
Additional performance requirements may be defined by the owner/user. Additional process parameters required to confirm system capabilities, including specifying the process fluid's incoming temperature and other properties, should be provided by the owner/user.

SD-6.4.3 Operating Capabilities and System Function

SD-6.4.3.1 Priming. The system shall be capable of a priming operation to fill the piping with liquid, remove air, and establish pressure and flow control. The thermal treatment system should be primed by the process liquid to be treated or a priming liquid (e.g., WFI), or both.

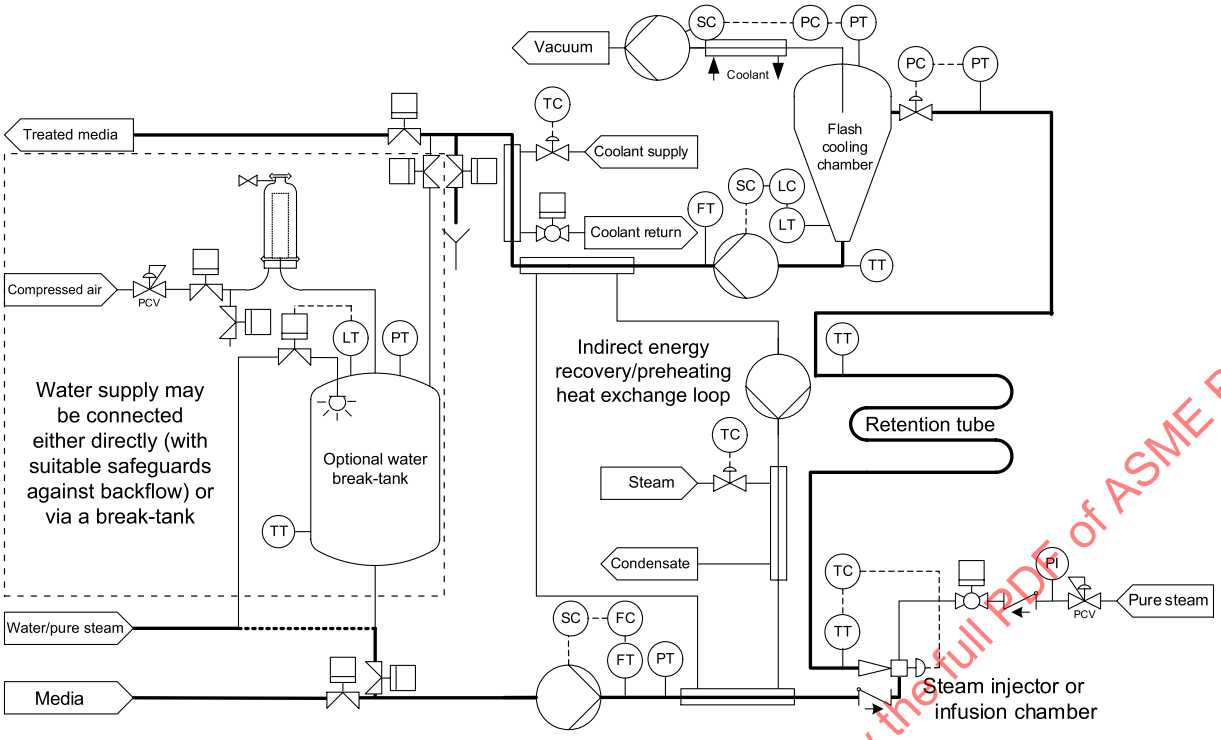
SD-6.4.3.2 Thermal Sanitization. The sanitization conditions (e.g., time and temperature) of the system shall be defined prior to the design or selection. UHT systems shall be designed to enable sanitization. HTST

Figure SD-6.4.1.1-1
Example of HTST Process Flow Schematic Diagram



GENERAL NOTES:
(a) Only major piping and instruments are shown.
(b) Additional or alternative piping, valves, instruments, and equipment may be required for the following purposes, including:
(1) pressure safety
(2) media prefiltration with differential pressure monitoring
(3) CIP requirements
(4) SIP or hot water sanitization requirements
(5) alternative skid startup sanitization methods
(6) single-pass media startup sanitization methods
(7) low-pressure condensate return
(8) maintenance and calibration requirements
(9) energy recovery

Figure SD-6.4.1.1-2
Example of Direct Steam Injection UHT Process Flow Schematic Diagram



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(3) CIP requirements
(4) SIP or hot water sanitization requirements
(5) alternative skid startup sanitization methods
(6) single-pass media startup sanitization methods
(7) low-pressure condensate return
(8) maintenance and calibration requirements
(9) energy recovery

systems shall be designed to enable sanitization when the treated process liquid has the potential to be compromised by the priming activities. The components (e.g., the receiving vessel, cooling exchanger, flash chamber) requiring thermal sanitization to meet functional closure criteria should be identified during design development.

SD-6.4.3.3 Temperature Stabilization. Thermal treatment systems shall be designed to stabilize the temperature of the liquid before initiating forward flow to the destination. Heating, cooling, flow rate, and back pressure control loops shall be enabled and allowed to stabilize prior to heat treatment.

If the system uses a priming liquid, such as WFI, the system shall be designed to stabilize the temperature using the priming liquid and then transition to and meet the performance requirements using the process liquid. Stabilization using the process liquid should continue until all the priming liquid has been cleared from the system, at which point the system shall initiate forward flow of the heat-treated process liquid to the destination.

SD-6.4.3.4 Heat Treatment. The system shall be designed to deliver heat-treated process liquid to the destination only if the performance requirements are met. If they are not met, the system shall divert the liquid to another destination (typically to a drain or a collection vessel). If the heat treatment conditions are not maintained, the owner/user shall specify whether the system resanitizes itself, continues diverting until the temperature and flow requirements are reestablished without resanitization, or performs a shutdown sequence.

The system shall be designed to continue heat treatment until the desired amount of liquid is treated. The owner/user shall specify whether the system flushes residual treated process liquid forward using heat-treated priming liquid to maximize recovery at the conclusion of the process batch.

SD-6.4.3.5 Post-Use Sequence. The owner/user shall specify whether the system shall be designed to perform a cold flush of the HTST or UHT equipment prior to cleaning to minimize soil buildup at the end of processing. The post-use sequence should finish by draining the system or promptly initiating the CIP sequence.

SD-6.4.4 System Design

(a) The following parameters shall be monitored and controlled by the system:

(1) heater outlet temperature

(2) cooler outlet temperature

(3) flow rate

(4) back pressure

(b) The following parameter shall be monitored by the system: retention tube outlet temperature.

(c) The owner/user shall specify whether the system shall be primed using compendial water (from a break-tank or from a backflow-protected direct water system connection) or sanitized and primed using the process liquid.

(d) The following should be considered in selection of materials used in fabrication of HTST/UHT systems:

(1) Cyclic temperature and pressure conditions may shorten the life of materials.

(2) Solutions at high temperature may accelerate the rate of metal corrosion or elastomer/polymer degradation.

(3) High-temperature operating conditions used in UHT systems may exceed the temperature ratings of typical bioprocessing equipment or components.

(e) Although UHT processing conditions are above the temperature limit specified in SD-2.3.1.1, process contact materials used for these systems shall be selected to meet the higher temperature requirements of the process.

SD-6.4.4.1 Heat Exchangers. Heat exchangers shall be designed to meet the performance requirements in SD-6.4.2 and the applicable design criteria of SD-3.6. Heat exchangers shall be designed to achieve fully developed turbulent flow conditions during process and CIP operations, on the process liquid contacting side(s) of the exchanger. Heat exchangers should be designed and operated such that the pressure of the treated process liquid is higher than the pressure of the utility or untreated process liquid during heat treatment to reduce the risk of process liquid contamination, unless the owner/user has assessed the risk of an alternate design. The owner/user should identify any requirements needed to minimize process fouling or enhance cleaning performance (e.g., minimum Reynolds number or velocity, maximum process contact surface temperature).

Direct energy recovery heat exchangers with process fluids on both hot and cold sides (Figure SD-6.4.1.1-1) shall be of hygienic design on both sides. Indirect energy recovery heat exchangers (Figure SD-6.4.1.1-2) shall be of hygienic design on the process fluid side.

The following types of heat exchangers may be used in thermal treatment systems:

(a) Shell and Tube. Shell-and-tube heat exchangers may be straight tube or U-tube. The effect of bypass through the bonnet drain slots and slippage between the bonnet and tube sheet shall be considered in thermal design of the heat exchanger.

(b) Coil-in-Shell. Coil-in-shell heat exchangers shall be installed in a drainable vertical orientation.

(c) Electric. Electric heat exchangers shall be designed to provide uniform heating (e.g., where electric current is applied directly to the process contact tube).

(d) Tube-in-Tube. Process liquid should flow through the inner tube. Process fluid may also flow through the outer tube in direct energy recovery heat exchangers.

(e) Plate-and-Frame. See cautions in SD-3.6 regarding use of plate-and-frame heat exchangers before considering use in this application.

SD-6.4.4.2 Steam Injectors

(a) Steam injectors shall introduce steam (typically pure steam) directly into process liquids.

(b) Steam injectors shall be installed such that single-phase flow is achieved at the desired outlet temperature. A sight glass installed downstream of the steam injector is recommended to confirm single-phase flow.

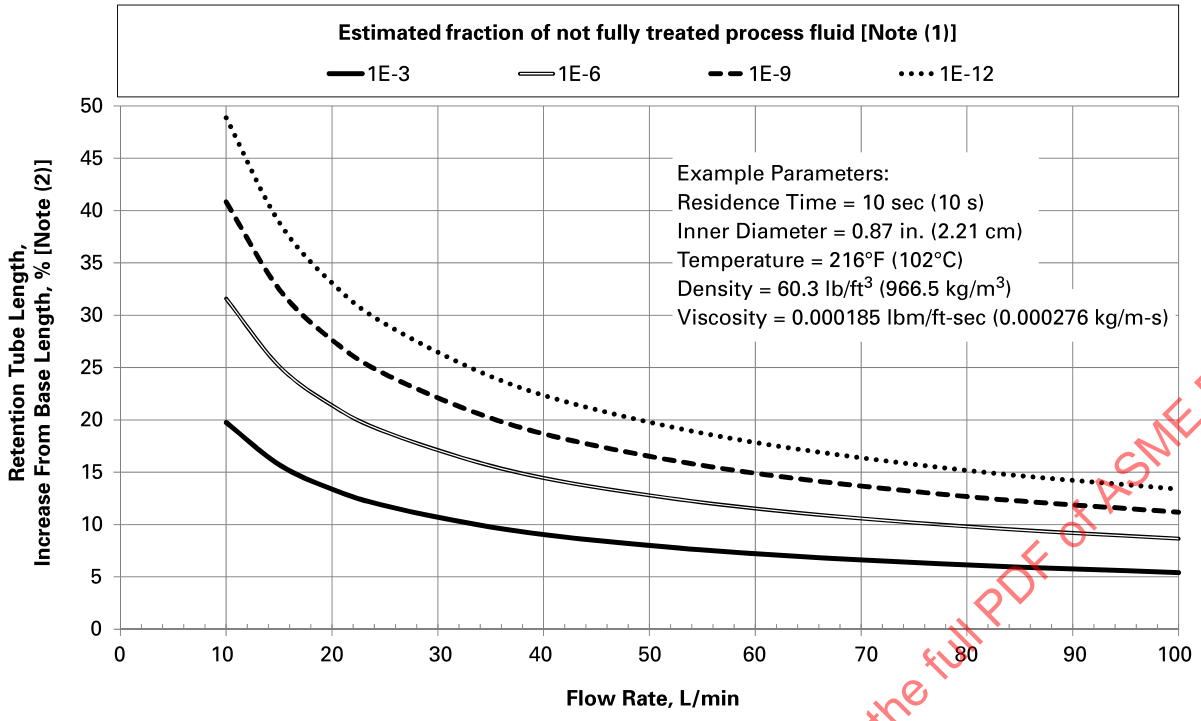
(c) Steam injectors shall be oriented to permit CIP, or designed for disassembly and cleaning out of place (COP), with agreement from the owner/user. Where the steam injection system is designed for CIP, it shall be drainable and exposed to CIP solution across the seat of the steam injection valve.

(d) Media dilution and changes in retention time due to condensate addition shall be accounted for in the system design.

SD-6.4.4.3 Flash Chambers. [Reserved for future content]

SD-6.4.4.4 Pumps. Process contact pumps used in HTST/UHT systems shall be hygienic and shall conform to SD-3.3.

Figure SD-6.4.4.5-1
Example of Additional Retention Tube Length Required to Account for Axial Mixing



NOTES:
(1) "Not fully treated" fluid is defined as fluid whose retention time is less than the required retention time.
(2) "Base length" is the average fluid velocity in the retention tube multiplied by the required retention time.

SD-6.4.4.5 Retention Tube

(a) To account for axial dispersion in the piping, the average residence time necessary to achieve the required residence time shall be defined by the owner/user.

NOTE: The average residence time should be specified so as to meet the owner/user-defined probability that each process fluid particle is retained for the required residence time. As an example, the Taylor equation for axial dispersion in turbulent flow was used to develop Figure SD-6.4.4.5-1 which shows the theoretical additional retention tube length required for a water-like liquid treated at 216°F (102°C) for 10 sec in a 1-in. (25-mm) nominal retention tube to account for axial dispersion, assuming an insignificant number of bends. In the figure, to ensure that less than 1 particle out of 10^{12} has less than the 10-sec required residence time at 9.2 gal/min (35 L/min), the retention tube length would have to increase by 24%. Actual retention tube geometry, such as the number and radii of elbows, coils, or U-bends, may impact the results.

(b) The retention tube diameter should be no larger than the main system piping diameter to minimize the residence time range due to axial dispersion.

(c) The retention tube shall be designed to enable visual inspection at its inlet and outlet. The owner/user shall specify whether inspection is required for two-phase flow during operation or for cleaning effectiveness.

(d) The retention tube shall be designed to maintain a consistent temperature within the tube during heat treatment (e.g., the tube should be insulated and shall not have branches or tees that could result in low local temperatures).

(e) No device shall be permitted for short-circuiting a portion of the retention tube (e.g., bypass valves) to compensate for changes in the process liquid flow rate.

(f) The retention tube shall have a continuous upward slope toward the discharge conforming to Table SD-2.4.3.1-1 category GSD3 to ensure that air is purged from the retention tube during operation. It shall be drainable during cleaning and/or sterilization operations.

(g) No portion of the retention tube between the inlet and the outlet temperature sensors shall be heated.

SD-6.4.4.6 Flow Control. The flow rate shall be controlled and monitored to ensure proper system operation.

SD-6.4.4.7 Back Pressure Control. The system shall be designed to ensure that pressure downstream of the heating exchanger or steam injector is above the process

fluid boiling pressure, until the treated fluid has been cooled or until it reaches a flash chamber for cooling. A pressure of at least 10 psi (0.7 bar) above the boiling pressure is recommended.

SD-6.4.4.8 Instrumentation. [Reserved for future content]

SD-6.4.4.9 Interfaces

(a) The owner/user shall specify the maximum allowable discharge temperature for connections to the system outlet and drains.

(b) The owner/user shall specify whether system sanitization/sterilization ends within the system boundary or extends beyond the system boundary to upstream or downstream equipment.

(c) To design appropriate interfaces with source and destination systems, the owner/user shall provide the stated purpose of the system and the functional location within the process (e.g., upstream or downstream of sterilizing filters). The owner/user shall specify whether the thermal treatment system is intended to be implemented as part of an open, functionally closed, or briefly exposed process.

SD-6.4.5 Design for Bioburden Control

SD-6.4.5.1 Drainability. The process contact portions of the system shall be drainable per SD-2.4.3.

SD-6.4.5.2 Cleaning. Thermal treatment systems shall be designed for CIP of process contact surfaces, unless other methods are specified where necessary. Where fouling of heated surfaces may occur, cleaning and operational procedures (e.g., visual inspection) should address potential fouling of those segments of the system. When compendial water from a break-tank is used in nonrecirculating mode to condition and flush the system, provision shall be made for the sanitization of the water tank and its piping at a minimum.

SD-6.4.5.3 Chemical Sanitization/Sterilization. If chemical sanitization or sterilization of the system is required, the area within the sterile envelope or boundary shall be designed for exposure to and removal of the sanitizing agent while maintaining the sanitized state.

SD-6.4.5.4 Thermal Sanitization/Sterilization. If thermal sanitization or sterilization of the system is required, the area within the sterile envelope or boundary shall be designed for SIP or for sanitizing/sterilizing the system with hot liquid.

SD-6.4.5.5 Post-Use Storage. [Reserved for future content]

SD-6.4.6 Design for Serviceability, Examination, and Operation. [Reserved for future content]

SD-6.4.7 Testing. System performance requirements (e.g., residence time at temperature) to be tested for HTST or UHT shall be defined by the owner/user. The system design should accommodate test instrumentation required to verify the system performance and confirm the control/monitoring process performance.

(a) Temperature performance should be verified using temperature measurement devices independent of the system instruments at the inlet and outlet of the retention tube. The independent sensors should be positioned in a manner that allows measurement of the bulk fluid temperature.

(b) Average residence time should be determined. It may be determined by dividing the retention tube volume by the measured flow rate.

(c) If a surface temperature limit has been specified by the owner/user, the heating surface temperature should be verified. For electrically heated tubing, the exterior surface temperature may be measured to provide an indirect, but conservative, measure of the interior surface temperature. For steam-liquid or liquid-liquid heat exchangers, the utility-side (e.g., steam or hot water) inlet temperature may be measured to provide an indirect, but conservative, measure of the tube surface temperature.

(d) Initial testing of new equipment should document the heat supplied to meet the process requirements. The heat supplied can be documented as power input for electrically heated tubes, steam pressure for steam heat exchangers, and on-process liquid inlet and outlet temperatures for liquid-liquid heat exchangers.

(e) Initial testing of system performance should document the steady-state pump speed, pump differential pressure, flow rate, system back pressure, and back pressure control valve position.

SD-6.5 Immersion Washers

SD-6.5.1 General. This section describes the requirements for immersion washers used in bioprocessing that are designed to clean parts out of place from their typical installation. Immersion washers are a subcategory of clean-out-of-place (COP) washers, which includes cabinet washers (see SD-6.1). When using immersion washers, parts are completely submerged within an immersion tank throughout the cleaning cycle. Requirements in this section are intended to be applied to immersion washers, but may be applied to other types of washers where appropriate.

The following terms are defined for this section:

designed load immersion basket/rack: a basket or rack to hold parts that is designed for a specific, repeatable loading configuration. A designed load basket or rack is used for geometrically complex parts where there is concern with cleanability of the part due to it requiring specific orientation or placement, liquid holdup after system draining, or entrapped air during a cleaning cycle.

end nozzle zone: a hydraulic circuit with nozzles or jets that encourages end-to-end flow within an immersion tank.

general load immersion basket/rack: a basket or rack to hold parts that is not designed for any specific loading configuration or orientation of the parts. A general load basket or rack is used for geometrically simple parts (e.g., gaskets) or non-process contact surface components (e.g., clamps, tools) where repeatable orientation is not critical.

immersion tank: the vessel designed to hold and allow delivery of cleaning solutions in which parts are immersed.

parts: any component to be cleaned in the immersion washer, such as pipes, hoses, clamps, gaskets, fittings, and accessories.

side nozzle zone: a hydraulic circuit with nozzles or jets that encourages rotational flow within an immersion tank.

SD-6.5.2 System Performance Requirements. Immersion washers shall be capable of delivering and removing cleaning solutions from surfaces of parts across multiple phases of a cleaning cycle. Immersion washers may be self-contained, or receive cleaning solutions from a CIP system. The following are typical general phases of an immersion washer cleaning cycle:

(a) pre-rinse
(b) wash
(c) rinse
(d) final rinse

The design should allow for multiple chemical additions during washing phases. The hydraulic conditions (i.e., pressure and flow rate) of all rinsing phases should be the same as for wash phases to ensure consistent rinsing of parts, immersion tank interior, and hydraulic circuit. The final rinse may be performed with recirculated final rinse water integrated with drain steps to remove residual cleaning solutions. The design should be capable of providing a final rinse phase at an elevated temperature [e.g., >149°F (65°C)] to improve air-drying efficiency.

SD-6.5.3 Operating Capabilities and System Function

(a) The immersion washer should control and monitor time of exposure (contact time) during wash and rinse phases.

(b) The immersion washer shall control and monitor cleaning solution temperature during all washing and rinsing phases.

(c) The immersion washer should monitor the pressure or flow of cleaning solutions supplied to zones within the immersion tank or immersion basket/rack.

(d) The immersion washer shall be designed to provide analytical verification of final rinse water quality (e.g., conductivity, TOC, number of final rinse steps).

(e) For immersion washer capabilities for chemical addition, see SD-6.1.4.7.

(f) For immersion washer recirculation pump requirements, see SD-6.1.4.8(b) and SD-6.1.4.8(c).

(g) Immersion washer pumps should have sufficient capacity (flow and pressure) for all zones used in the washer.

(h) For immersion washer heat exchanger requirements, see SD-6.1.4.9.

SD-6.5.4 System Design

(a) Immersion baskets/racks (general or designed load) should incorporate thermoplastic or thermoset material components to prevent scratching of the parts and the I.D. surface of the immersion tank.

(b) Materials of construction of immersion washer process contact surfaces shall adhere to the same requirements set forth in the cabinet washers section [see SD-6.1.3(a)].

(c) Materials of construction and general design of the immersion tank shall follow requirements for vessel general design (see SD-3.4.1). The full vacuum service design requirement is not applicable to atmospheric immersion tanks.

(d) The surface finishes for the interior surfaces of the immersion tank, process contact tubing surfaces, and any other process contact surfaces shall be specified by the owner/user using designations provided in Table SF-2.4.1-1. Electropolishing is not required for immersion washers.

(e) The surface finish of baskets/racks, supports, thermowells, guards, and other internal tank components should meet the surface finish requirements of the tank. Surface finish verification may not be possible for all components of an immersion washer's baskets/racks.

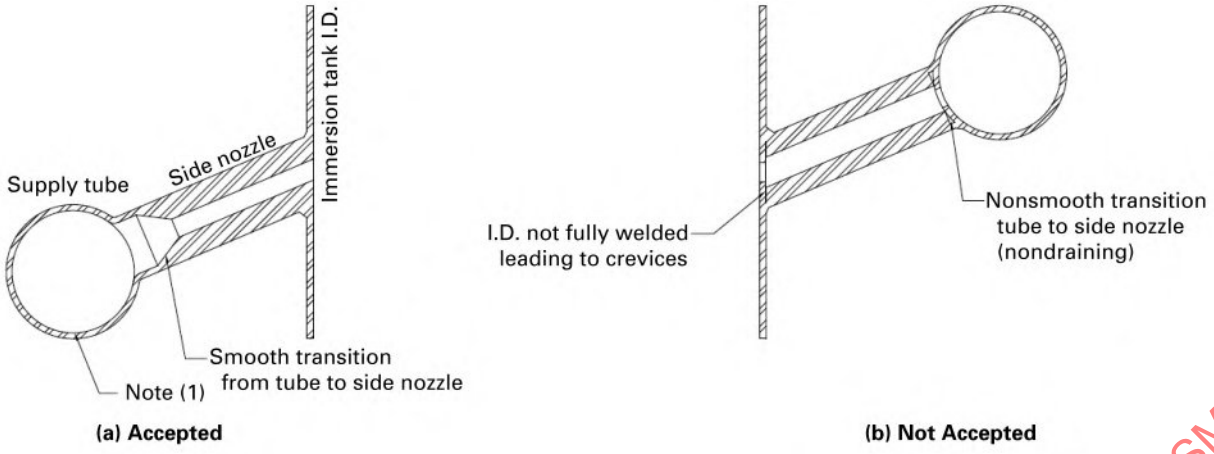
(f) The internal surface finish of the immersion tank cover should be the same as specified for the immersion tank internal surfaces.

SD-6.5.4.1 Zone Design

(a) Immersion washer design can include multiple zones to clean parts through various methods. Zone piping design shall follow SD-3.1.2.2, with the consideration that zone branch connections shall be opened between each phase to avoid carryover. All zones should be targeted during each phase to provide consistent flushing.

(b) Turbulence is critical for cleaning within an immersion washer, and zone design should provide adequate turbulence to all part surfaces. For example, tubing or similar parts that are not exposed to turbulence on the I.D. from a side nozzle zone would require an end nozzle zone or direct connection to a zone to provide adequate I.D. flow.

Figure SD-6.5.4.2-1
Immersion Tank Side Nozzle Design



NOTE: (1) Supply tubing and all side nozzles should be drainable, either back through the supply tube header or into the immersion tank.

(c) For zones with piping manifolds within the immersion tank, baskets, or racks, the fabrication of the piping manifolds shall conform to the applicable sections of system piping (see SD-3.1.2.3).

SD-6.5.4.2 Tank and Cover Openings

(a) Immersion tank and cover opening design shall adhere to the same requirements used for cabinet washers (see SD-6.1.4.1).

(b) Side nozzles shall be of hygienic design (see Figure SD-6.5.4.2-1).

(c) Immersion tank covers should be used and designed to reduce operator exposure to splashing during operation as well as to minimize added humidity to the area around the immersion washer. Both sealed and nonsealed designs are permitted.

(d) Sealed (e.g., gasket or O-ring) immersion tank covers shall be designed to prevent wash fluid from leakage during the wash cycle.

(e) Nonsealed immersion tank covers should be designed to minimize wash fluid leakage during the wash cycle.

(f) Both sealed and nonsealed types should be designed to minimize wash droplet formation above the immersion tank and loaded parts.

(g) Process contact static seals used in immersion washers shall conform to the requirements of Part MC.

(h) The external surfaces (e.g., frame, immersion tank O.D.) shall meet the owner/user's specified requirements of the installed location of the equipment.

(i) External surfaces should be insulated to minimize heat transmission

SD-6.5.4.3 Baskets and Racks

(a) General load immersion baskets/racks should be designed to accommodate variable configurations and load items. Parts used in these baskets/racks do not require a specific orientation for drainability or to prevent air entrapment.

(b) Designed load immersion baskets/racks should be designed for repeatable loading and may be subject to verification, if required by the owner/user, to assure removal of entrapped air. Load items as well as the designed load immersion basket/rack shall be drainable.

(c) All immersion baskets/racks should be designed for disassembly required for inspection and maintenance.

SD-6.5.4.4 Interfaces. Immersion washers' parts are loaded and unloaded in the same area/room classification. If process flow requires a separation of clean and dirty parts, an immersion washer should not be used.

SD-6.5.5 Design for Bioburden Reduction

SD-6.5.5.1 Drainability

(a) Immersion washer process contact surfaces shall adhere to SD-2.4.3.

(b) For rectangular immersion tanks sloped both to center and along the tank length, a minimum lengthwise slope designation of GSD3 (see Table SD-2.4.3.1-1) should be used for drainability. Other surfaces sloping to drain within the tank are also recommended to have a minimum slope of GSD3.

SD-6.5.5.2 Cleaning. The interior surfaces and components of the tank as well as the baskets/racks are considered process contact surfaces and should conform to SD-2.4.2 except for SD-2.4.2(a)(4). These

surfaces include the immersion tank wall I.D. above an overflow port and the immersion tank cover I.D. surfaces with the potential to drip onto cleaned parts within the immersion tank.

(a) Engraving or embossing of materials (for identification or traceability) is permitted on exterior process contact surfaces, such as the exterior of process contact tubing in the washer. Engraving or embossing should be limited to only what is needed for unique identification or traceability.

(b) Adherence to SD-2.4.2(a)(2) for the immersion tank wall I.D. above an overflow port and immersion tank cover I.D. surfaces should be considered by the owner/user depending on the criticality of the parts being cleaned.

(c) Final rinse tank level should be higher than wash solution rinse level to promote quicker achievement of final rinse conditions.

Parts with recessed holes or cavities should not be cleaned in immersion washers. Risk of air entrapment or inability to drain may impede exposure to and removal of cleaning solution.

SD-6.5.6 Design for Serviceability, Examination, and Operation. Immersion washers should be designed to enable access for inspection and service of components that are subject to wear, and to allow for periodic calibration of instruments.

SD-6.5.7 Testing

SD-6.5.7.1 Flow Coverage. Designed load immersion washer baskets/racks designed for repeatable loading should have flow coverage (e.g., riboflavin) testing performed for verification of liquid coverage of parts' surfaces. The spray coverage testing described in SD-7.1 is applicable to the flow coverage testing for immersion washers. If Nonmandatory Appendix M is used, it is applicable to immersion washers, with the following additional considerations:

(a) The scope of the riboflavin application and expected removal should be documented and agreed to by all parties (e.g., parts and baskets/racks only; parts, baskets/racks, and immersion tank process contact surfaces).

(b) Riboflavin may be applied while parts are loaded in the baskets/racks inside of the immersion tank, or may be applied to parts prior to loading into the basket/rack or immersion tank. Application prior to loading may be required for parts with limited access areas such as tubing lengths.

(c) Immersion tank filling should occur as in normal operation and to the normal operating level. As once-through rinsing is not applicable to immersion washers, a complete fill, zone(s) rinsing, and drain should be performed not less than two times. The maximum number of zone rinses (complete fill and drain) during the riboflavin testing shall not exceed the total number of phases with complete fill and drain steps during an owner/user's normal operating wash cycle. Only the zones applicable to the components being tested should be used. Pertinent information such as zones used, time of rinse, and zone sequencing should be recorded.

(d) Riboflavin inspection may occur while parts are still loaded in the immersion tank, outside of the immersion tank, or through a combination of both. Inspection outside of the immersion tank may be needed for parts with limited access areas. Care should be taken while unloading parts from the baskets/racks or immersion tank to avoid false results due to transfer of residual riboflavin from other parts.

General load immersion washer baskets/racks are not subject to the same testing due to the nonrepeatable and nondesignated loading conditions and variations in parts being cleaned.

SD-6.5.7.2 Drainability. Drainability testing for immersion tanks should use methods described in SD-7.4 for vessels, with the following additional considerations:

(a) At minimum, the immersion tank should be filled to completely submerge the tank bottom.

(b) Drainability testing intended for ensuring immersion tank drainability should be performed without any baskets/racks loaded.

(c) Any outlet strainer or screen used in normal operation should be installed.

(d) Drainability testing can be performed on designed load baskets/racks and loaded parts to verify draining of surfaces on these components. The baskets/racks and parts loading information and configuration should be recorded, and the immersion tank should be filled to at minimum above the highest component of the basket/rack or loaded part.

SD-6.6 Isolator Systems

SD-6.6.1 General. Isolator systems, hereafter referred to as isolators, are used to create a controlled environment for bioprocessing and quality control testing that is isolated from operators and the background environment. This section describes the design requirements for two types of isolators, as follows:

(a) aseptic isolators, which are designed to protect the process from the environment, enable aseptic processing (e.g., cell bank processing, liquid filling of final product)

(b) containment isolators, which are designed to protect the operator environment from the process and enable safe processing of potent compounds (or other hazards) in an isolated environment

This section does not address equipment/components used inside the isolator. Requirements of the process and process equipment enclosed by the isolator should be provided by the owner/user. This section is not applicable

to restricted access barrier systems, which restrict access but do not provide environmental isolation.

SD-6.6.2 System Performance Requirements. The following system performance requirements shall be defined:

(a) environmental classification inside and outside the isolator

(b) airflow conditions as unidirectional or turbulent

(c) pressure differential target to background environment

(d) log reduction for decontamination

(e) overall cycle time limit for decontamination and aeration

(f) temperature operating ranges

(g) humidity operating ranges

(h) recirculation air, make-up air, and total exhaust air flow limitations

(i) allowable decontamination agent (e.g., vapor phase hydrogen peroxide) concentration at the end of aeration for product protection

SD-6.6.3 Operating Capabilities and System Function

SD-6.6.3.1 Differential Pressure Control. Differential pressure set points should be adjustable in the range of 0.06 in. to 0.18 in. (15 Pa to 45 Pa) of the water column. Phase transitions in the isolator system (e.g., re-dosing to aeration, aeration to production) shall be controlled without loss of pressure balance in the surrounding room specified by the owner/user.

It is permissible for the set point to be positive or negative to the surrounding room as defined by the owner/user to meet the product manufacturing requirements. The differential pressure (between the isolator interior and exterior) should be maintained within 0.02 in. (5 Pa) of water column of the set point.

SD-6.6.3.2 Temperature and Humidity. The isolator should be designed to monitor operational, decontamination, and aeration temperatures within the range specified by the owner/user.

Humidification requirements are application dependent and should be agreed to by the owner/user. Consideration should be given to decontamination requirements, product requirements, potential static electricity discharge, and condensation within the isolator or connected equipment (e.g., lyophilizer).

SD-6.6.3.3 Decontamination. Unless otherwise specified by the owner/user, the decontamination cycle shall demonstrate a five log reduction of microorganisms. The complete decontamination cycle includes leak testing, conditioning, decontamination, and aeration of residual decontamination agents. The isolator shall be designed to reduce the level of the residual decontamination agent to a concentration to be specified by the owner/user. If vapor phase hydrogen peroxide is used, the aeration shall reduce the residual vapor phase hydrogen peroxide to <1.0 ppm at the specified operating temperature for operator safety. The isolator should be designed to prevent opening during decontamination (e.g., incorporating door and window interlocks).

SD-6.6.3.4 Venting During Aeration. The isolator shall be designed to safely exhaust decontamination gas through a dedicated exhaust system. For example, if hydrogen peroxide gas is exhausted, a building stack or catalytic filter may be required to safely convert the hydrogen peroxide into water vapor and oxygen as it is released to the environment.

SD-6.6.4 System Design. Isolator systems contain bioprocessing equipment and normally do not have product contact surfaces. The owner/user shall specify

(a) surfaces required to be designed for product contact

(b) isolator designation as aseptic or containment

(c) product sensitivity to decontamination agents

(d) specific environmental requirements (e.g., inert gas blanketing)

Process contact surfaces should be impervious, nonreactive, nonadditive, and resistant to cleaning/decontaminating agents. Metallic process contact surfaces shall be fabricated with 316-type or 316L-type stainless steel by welded construction, unless otherwise approved by the owner/user. Exterior non-process contact surfaces may be fabricated with 304-type or 304L-type stainless steel by welded construction.

All equipment should be compatible (chemically resistant, nonpermeable) with cleaning and sanitization agents specified by the owner/user, e.g., sporicidal agents, peracetic acid, hydrogen peroxide gas, or 70% IPA.

Glove ports, comprising a glove and sleeve sealed into the wall or window of an isolator, shall be made with materials resistant to decontamination agents and specified sanitizing/cleaning agents (e.g., hard coated aluminum, stainless steel, UHMWPE).

Unless otherwise specified by the owner/user, process contact surfaces of metal construction should have a surface roughness of 35 µin. R_a (0.89 µm) or less. Unless otherwise specified by the owner/user, the exterior (non-process contact surfaces) of metal construction should have a surface roughness compatible with the associated environmental classification. If the exterior operational environment is ISO class 8, a surface finish of 48 µin. R_a (1.2 µm) or less is recommended for metal construction.

SD-6.6.4.1 Isolator Shell. The isolator shell (the main work chamber of the isolator), which may include windows, lights, and openings, should be designed to integrate internal equipment with ergonomic operations. The isolator shell construction should be designed to accommodate the user-specified pressure differential with limited shell deformation. Isolator shell deformation limits should accommodate openings where brittle material may be used such as glass windows and lights.

To ensure isolator shell seal integrity, tolerances for isolator shell and connection points should accommodate the potential for weld heat distortion. The shell shall be fabricated using welded construction unless otherwise specified by the owner/user.

The isolator shell construction radii of internal corners and seams should be 0.6 in. (15 mm) or greater to facilitate cleanability.

The aseptic isolator design should provide a barrier or sufficient space for the separation of particulate generating operations (e.g., stoppering and capping) from the product filling operations.

SD-6.6.4.2 Isolator Base Plate. The isolator base plate (the lowest part of the isolator interior interfacing with the isolator shell) shall be designed to separate the isolator environment from the area below, which may contain drives, motors, electrical installation, and other components. The isolator base plate surfaces exposed to the isolator environment are considered process contact surfaces. Isolator base plate penetrations shall be designed with integral seals to establish a pressure boundary to avoid contamination. Penetrations should use rounded corners with minimum radii of 0.6 in. (15 mm) to facilitate cleanability.

The isolator base plate thickness shall be designed to support process equipment specified by the owner/user.

Where isolators are designed for CIP or liquid washing, the isolator base plate shall be sloped to one or more drains in the isolator base plate.

When the isolator manufacturer does not fabricate the base plate, dimensions and tolerances for tight integration with the isolator shell shall be provided to the isolator manufacturer by the isolator base plate fabricator or owner/user.

SD-6.6.4.3 Doors/Windows. Doors/windows should be designed, installed, and sealed to maintain the shell integrity and cleanability. The design shall provide access to clean the inside of the windows.

Both fixed and operable window designs are permitted. Door and operable window designs should consider interlocks to prevent opening during decontamination.

SD-6.6.4.4 Lighting. Lights should be designed, installed, and sealed to allow illumination of the isolator interior while maintaining the shell integrity and without compromising cleanability. The owner/user should specify product sensitivities to certain wavelengths (e.g., UV wavelengths) or to light intensity levels. The type and intensity of light at the work location should be specified by the owner/user to meet ergonomic requirements (e.g., fluorescent lighting at 75 foot-candles to 80 foot-candles (0.026 lumens/m^2 to 0.028 lumens/m^2) or LED lighting at 45 foot-candles to 50 foot-candles (0.016 lumens/m^2 to 0.017 lumens/m^2). If specified, the design should accommodate different levels of lighting within the isolator (e.g., at least one for processing and one for cleaning/sanitization). The placement and orientation of the lighting should minimize reflection and glare on the windows.

SD-6.6.4.5 Glove Ports. The design of an isolator should include a mock-up activity to determine the final position of any glove port. The mock-up should include a life-size model of the isolator and the equipment planned for use in the isolator for verifying ergonomics and accessibility. Both oval and circular shapes are permitted. Glove seal construction inside the isolator shall be free of crevices, threaded fasteners, or any areas difficult to clean and decontaminate. The glove port shall be designed to provide an integral seal with the isolator.

For containment isolators, the glove port shall be designed to allow a glove change without exposing the used glove to operators.

SD-6.6.4.6 ULPA/HEPA Filters. For aseptic isolators, the total nonviable particulate concentration shall meet ISO class 5 requirements using ULPA or HEPA filters. For aseptic isolators, the design should be capable of unidirectional (downward) airflow during normal operation with airflow velocity of 90 ft/min (0.46 m/s) ± 20% as measured 6 in. to 12 in. (15.2 cm to 30.5 cm) below the diffuser membrane. Turbulent airflow conditions are permitted during decontamination and aeration.

For containment isolators, ULPA filters are recommended. Airflow breach velocity (e.g., as measured from an open glove port) should be between 100 ft/min and 125 ft/min (0.51 m/s and 0.64 m/s), unless otherwise specified by the owner/user.

SD-6.6.4.7 Transfer Ports. The aseptic isolator design shall provide for aseptic transfer of components required for the operation (e.g., caps, stoppers for filling). The design should accommodate component transfer for initial setup and to replenish supplies during operation.

Connected tubing from a final filter into filling heads in an isolator shall have an integral seal at the isolator shell. The recommended location for the final filter is outside the isolator.

A rapid transfer port (RTP, sometimes referred to as an alpha-beta port) in which mating ports between the isolator and another container or system, whose exposed door surfaces become sealed when interlocked to each other, shall be designed to maintain isolation integrity while transferring materials into and out of an isolator. The mating surfaces of RTPs shall create a seal such that opened ports do not expose the isolator environment to surfaces that have not been decontaminated.

RTPs should be located to accommodate the operator access through glove ports and allow adequate clearance from internal equipment when open. Sizes should be

specified to include the beta container seal clearance when docked. In containment applications, a mechanical interlock should be provided to prevent the alpha door from being opened when the beta container is not docked. The use of RTPs for powder transfers that come into direct contact with seals is not permitted.

Split valves that use the same interface technology as RTPs, except that the interlock acts as a butterfly valve, may be used for liquid or solids additions into an isolator. Split valves are permitted for use in both aseptic and containment isolators.

Pass-in/pass-out holes (openings that allow the transfer of material into and out of isolators while in operation) shall be designed to be sealed by an external door during a decontamination cycle. The design of aseptic isolators should not permit opened doors of pass-in/pass-out holes to rest in a position above the aseptic operations. The isolator shall be designed to maintain specified pressure differentials and airflow velocities with open pass-in/pass-out holes during normal operation.

SD-6.6.4.8 Airlock/Decontamination Chamber. Airlock/decontamination chambers, compartments with an inner door and outer door used for moving material into and out of the isolator, shall be designed with double-interlocked doors, which prevent the outer door (to room) from being opened while the inner door (to isolator) is open. Both doors should also be interlocked from opening during the decontamination cycle. The inner door shall be interlocked such that it can only be opened after a successful decontamination cycle.

SD-6.6.4.9 Internal Components. For piping/tubing, all wetted process contact tubing shall conform to SD-2.4.2 and shall be either sloped or provided with an air purge, or both, to enable liquid removal from lines per SD-2.4.3 and Nonmandatory Appendix C. Welded joints are preferred. If disassembling of the pipe/tube system is required, hygienic process connections shall be used. Exposed threads (e.g., the exterior of hygienic clamps) should be avoided within the isolator.

Brackets or other equipment shall not be located directly above open containers in aseptic isolator interiors.

SD-6.6.4.10 Instruments

(a) Hydrogen Peroxide Detection. When hydrogen peroxide is used as a decontaminating agent, the system should be designed to detect residual hydrogen peroxide above specified critical levels for product and personnel safety. For personnel safety, residual hydrogen peroxide shall be less than 1 ppm. The owner/user shall specify the residual level limit to protect the product. The measurement principle and detection limit of sensors should be agreed on between the manufacturer and owner/user. The sensor position shall provide for monitoring the worst-case location within the isolator.

(b) Viable Particle Indicators. The isolators designed to create ISO class 5 conditions shall include continuous active air sampling for viable particle monitoring during active processing.

(c) Nonviable Particle Indicators. The isolators designed to create ISO class 5 conditions shall include continuous particle monitoring for nonviable particles.

SD-6.6.4.11 Seals. All elastomer seals shall meet 21 CFR 177.2600 or equivalent. Gaskets and O-ring seals used to seal the isolator are not considered product contact surfaces, but should be nonshedding where exposed to the aseptic environment. Where seals are exposed to cleaning or decontamination processes, they are considered process contact surfaces and shall be resistant to cleaning and decontamination fluids. Process contact elastomers shall conform to the applicable requirements in Part PM or Part MC. The potential for seal degradation and chemical absorption and subsequent desorption should be considered in the selection of seal materials. For example, silicone and EPDM offer resistance to many cleaning and decontamination agents.

Inflatable seals and static seals are permitted. For example, inflatable seals are acceptable for doors/windows that are designed to be opened during setup and cleaning procedures. The potential for occluded areas should be considered in the design and use of inflatable seals. Inflatable seals shall have a continuous leak check, using either constant pressure or constant flow.

Seals between the isolator shell and mating equipment (e.g., depyrogenation tunnel, lyophilizer) should be designed to accommodate the effects of the thermal dilation/contraction of the mating equipment. The temperature at these interfaces should be considered in the selection of seal material.

When an isolator system comprises multiple connected isolators, seals between isolators shall be designed to expose seal surfaces to decontamination agents during a decontamination cycle. Single or double seals are permitted between isolator chambers.

SD-6.6.4.12 External Surfaces. Exterior design requirements of SD-2.4.4.2 are applicable to isolators. The external surfaces of an aseptic isolator shall be compatible with the environmental classification to which it interfaces. The following design practices should be considered:

(a) All cables should be covered.

(b) Gaps between the isolator and other equipment, such as depyrogenation tunnels or lyophilizers, should be sealed.

SD-6.6.5 Design for Bioburden Control

SD-6.6.5.1 Drainability. Horizontal process contact surfaces of the isolator shall be drainable. If CIP of the isolator is specified, all permanently installed internal liquid distribution piping (e.g., spray wands) should be

sloped to meet the requirements of Table SD-2.4.3.1-1 category GSD2 where possible or supplied with an air purge to facilitate liquid removal per SD-2.4.3 and Nonmandatory Appendix C.

SD-6.6.5.2 Cleaning. Selection of cleaning agents should be made with consideration of all process contact materials including elastomer seals and sensors. If CIP of the isolator is specified, all process contact surfaces shall be exposed to cleaning solutions and accessible for visual verification.

SD-6.6.5.3 Chemical Sanitization/Sterilization. All transport systems shall be set in a position (or in motion) such that all process contact surfaces are exposed to the chemical agent used for the decontamination cycle.

SD-6.6.5.4 Thermal Sanitization/Sterilization. [Reserved for future content]

SD-6.6.5.5 Post-Use Storage. Aseptic isolators should be designed to maintain an ISO class 5 environment under dynamic and static conditions for a period of time specified by the owner/user. A post-use storage time under static conditions should be specified by the owner/user and verified through environmental monitoring.

SD-6.6.6 Design for Serviceability, Examination, and Operation. The isolator systems should be designed to enable safe access for inspection and service of components that are subject to wear, and to allow periodic calibration of instruments.

The isolator systems should be designed to provide adequate space for maintenance accessibility of all mechanical components.

SD-6.6.7 Testing

SD-6.6.7.1 Isolator Leak Testing. Both the pressure decay and pressure hold methods of leak-rate testing are acceptable. When choosing a test method, consideration should be given to the size of the isolator, time required for testing, and external influences that may affect testing (e.g., room temperature changes, room pressure changes).

The maximum leak rate shall be no greater than 1% of the isolator volume per hour with all pass-in/pass-out holes and RTP fittings closed and sealed (ISO 14644-7:2004, ISO 10648-2:1994 class 3). Leak-rate test pressures should be selected at 3 times to 5 times the working pressure as agreed to by owner/user. The temperature during the leak test shall not change more than 0.9°F (0.5°C).

SD-6.6.7.2 Glove Leak Testing. System integrity should be confirmed by a glove leak test. A glove port assembly tester is recommended to locate a potential glove leak. It is recommended to test both the installation and the glove sleeve.

Leak testing methods found in ISO 14644-7 are acceptable. Unless otherwise specified by the owner/user, the maximum permissible leak of 0.5% of volume per hour is recommended. The use of a completely automated device that uses pre-assigned test recipes is recommended.

SD-6.6.7.3 ULPA/HEPA Testing. The isolator design shall include integral DOP (dispersed oil particulate) or PAO (polyalphaolefin) ports for HEPA filter integrity testing with dioctyl phthalate or other approved testing aerosol challenge. For aseptic isolators, the methods consistent with the certification standards for an ISO class 5 cleanroom should be applied.

SD-6.6.7.4 Mock-Up. Unless otherwise agreed to by the owner/user, a mock-up at the factory or user site should be conducted prior to fabrication of aseptic isolators to assess aseptic operations through glove ports and associated ergonomics. When possible, the actual equipment or models of the actual equipment should be in place for the mock-up.

SD-6.6.7.5 Airflow Verification and Visualization Testing. The design of airflow in aseptic isolators should be verified to maintain ISO class 5 conditions.

Airflow visualization studies should be conducted under specified conditions (e.g., ISO class 5) to demonstrate that the unidirectional airflow minimizes the risk of contamination during operation. It should demonstrate a sweeping action over and away from the sterilized/decontaminated equipment, product, containers, and closures.

Airflow visualization studies should document the airflow patterns under static conditions, dynamic (operating) conditions, and the airflow during all interventions (e.g., clearing a jammed vial).

SD-7 DESIGN CONFORMANCE TESTING

Design conformance testing shall not result in the formation of any surface anomalies or contamination. All design conformance tests and test results documentation shall have the date and time recorded. Each test document shall include a record of personnel who performed and confirmed the test results.

SD-7.1 Spray Device Coverage Test (24)

An acceptable spray device coverage test procedure is provided in Nonmandatory Appendix M. The purpose of the spray device coverage test is to demonstrate and document liquid coverage of the process contact surfaces. The test provides information about liquid coverage and the conditions necessary to achieve this coverage as a prerequisite for cleaning of the process equipment. Effective coverage shall be visually determined using a fluorescent solution and an ultraviolet lamp or by other verification methods as agreed to by the owner/user and manufacturer. The minimum acceptable water quality is

noncompendial purified water (e.g., reverse osmosis or deionized). Acceptance criteria and coverage test protocol should be agreed to by the owner/user and manufacturer.

Spray device coverage tests are not intended to demonstrate cleanability. Cleanability is achieved through the equipment design, spray coverage, knowledge of the soils, cleaning agent selection, and TACT cleaning process parameters (see SD-6.3.1). Cleanability should be demonstrated using a complete cleaning cycle.

SD-7.2 Cleaning, Steaming, and Bioburden Control Testing

Cleaning, steaming, and bioburden control testing (in addition to spray device testing) shall be as agreed to by the owner/user and manufacturer, and in accordance with accepted industry standards.

SD-7.3 Fluid Requirements for Leak Testing

Where leak testing is required, the following fluids shall be used:

(a) Hydrostatic testing shall use clean purified or deionized water filtered at 25 μ or better, unless otherwise agreed to by the owner/user.

(b) Pneumatic testing shall use oil-free clean dry air, nitrogen, or inert gas filtered at 25 μ or better, unless otherwise agreed to by the owner/user.

SD-7.4 Vessel Drainability Test

Specific steps or operations in a bioprocess may require vessels to be drainable. A drainability test for such vessels shall be conducted to confirm that the vessel has been designed and manufactured without any low point other than its intended outlet or outlets. As a proposed test procedure, the following should be considered:

(a) The vessel shall be in its intended operating orientation within a tolerance agreed to by the owner/user.

(b) The vessel shall be filled with water approximately to the weld seam that joins the shell to the bottom head.

(c) The outlet valve shall be opened, the vessel shall be vented to atmosphere, and the vessel shall be allowed to drain.

(d) There shall be no puddles of water left on the vessel other than that retained due to surface tension.

Residual water may be present in the form of droplets that typically do not exceed a diameter of 0.2 in. (5 mm). Residual water droplets adhere to process surfaces due to surface tension and are not indicative of a vessel's drainability. Observed puddles that are displaced with a 1.0-in. (25-mm) rubber dowel applied perpendicular to the puddle and re-form at the point of displacement indicate a flat or unintended low point, and that area shall be repaired. Puddles that are displaced with a 1.0-in. (25-mm) diameter rubber dowel applied perpendicular to the puddle and do not return to the point of displacement are considered to be large droplets and do not constitute a test failure.

NOTE: This vessel drainability test is not intended for flat-bottom cartridge-mount filter housings.

CHAPTER 5
PROCESS COMPONENTS FOR MULTIUSE

PART DT
DIMENSIONS AND TOLERANCES FOR PROCESS COMPONENTS

DT-1 PURPOSE AND SCOPE

The purpose of this Part is to provide requirements that ensure process component fit-up and compatibility.

This Part specifies dimensions, tolerances, and all supplementary conditions for process components.

(24) DT-2 PRESSURE RATING

Table DT-2-1 shows the maximum allowable working pressure and temperature ratings for metallic fittings manufactured per DT-4.1 and manufactured from materials listed in Tables MM-2.1-1 through MM-2.1-3.

Metallic fittings manufactured to pressure and temperature ratings that exceed those in Table DT-2-1 must be justified by methods accepted by ASME B31.3.

Special angle branch connections per DT-4.3 shall be rated per the manufacturer's pressure and temperature ratings.

Valves manufactured to this Part shall be rated per the manufacturer's marked pressure and temperature ratings.

DT-3 WALL THICKNESS

The nominal wall thickness of the fittings and process components at the point of joining shall be the same as the tube to which they are welded. The thickness of the weld ends shall conform with the tolerances listed in Tables DT-3-1 and DT-3-2.

After fabrication and surface treatment, the wall thickness in any formed part of the fitting or process component, excluding tube, beyond the control portion as defined in DT-7, shall be a minimum of 65% of the nominal wall thickness. For guidelines regarding welds, see Part MJ. All welds shall meet the provisions of MJ-8 and Figure MJ-8.4-1.

(24) DT-4 DIMENSIONS

Fittings and process components are designed for use with nominal outside diameter (O.D.) tubing for the sizes listed in Table DT-4-1. The dimensions are accompanied with soft metric conversions from the U.S. Customary units and are listed for reference only (see GR-9). For nominal metric size tubing and fittings, refer to the appropriate international standards.

DT-4.1 Fitting Dimensions

Dimensions for fittings that are governed by this Standard are grouped and categorized into tables.

All sizes shown in these tables are nominal O.D. tube sizes.

All automatic weld end fittings shall have minimum tangent lengths per Table DT-4.1-1. The tangent length, T_L, is defined as the straight length measured from the welding end.

The categorized groups in DT-4.1.1 through DT-4.1.5 designate specific fitting dimensions.

DT-4.1.1 Elbows/Bends. See Tables DT-4.1.1-1 through DT-4.1.1-10.

DT-4.1.2 Tees/Crosses. See Tables DT-4.1.2-1 through DT-4.1.2-13. The branch shall not intersect the longitudinal weld of the run.

DT-4.1.3 Reducers. See Tables DT-4.1.3-1 through DT-4.1.3-3.

DT-4.1.4 Ferrules. See Table DT-4.1.4-1. Metallic hygienic clamp ferrule dimensions are specified in Table DT-7.1-1. Polymeric hygienic clamp ferrule dimensions are specified in Table DT-7.1-2.

DT-4.1.5 Caps. See Tables DT-4.1.5-1 and DT-4.1.5-2.

DT-4.2 Nonstandard Fitting Dimensions

Fittings not specifically described in Tables DT-4.1.1-1 through DT-4.1.5-2 may be constructed using combinations of centerline-to-end dimensions from the tables.

For tees and crosses, use Tables DT-4.1.2-4 and DT-4.1.2-8 for standard clamp leg lengths; Tables DT-4.1.2-2 and DT-4.1.2-7 for short-outlet branch clamp lengths; Table DT-4.1.2-3 for short-outlet run clamp lengths; and Table DT-4.1.2-1 for weld end lengths. Consideration shall be made for clamp clearances

when fabricating fittings not depicted in Tables DT-4.1.1-1 through DT-4.1.5-2.

DT-4.3 Special Angle Fittings Dimensions

Special angle fittings can be offered if in accordance with all DT tables, with the exception of "*O*" (off angle) in Table DT-3-1. Fittings furnished to this Standard shall not be mitered.

DT-4.4 Valve Dimensions

The dimensions of the valve or valve fabrication shall conform to the manufacturer's standards, or as agreed to by the purchaser and manufacturer.

The categorized group in DT-4.4.1 designates specific valve dimensions.

DT-4.4.1 Two-Way, Weir-Style Diaphragm Valves. See Table DT-4.4.1-1. All sizes shown are nominal O.D. tube sizes.

DT-4.5 Filter Dimensions

Standard dimensions for filter components covered by this Standard are referenced in SD-3.8 and are given in Tables DT-4.5.1-1 and DT-4.5.2-1.

DT-4.5.1 Code 7 Tapered Locking Tab Retainer: Recessed. See Table DT-4.5.1-1.

DT-4.5.2 Code 7 Tapered Locking Tab Retainer: External. See Table DT-4.5.2-1.

DT-4.6 Tube Dimensions

Tube dimensions shall meet the nominal outside diameter (O.D.) tubing sizes and tube wall thicknesses listed in Table DT-4-1.

DT-5 MATERIALS

Materials used in the manufacture of fittings and other process components shall conform to one of the material specifications listed in Part MM.

DT-6 TESTS

Hydrostatic testing of each fitting is not required in this Standard; however, fittings shall be capable of withstanding a hydrostatic test pressure of 1.5 times the pressure rating shown in Table DT-2-1 at 100°F (38°C).

DT-7 TOLERANCES

DT-7.1 Fitting and Process Component Tolerances

Tables DT-3-1, DT-3-2, DT-7.1-1 (metallic), and DT-7.1-2 (polymeric) list the required tolerances for fabricated fittings and process components, excluding tube, depicted by this Standard. Table DT-7.1-1 lists the required tolerances for metallic machined hygienic clamp ferrule profiles. Table DT-7.1-2 lists the required tolerances for polymeric hygienic clamp ferrule profiles. When metallic ferrules are welded to a process component and polished, then the tolerances in Tables DT-3-1 and DT-3-2 shall apply.

These tolerances shall apply after heat and surface treatment. The control portion of the fitting or process components (refer to *C* in the Table DT-3-1 illustration) is the length from the welding end over which tolerances for wall thickness and O.D. are maintained. The length of the control portion is fixed for all sizes at 0.75 in. (19 mm). For exceptions, see Table DT-4.1.4-1 for ferrule lengths and Table DT-4.1.5-1 for automatic tube weld caps.

DT-7.2 Tubing Tolerances (24)

For tubing tolerances, refer to ASTM A270, including Supplementary Requirement S2. See Table DT-7.2-1 for tubing end square cut tolerances.

DT-7.3 Transfer Panel Nozzle and Jumper Tolerances

Table DT-7.3-1 lists the required tolerances for transfer panel nozzles and jumpers.

DT-8 WELD ENDS

Where austenitic stainless steels listed in Tables MM-2.1-1 and MM-2.1-3 are specified, weld ends of process components that are to be autogenously welded shall conform to the requirements for chemical composition as prescribed in MM-5.2.1.1(a). For nonautomatic weld ends, the chemical composition shall meet the requirements of the applicable ASTM specification.

Automatic weld ends furnished to this Standard shall be furnished with square-cut ends, free from burrs and breaks. All weld end connections for valves shall have a minimum unobstructed weld end length equal to or greater than the minimum control portion as per DT-7.

DT-9 HYGIENIC CLAMP UNIONS

DT-9.1 Typical Hygienic Clamp Unions

Typical hygienic clamp unions are described in MC-2.2.2.

DT-9.2 Hygienic Gaskets

Fittings and process components with hygienic clamp unions furnished to this Standard shall employ gasket materials and gasket designs that meet the requirements of Table DT-2-1 and Part MC. Gasket seal performance in the clamp union shall be based on the principles of MC-4 and shall conform to the dimensional requirements of Figure MC-4.2-1 when the union assembly is tightened to an amount recommended by the manufacturer.

Gasket seal width as shown in Figure MC-4.2-1 shall be a maximum of 0.095 in. in the uncompressed condition prior to installation.

DT-9.3 Connections

Connections meeting all dimensions of Table DT-7.1-1 are considered interchangeable. Alternative sealing designs are acceptable, provided the following are met:

(a) dimensions *A*, *B*, *C*, and *D* of Table DT-7.1-1

(b) dimensions *A* and *B* of Table DT-9.3-1

In the case of non-flow-through connections, dimension *B* of Table DT-7.1-1 shall not apply. All connections shall meet the applicable requirements of SD-3.1, MC-3.3.2.1, and MC-3.3.2.2.

DT-9.4 Hygienic Clamps

Hygienic clamps shall be designed and manufactured through the entire range of all union component dimensional tolerances to accomplish the following:

(a) completely retain all components in a fully sealed state to meet the requirements of DT-2

(b) maintain proper component alignment during installation and operation per MC-3.3.2.1

(c) cause the ferrules to be aligned to meet a uniform nominal gap per Figure MC-4.2-1 when installed and tightened to the proper design specifications

(d) cause the gauging and contact diameter between the ferrules and the mating surfaces of the clamp to occur at the gauging diameter (*A*) specified in Table DT-9.3-1 when installed and tightened to achieve the nominal gap per Figure MC-4.2-1

NOTE: As this is a nominal design condition, manufacturing tolerances of the components will cause some variation in the actual gauging and contact diameter at assembly.

(e) avoid any interference with any clamp union components or itself that would prevent proper assembly when assembled with all components (see Figure DT-9.4-1)

DT-10 MINIMUM EXAMINATION REQUIREMENTS

DT-10.1 Visual Inspection

For fittings and process components including, but not limited to, tubing, valves, pumps, filter housings, and instrumentation, each item shall be visually examined for the following criteria, as a minimum. It is not a requirement that the packaged components be removed from the original packaging, provided the following can be verified:

(a) manufacturer's name, logo, or trademark

(b) alloy/material type

(c) description including size and configuration

(d) heat number/code

(e) process contact surface finish designation [only one surface finish (SF) designation allowed]

(f) reference to ASME BPE

(1) ASME BPE Certificate of Authorization holders shall mark the reference to this Standard by applying their ASME Certification Mark with BPE Designator. See Figure CR-1-1.

(2) Non-ASME BPE Certificate of Authorization holders shall only mark "BPE."

(g) pressure rating for valves

(h) no damage or other nonconformances

DT-10.2 Documentation Verification

See Part GR for documentation verification requirements.

DT-10.3 Physical Examination

For this paragraph, a "lot" shall be defined as a specific combination of size, configuration, and heat number for fittings and process components including, but not limited to, tubing, valves, pumps, filter housings, and instrumentation in a single shipment.

When required by the owner/user, a percentage of each incoming lot shall be physically examined for all the following criteria:

(a) wall thickness (for weld ends only)

(b) outside diameter (for weld ends only)

(c) surface finish (as specified)

(d) visual

When required examination reveals a defect(s), an additional 10% of that lot shall be examined for the specific defect(s). If this examination reveals another defect, an additional 10% of that lot shall be examined for the specific defect(s). If additional defects are found, perform 100% examination or reject the balance of the lot. All examined and accepted material in this lot may be retained and used.

The completed Material Examination Log shall describe all of the features listed above. The results of the examination shall be recorded on a Material Examination Log. This documentation may be one line item for the total quantity of a particular size, configuration, and heat number. The information required to be on the Material Examination Log may be in any format, written or tabular, as long as all information is included or referenced.

See Forms MEL-1 and MER-1, which have been provided as a guide for the Material Examination Log (see Nonmandatory Appendix B).

DT-11 MARKING

DT-11.1 Fittings, Valves, and Instrumentation Marking Information

Except as specified in DT-11.1.1, each process component shall be permanently marked to maintain traceability by any suitable method not injurious to the process contact surface to show the following:

(a) a number or unique identifier that provides traceability to the applicable MTR, surface test report, or other certifications. This number may be a heat number/manufacturer's code or serial number, marked on each process contact component.

(b) material type.

(c) valve pressure rating.

(d) manufacturer's name, logo, or trademark.

(e) reference to this Standard (ASME BPE).

(1) ASME BPE Certificate of Authorization holders shall mark the reference to this Standard by applying their ASME Mark with BPE Designator. See Figure CR-1-1.

(2) Non-ASME BPE Certificate of Authorization holders shall only mark "BPE."

(f) process contact surface designation for the appropriate BPE specification [only one surface finish (SF) designation allowed].

NOTE: All marking of a process component should be made outside of the control portion to optimize welding fit-up and identification.

DT-11.1.1 Exceptions

(a) Where the available marking area does not permit complete marking, the process component shall be marked, at a minimum, with the items identified in Table DT-11.1.1-1.

(b) Where the markings have been removed due to fabrication into another component or system, the heat number or manufacturer's code and material type shall be re-marked on the fitting or process component.

(c) Polymeric fittings do not require marking per this section (see PM-2.2.2).

DT-11.2 Modified Surfaces

When the surface finish of a process component is modified, the surface finish designation marking shall be changed to match the final surface finish designation according to Table SF-2.4.1-1. Only the final finish designation shall be indicated.

After removal of the original markings, all dimensions and tolerances shall conform to Table DT-3-1 and, as applicable, Table DT-3-2.

DT-12 PACKAGING

All end connections of fittings or process components shall be protected with end caps. Additionally, fittings shall be sealed in transparent bags or shrink wrapped. Additional packaging for process components, other than fittings, shall be as agreed to by the purchaser and manufacturer.

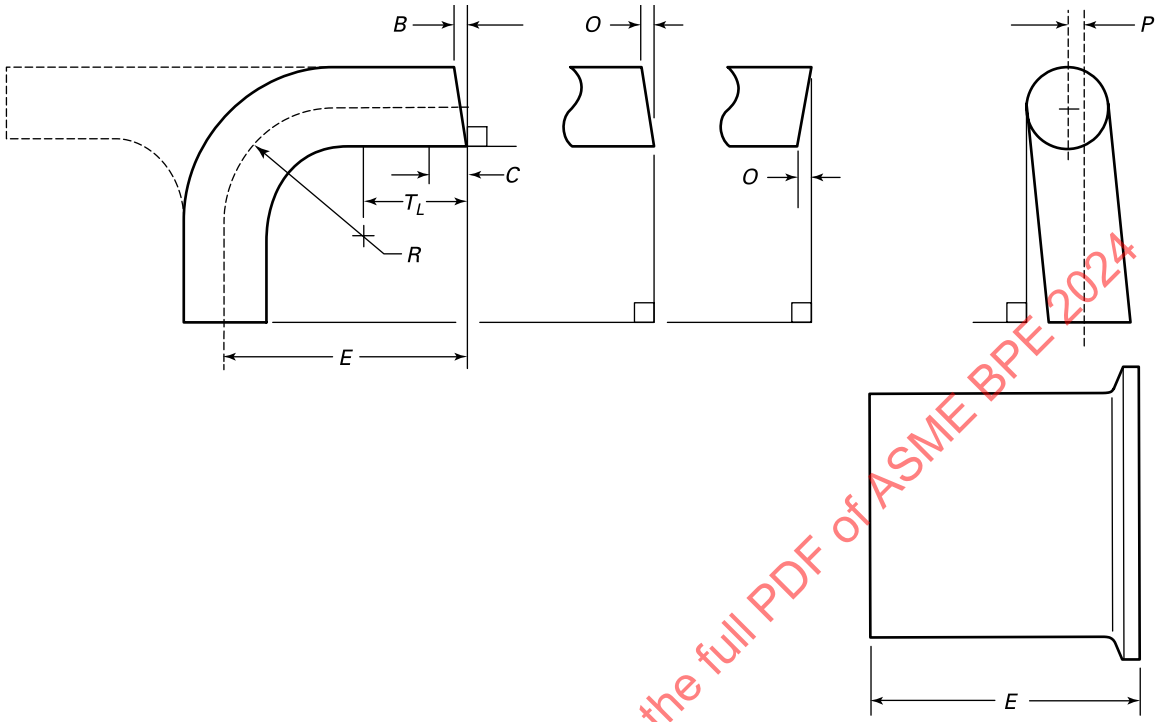
(24)

Table DT-2-1
Metallic Fittings: Rated Internal Working Pressure

Temperature		<3 in.		3 in.		4 in.		6 in.	
°F	°C	psig	kPa	psig	kPa	psig	kPa	psig	kPa
100	38	200	1 379	200	1 379	200	1 379	150	1 034
200	93	200	1 379	200	1 379	200	1 379	150	1 034
300	149	188	1 293	188	1 293	188	1 293	141	970
400	204	170	1 173	170	1 173	170	1 173	128	880

GENERAL NOTES:
(a) Manufacturers may publish higher pressure ratings; see DT-2.
(b) Hygienic clamp connections shall meet criteria in DT-9.

Table DT-3-1
Final Tolerances for Mechanically Polished Fittings and Process Components, Excluding Tube



Nominal Size, in.	O.D.		Wall Thickness		Squareness Face to Tangent, *B*		Off Angle, *O*		Equivalent Angle (for *O*) deg	Off Plane, *P*		Centerline Radius (CLR), *R*	
	in.	mm	in.	mm	in.	mm	in.	mm		in.	mm	in.	mm
1/4	±0.005	±0.13	+0.003/−0.004	+0.08/−0.10	0.005	0.13	0.009	0.23	2.1	0.030	0.76	0.563	14.30
3/8	±0.005	±0.13	+0.003/−0.004	+0.08/−0.10	0.005	0.13	0.012	0.30	1.8	0.030	0.76	1.125	28.58
1/2	±0.005	±0.13	+0.005/−0.008	+0.13/−0.20	0.005	0.13	0.014	0.36	1.6	0.030	0.76	1.125	28.58
3/4	±0.005	±0.13	+0.005/−0.008	+0.13/−0.20	0.005	0.13	0.018	0.46	1.4	0.030	0.76	1.125	28.58
1	±0.005	±0.13	+0.005/−0.008	+0.13/−0.20	0.008	0.20	0.025	0.64	1.4	0.030	0.76	1.500	38.10
1 1/2	±0.008	±0.20	+0.005/−0.008	+0.13/−0.20	0.008	0.20	0.034	0.86	1.3	0.050	1.27	2.250	57.15
2	±0.008	±0.20	+0.005/−0.008	+0.13/−0.20	0.008	0.20	0.043	1.09	1.2	0.050	1.27	3.000	76.20
2 1/2	±0.010	±0.25	+0.005/−0.008	+0.13/−0.20	0.010	0.25	0.054	1.37	1.2	0.050	1.27	3.750	95.25

Table DT-3-1
Final Tolerances for Mechanically Polished Fittings and Process Components, Excluding Tube (Cont'd)

Nominal Size, in.	O.D.		Wall Thickness		Squareness Face to Tangent, *B*		Off Angle, *O*		Equivalent Angle (for *O*) deg	Off Plane, *P*		Centerline Radius (CLR), *R*	
	in.	mm	in.	mm	in.	mm	in.	mm		in.	mm	in.	mm
3	±0.010	±0.25	+0.005/−0.008	+0.13/−0.20	0.016	0.41	0.068	1.73	1.3	0.050	1.27	4.500	114.30
4	±0.015	±0.38	+0.008/−0.010	+0.20/−0.25	0.016	0.41	0.086	2.18	1.2	0.060	1.52	6.000	152.40
6	±0.030	±0.76	+0.015/−0.015	+0.38/−0.38	0.030	0.76	0.135	3.43	1.3	0.060	1.52	9.000	228.60

GENERAL NOTES:

(a) Tolerance on end-to-end and center-to-end dimension *E* is ±0.050 in. (1.27 mm) for all fittings and process components depicted. For those not depicted in this Standard, see manufacturer for standards.

(b) See Table DT-3-2 for electropolished wall thickness tolerances.

(c) See DT-7 (Tolerances) for *C* control portion lengths.

(d) See Table DT-4.1-1 for T_L tangent length dimensions.

(e) Tolerance for centerline radius (CLR) is ±10% of the nominal dimension (*R*).

(f) See DT-7.2 for tubing tolerances.

Table DT-3-2
Final Tolerances for Electropolished Fittings and Process Components, Excluding Tube

Nominal Size, in.	Wall Thickness	
	in.	mm
¼	+0.003/−0.006	+0.08/−0.15
⅜	+0.003/−0.006	+0.08/−0.15
½	+0.005/−0.010	+0.13/−0.25
¾	+0.005/−0.010	+0.13/−0.25
1	+0.005/−0.010	+0.13/−0.25
1½	+0.005/−0.010	+0.13/−0.25
2	+0.005/−0.010	+0.13/−0.25
2½	+0.005/−0.010	+0.13/−0.25
3	+0.005/−0.010	+0.13/−0.25
4	+0.008/−0.012	+0.20/−0.30
6	+0.015/−0.017	+0.38/−0.43

GENERAL NOTE: See DT-7.2 for tubing tolerances.

Table DT-4-1
Nominal O.D. Tubing Sizes

Nominal Size, in.	Tube O.D.		Tube Wall Thickness	
	in.	mm	in.	mm
¼	0.250	6.35	0.035	0.89
⅜	0.375	9.53	0.035	0.89
½	0.500	12.70	0.065	1.65
¾	0.750	19.05	0.065	1.65
1	1.000	25.40	0.065	1.65
1½	1.500	38.10	0.065	1.65
2	2.000	50.80	0.065	1.65
2½	2.500	63.50	0.065	1.65
3	3.000	76.20	0.065	1.65
4	4.000	101.60	0.083	2.11
6	6.000	152.40	0.109	2.77

GENERAL NOTE: See DT-7.2 for tubing tolerances.

Table DT-4.1-1
Tangent Lengths

Nominal O.D. Tube Size, in.	Tangent, T_L	
	in.	mm
1/4	1.500	38.10
3/8	1.500	38.10
1/2	1.500	38.10
3/4	1.500	38.10
1	1.500	38.10
1 1/2	1.500	38.10
2	1.500	38.10
2 1/2	1.500	38.10
3	1.750	44.45
4	2.000	50.80
6	2.500	63.50

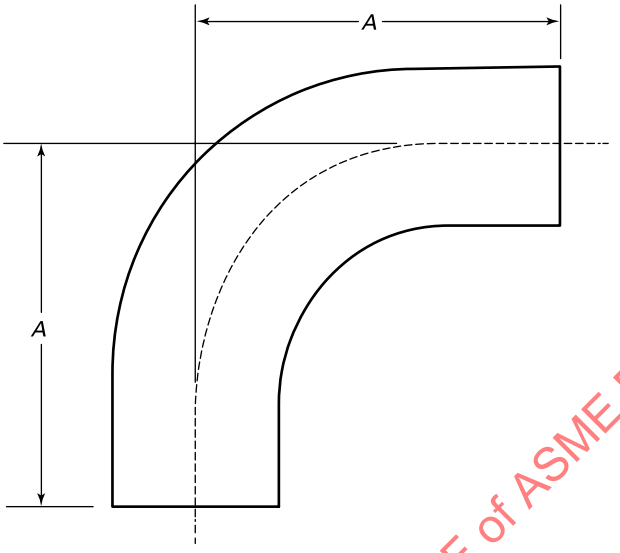
GENERAL NOTES:

(a) Minimum tangent lengths for ferrules do not apply. See Table DT-4.1.4-1, dimensions *B* and *C*, for available length options.

(b) Minimum tangent length for 1/4 in. to 3/4 in. size automatic tube weld: 180 deg return bend does not conform (see Table DT-4.1.1-7, dimension *B*).

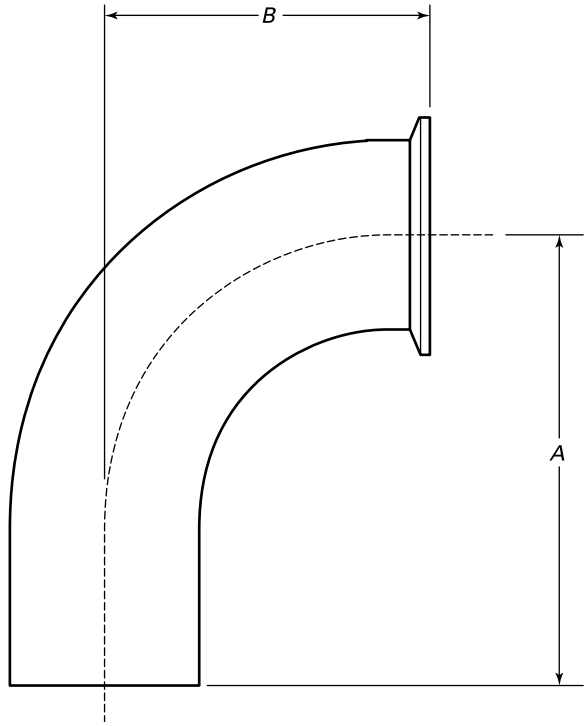
(c) Minimum tangent lengths for Tables DT-4.1.2-2, DT-4.1.2-3, DT-4.1.2-7, DT-4.1.3-1, and DT-4.1.3-2 do not apply.

Table DT-4.1.1-1
Automatic Tube Weld: 90-deg Elbow



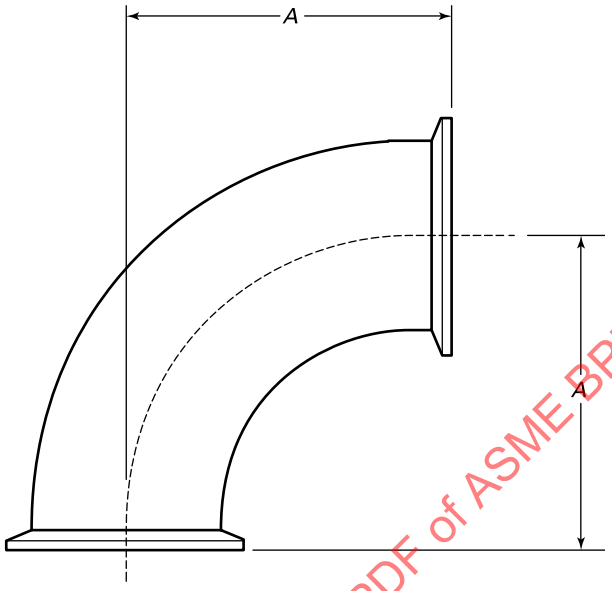
Nominal Size, in.	A	
	in.	mm
1/4	2.625	66.68
3/8	2.625	66.68
1/2	3.000	76.20
3/4	3.000	76.20
1	3.000	76.20
1 1/2	3.750	95.25
2	4.750	120.65
2 1/2	5.500	139.70
3	6.250	158.75
4	8.000	203.20
6	11.500	292.10

Table DT-4.1.1-2
Automatic Tube Weld: Hygienic Clamp Joint, 90-deg Elbow



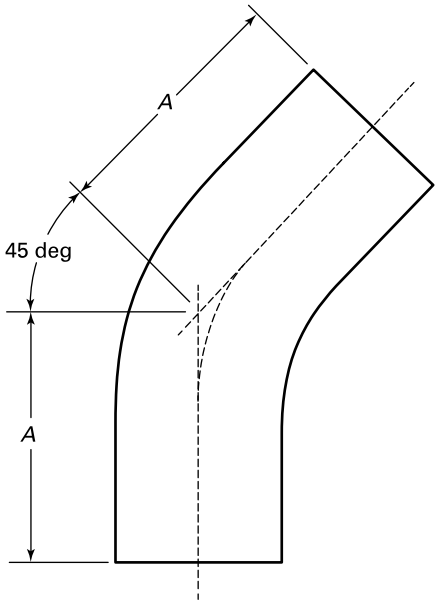
	A		B	
Nominal Size, in.	in.	mm	in.	mm
¼	2.625	66.68	1.625	41.28
⅜	2.625	66.68	1.625	41.26
½	3.000	76.20	1.625	41.28
¾	3.000	76.20	1.625	41.28
1	3.000	76.20	2.000	50.80
1½	3.750	95.25	2.750	69.85
2	4.750	120.65	3.500	88.90
2½	5.500	139.70	4.250	107.95
3	6.250	158.75	5.000	127.00
4	8.000	203.20	6.625	168.28
6	11.500	292.10	10.500	266.70

Table DT-4.1.1-3
Hygienic Clamp Joint: 90-deg Elbow



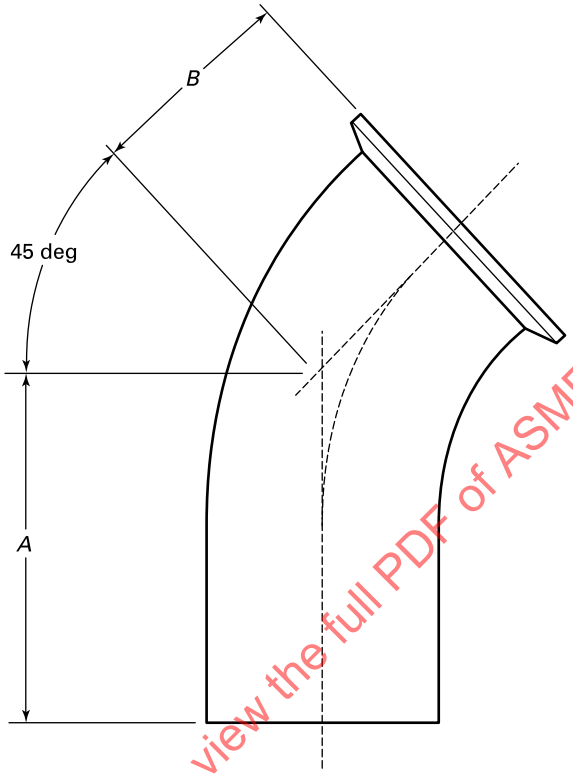
	A	
Nominal Size, in.	in.	mm
¼	1.625	41.28
⅜	1.625	41.28
½	1.625	41.28
¾	1.625	41.28
1	2.000	50.80
1½	2.750	69.85
2	3.500	88.90
2½	4.250	107.95
3	5.000	127.00
4	6.625	168.28
6	10.500	266.70

Table DT-4.1.1-4
Automatic Tube Weld: 45-deg Elbow



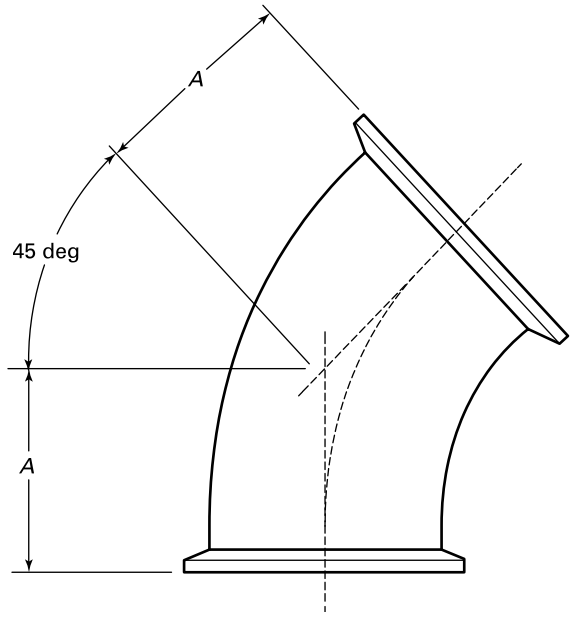
Nominal Size, in.	A	
	in.	mm
1/4	2.000	50.80
3/8	2.000	50.80
1/2	2.250	57.15
3/4	2.250	57.15
1	2.250	57.15
1 1/2	2.500	63.50
2	3.000	76.20
2 1/2	3.375	85.73
3	3.625	92.08
4	4.500	114.30
6	6.250	158.75

Table DT-4.1.1-5
Automatic Tube Weld: Hygienic Clamp Joint, 45-deg Elbow



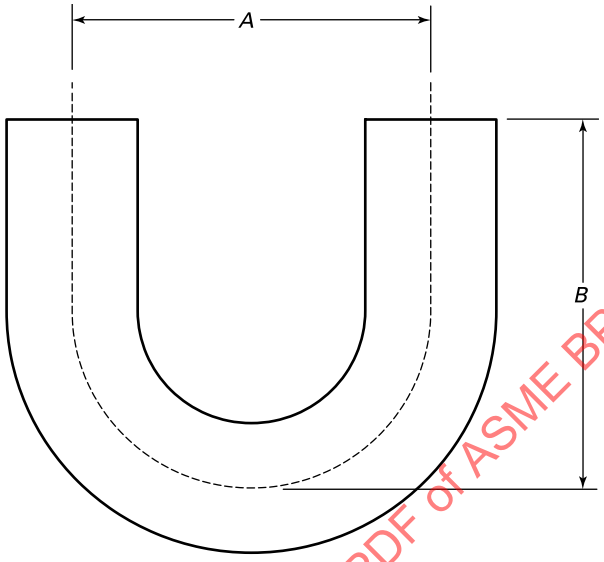
Nominal Size, in.	A		B	
	in.	mm	in.	mm
1/4	2.000	50.80	1.000	25.40
3/8	2.000	50.80	1.000	25.40
1/2	2.250	57.15	1.000	25.40
3/4	2.250	57.15	1.000	25.40
1	2.250	57.15	1.125	28.58
1 1/2	2.500	63.50	1.438	36.53
2	3.000	76.20	1.750	44.45
2 1/2	3.375	85.73	2.063	52.40
3	3.625	92.08	2.375	60.33
4	4.500	114.30	3.125	79.38
6	6.250	158.75	5.250	133.35

Table DT-4.1.1-6
Hygienic Clamp Joint: 45-deg Elbow



Nominal Size, in.	A	
	in.	mm
¼	1.000	25.40
⅜	1.000	25.40
½	1.000	25.40
¾	1.000	25.40
1	1.125	28.58
1½	1.438	36.53
2	1.750	44.45
2½	2.063	52.40
3	2.375	60.33
4	3.125	79.38
6	5.250	133.35

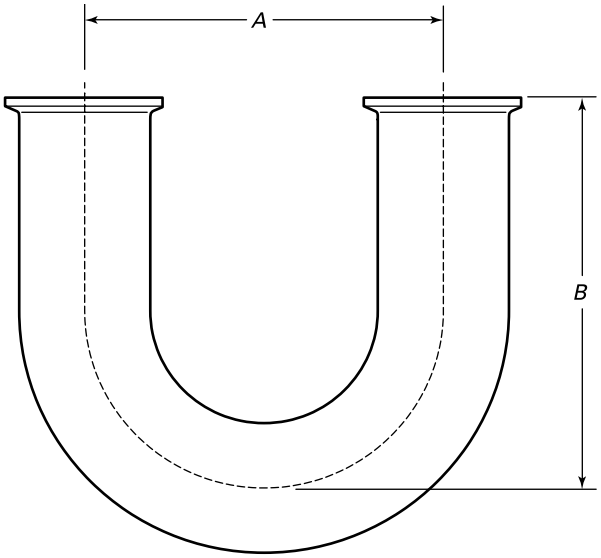
Table DT-4.1.1-7
Automatic Tube Weld: 180-deg Return Bend



Nominal Size, in.	A		B	
	in.	mm	in.	mm
¼	4.500	114.30	2.625	66.68
⅜	4.500	114.30	2.625	66.68
½	4.500	114.30	3.000	76.20
¾	4.500	114.30	3.000	76.20
1	3.000	76.20	3.000	76.20
1½	4.500	114.30	4.500	114.30
2	6.000	152.40	5.000	127.00
2½	7.500	190.50	5.750	146.05
3	9.000	228.60	6.500	165.10
4	12.000	304.80	8.500	215.90
6	18.000	457.20	11.500	292.10

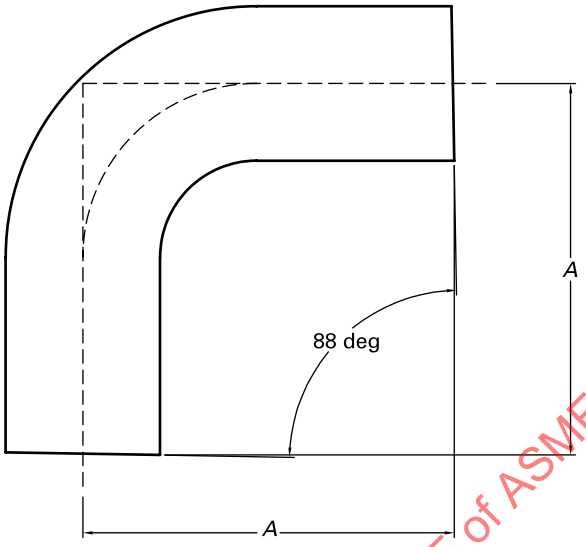
GENERAL NOTE: Nominal sizes ¼ in. to ¾ in. do not conform to Table DT-4.1.1-1.

Table DT-4.1.1-8
Hygienic Clamp Joint: 180-deg Return Bend



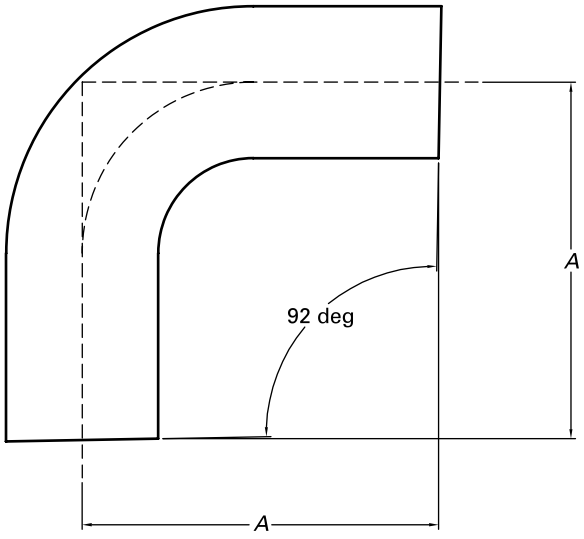
Nominal Size, in.	A		B	
	in.	mm	in.	mm
¼	4.500	114.30	3.125	79.38
⅜	4.500	114.30	3.125	79.38
½	4.500	114.30	3.500	88.90
¾	4.500	114.30	3.500	88.90
1	3.000	76.20	3.500	88.90
1½	4.500	114.30	5.000	127.00
2	6.000	152.40	5.500	139.70
2½	7.500	190.50	6.250	158.75
3	9.000	228.60	7.000	177.80
4	12.000	304.80	9.125	231.78
6	18.000	457.20	13.000	330.20

Table DT-4.1.1-9
Automatic Tube Weld: 88-deg Elbow



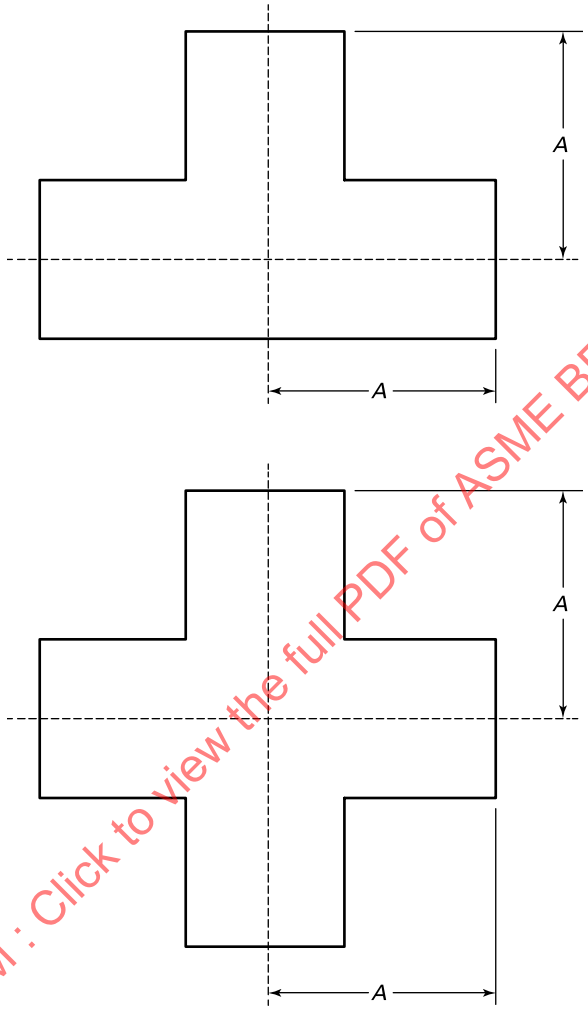
Nominal Size, in.	A	
	in.	mm
¼	2.700	68.58
⅜	2.700	68.58
½	3.065	77.85
¾	3.065	77.85
1	3.050	77.47
1½	3.800	96.52
2	4.810	122.17
2½	5.560	141.22
3	6.310	160.27
4	8.065	204.85
6	11.580	294.13

Table DT-4.1.1-10
Automatic Tube Weld: 92-deg Elbow



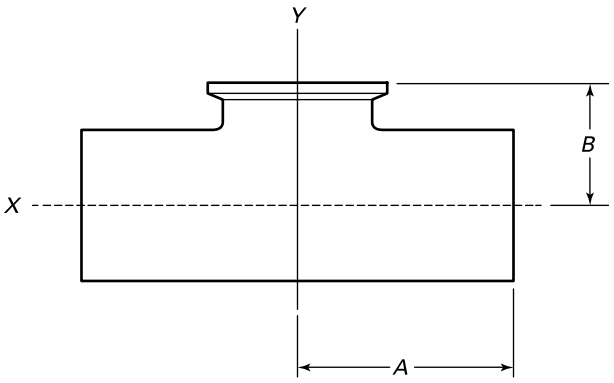
Nominal Size, in.	A	
	in.	mm
1/4	2.530	64.26
3/8	2.530	64.26
1/2	2.930	74.42
3/4	2.930	74.42
1	2.950	74.93
1 1/2	3.690	93.73
2	4.690	119.13
2 1/2	5.440	138.18
3	6.190	157.23
4	7.930	201.42
6	11.410	289.81

Table DT-4.1.2-1
Automatic Tube Weld: Straight Tee and Cross



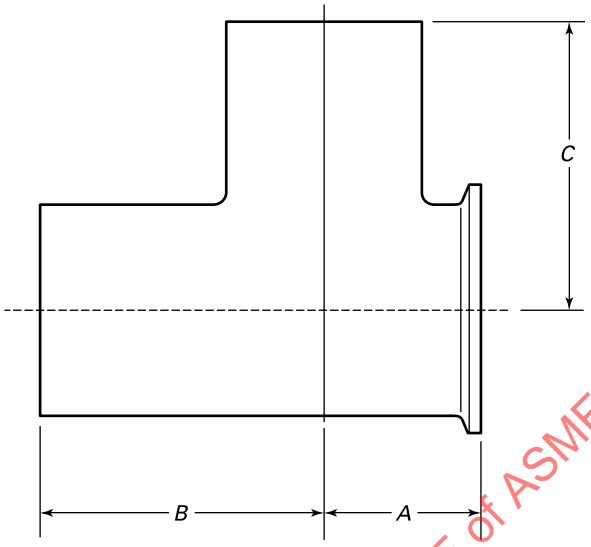
Nominal Size, in.	A	
	in.	mm
1/4	1.750	44.45
3/8	1.750	44.45
1/2	1.875	47.63
3/4	2.000	50.80
1	2.125	53.98
1 1/2	2.375	60.33
2	2.875	73.03
2 1/2	3.125	79.38
3	3.375	85.73
4	4.125	104.78
6	5.625	142.88

Table DT-4.1.2-2
Automatic Tube Weld:
Short-Outlet Hygienic Clamp Joint Tee



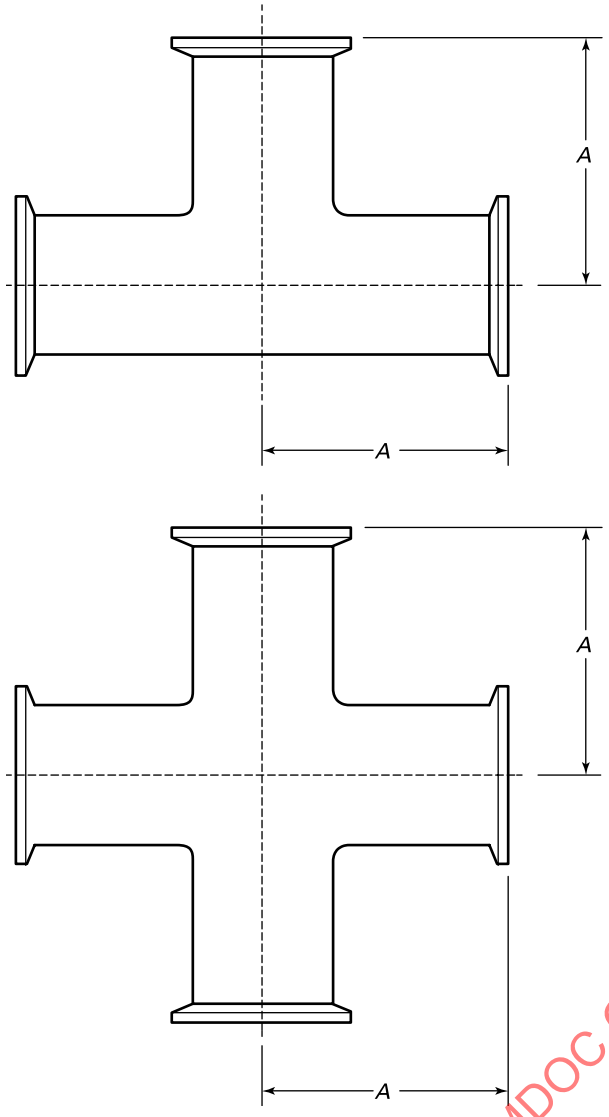
Nominal Size, in.	*A*		*B*	
	in.	mm	in.	mm
1/4	1.750	44.45	1.000	25.40
3/8	1.750	44.45	1.000	25.40
1/2	1.875	47.63	1.000	25.40
3/4	2.000	50.80	1.125	28.58
1	2.125	53.98	1.125	28.58
1 1/2	2.375	60.33	1.375	34.93
2	2.875	73.03	1.625	41.28
2 1/2	3.125	79.38	1.875	47.63
3	3.375	85.73	2.125	53.98
4	4.125	104.78	2.750	69.85
6	5.625	142.88	4.625	117.48

Table DT-4.1.2-3
Hygienic Mechanical Joint: Short-Outlet Run Tee



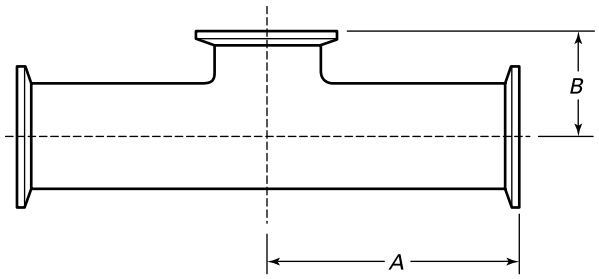
Nominal Size, in.	*A*		*B*		*C*	
	in.	mm	in.	mm	in.	mm
1/4	0.875	22.23	1.750	44.45	1.750	44.45
3/8	0.875	22.23	1.750	44.45	1.750	44.45
1/2	0.875	22.23	1.875	47.63	1.875	47.63
3/4	1.000	25.40	2.000	50.80	2.000	50.80
1	1.125	28.58	2.125	53.98	2.125	53.98
1 1/2	1.375	34.93	2.375	60.33	2.375	60.33
2	1.625	41.28	2.875	73.03	2.875	73.03
2 1/2	1.875	47.63	3.125	79.38	3.125	79.38
3	2.125	53.98	3.375	85.73	3.375	85.73
4	2.750	69.85	4.125	104.78	4.125	104.78
6	4.625	117.48	5.625	142.88	5.625	142.88

Table DT-4.1.2-4
Hygienic Clamp Joint: Straight Tee and Cross



Nominal Size, in.	A	
	in.	mm
1/4	2.250	57.15
3/8	2.250	57.15
1/2	2.375	60.33
3/4	2.500	63.50
1	2.625	66.68
1 1/2	2.875	73.03
2	3.375	85.73
2 1/2	3.625	92.08
3	3.875	98.43
4	4.750	120.65
6	7.125	180.98

Table DT-4.1.2-5
Hygienic Clamp Joint: Short-Outlet Tee



Nominal Size, in.	A		B	
	in.	mm	in.	mm
1/2	2.375	60.33	1.000	25.40
3/4	2.500	63.50	1.125	28.58
1	2.625	66.68	1.125	28.58
1 1/2	2.875	73.03	1.375	34.93
2	3.375	85.73	1.625	41.28
2 1/2	3.625	92.08	1.875	47.63
3	3.875	98.43	2.125	53.98
4	4.750	120.65	2.750	69.85
6	7.125	180.98	4.625	117.48

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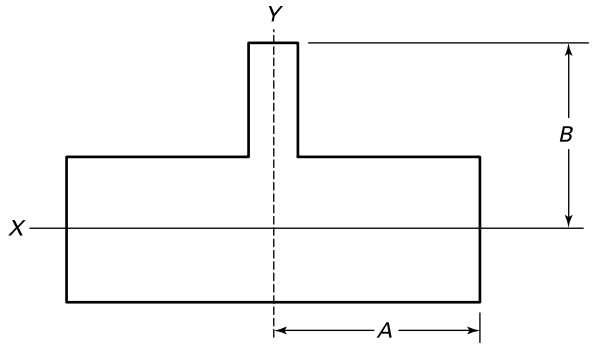
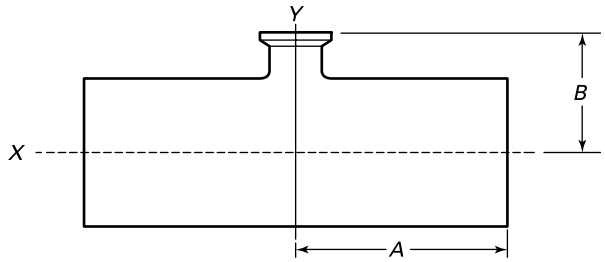
Table DT-4.1.2-6
Automatic Tube Weld: Reducing Tee



Nominal Size, in.		A		B		Nominal Size, in.		A		B	
X	Y	in.	mm	in.	mm	X	Y	in.	mm	in.	mm
3/8	1/4	1.750	44.45	1.750	44.45	2 1/2	1 1/2	3.125	79.38	2.875	73.03
						2 1/2	2	3.125	79.38	2.875	73.03
1/2	1/4	1.875	47.63	1.875	47.63						
1/2	3/8	1.875	47.63	1.875	47.63	3	1/2	3.375	85.73	3.125	79.38
						3	3/4	3.375	85.73	3.125	79.38
3/4	1/4	2.000	50.80	2.000	50.80	3	1	3.375	85.73	3.125	79.38
3/4	3/8	2.000	50.80	2.000	50.80	3	1 1/2	3.375	85.73	3.125	79.38
3/4	1/2	2.000	50.80	2.000	50.80	3	2	3.375	85.73	3.125	79.38
						3	2 1/2	3.375	85.73	3.125	79.38
1	1/4	2.125	53.98	2.125	53.98						
1	3/8	2.125	53.98	2.125	53.98	4	1/2	4.125	104.78	3.625	92.08
1	1/2	2.125	53.98	2.125	53.98	4	3/4	4.125	104.78	3.625	92.08
1	3/4	2.125	53.98	2.125	53.98	4	1	4.125	104.78	3.625	92.08
						4	1 1/2	4.125	104.78	3.625	92.08
1 1/2	1/2	2.375	60.33	2.375	60.33	4	2	4.125	104.78	3.875	98.43
1 1/2	3/4	2.375	60.33	2.375	60.33	4	2 1/2	4.125	104.78	3.875	98.43
1 1/2	1	2.375	60.33	2.375	60.33	4	3	4.125	104.78	3.875	98.43
2	1/2	2.875	73.03	2.625	66.68	6	1/2	5.625	142.88	4.625	117.48
2	3/4	2.875	73.03	2.625	66.68	6	3/4	5.625	142.88	4.625	117.48
2	1	2.875	73.03	2.625	66.68	6	1	5.625	142.88	4.625	117.48
2	1 1/2	2.875	73.03	2.625	66.68	6	1 1/2	5.625	142.88	4.625	117.48
						6	2	5.625	142.88	4.875	123.83
2 1/2	1/2	3.125	79.38	2.875	73.03	6	2 1/2	5.625	142.88	4.875	123.83
2 1/2	3/4	3.125	79.38	2.875	73.03	6	3	5.625	142.88	4.875	123.83
2 1/2	1	3.125	79.38	2.875	73.03	6	4	5.625	142.88	5.125	130.18

Table DT-4.1.2-7
Automatic Tube Weld: Short-Outlet Hygienic Clamp, Joint Reducing Tee

(24)



Nominal Size, in.		A		B		Nominal Size, in.		A		B	
X	Y	in.	mm	in.	mm	X	Y	in.	mm	in.	mm
3/8	1/4	1.750	44.45	1.000	25.40	2 1/2	2	3.125	79.38	1.875	47.63
1/2	1/4	1.875	47.63	1.000	25.40	3	1/2	3.375	85.73	2.125	53.98
1/2	3/8	1.875	47.63	1.000	25.40	3	3/4	3.375	85.73	2.125	53.98
3/4	1/4	2.000	50.80	1.000	25.40	3	1	3.375	85.73	2.125	53.98
3/4	3/8	2.000	50.80	1.000	25.40	3	1 1/2	3.375	85.73	2.125	53.98
3/4	1/2	2.000	50.80	1.000	25.40	3	2	3.375	85.73	2.125	53.98
1	1/4	2.125	53.98	1.125	28.58	3	2 1/2	3.375	85.73	2.125	53.98
1	3/8	2.125	53.98	1.125	28.58	4	1/2	4.125	104.78	2.625	66.68
1	1/2	2.125	53.98	1.125	28.58	4	3/4	4.125	104.78	2.625	66.68
1	3/4	2.125	53.98	1.125	28.58	4	1	4.125	104.78	2.625	66.68
1 1/2	1/2	2.375	60.33	1.375	34.93	4	1 1/2	4.125	104.78	2.625	66.68
1 1/2	3/4	2.375	60.33	1.375	34.93	4	2	4.125	104.78	2.625	66.68
1 1/2	1	2.375	60.33	1.375	34.93	4	2 1/2	4.125	104.78	2.625	66.68
2	1/2	2.875	73.03	1.625	41.28	4	3	4.125	104.78	2.625	66.68
2	3/4	2.875	73.03	1.625	41.28	6	1/2	5.625	142.88	3.625	92.08
2	1	2.875	73.03	1.625	41.28	6	3/4	5.625	142.88	3.625	92.08
2	1 1/2	2.875	73.03	1.625	41.28	6	1	5.625	142.88	3.625	92.08
2 1/2	1/2	3.125	79.38	1.875	47.63	6	1 1/2	5.625	142.88	3.625	92.08
2 1/2	3/4	3.125	79.38	1.875	47.63	6	2	5.625	142.88	3.625	92.08
2 1/2	1	3.125	79.38	1.875	47.63	6	2 1/2	5.625	142.88	3.625	92.08
2 1/2	1 1/2	3.125	79.38	1.875	47.63	6	3	5.625	142.88	3.625	92.08
						6	4	5.625	142.88	3.750	95.25

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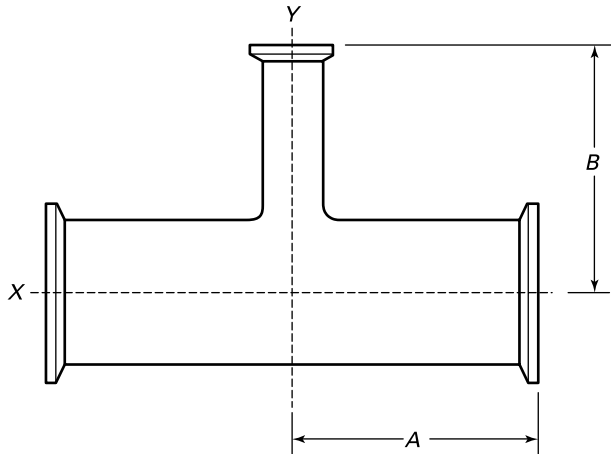
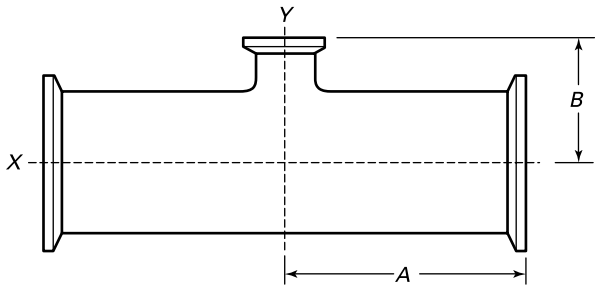
Table DT-4.1.2-8
Hygienic Clamp Joint: Reducing Tee



Nominal Size, in.		A		B		Nominal Size, in.		A		B	
X	Y	in.	mm	in.	mm	X	Y	in.	mm	in.	mm
3/8	1/4	2.250	57.15	2.250	57.15	2 1/2	2	3.625	92.08	3.375	85.73
1/2	1/4	2.375	60.33	2.375	60.33	3	1/2	3.875	98.43	3.625	92.08
1/2	3/8	2.375	60.33	2.375	60.33	3	3/4	3.875	98.43	3.625	92.08
3/4	1/4	2.500	63.50	2.500	63.50	3	1	3.875	98.43	3.625	92.08
3/4	3/8	2.500	63.50	2.500	63.50	3	1 1/2	3.875	98.43	3.625	92.08
3/4	1/2	2.500	63.50	2.500	63.50	3	2	3.875	98.43	3.625	92.08
1	1/4	2.625	66.68	2.625	66.68	3	2 1/2	3.875	98.43	3.625	92.08
1	3/8	2.625	66.68	2.625	66.68	4	1/2	4.750	120.65	4.125	104.78
1	1/2	2.625	66.68	2.625	66.68	4	3/4	4.750	120.65	4.125	104.78
1	3/4	2.625	66.68	2.625	66.68	4	1	4.750	120.65	4.125	104.78
1 1/2	1/2	2.875	73.03	2.875	73.03	4	1 1/2	4.750	120.65	4.125	104.78
1 1/2	3/4	2.875	73.03	2.875	73.03	4	2	4.750	120.65	4.375	111.13
1 1/2	1	2.875	73.03	2.875	73.03	4	2 1/2	4.750	120.65	4.375	111.13
2	1/2	3.375	85.73	3.125	79.38	4	3	4.750	120.65	4.375	111.13
2	3/4	3.375	85.73	3.125	79.38	6	1/2	7.125	180.98	5.125	130.18
2	1	3.375	85.73	3.125	79.38	6	3/4	7.125	180.98	5.125	130.18
2	1 1/2	3.375	85.73	3.125	79.38	6	1	7.125	180.98	5.125	130.18
2 1/2	1/2	3.625	92.08	3.375	85.73	6	1 1/2	7.125	180.98	5.125	130.18
2 1/2	3/4	3.625	92.08	3.375	85.73	6	2	7.125	180.98	5.375	136.53
2 1/2	1	3.625	92.08	3.375	85.73	6	2 1/2	7.125	180.98	5.375	136.53
2 1/2	1 1/2	3.625	92.08	3.375	85.73	6	3	7.125	180.98	5.375	136.53
						6	4	7.125	180.98	5.750	146.05

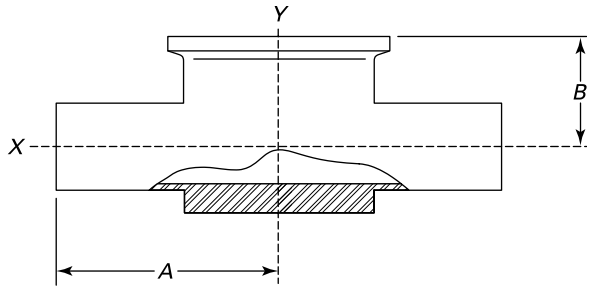
Table DT-4.1.2-9
Hygienic Clamp Joint: Short-Outlet Reducing Tee

(24)



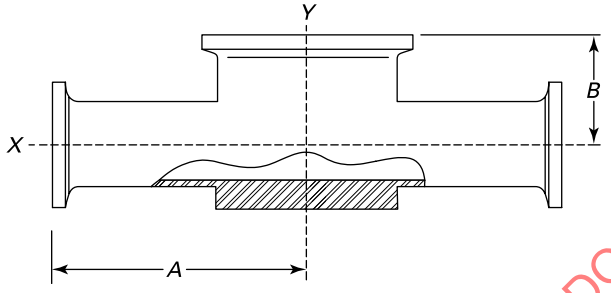
Nominal Size, in.		A		B		Nominal Size, in.		A		B	
X	Y	in.	mm	in.	mm	X	Y	in.	mm	in.	mm
3/8	1/4	2.250	57.15	1.000	25.40	2 1/2	1 1/2	3.625	92.08	1.875	47.63
						2 1/2	2	3.625	92.08	1.875	47.63
1/2	1/4	2.375	60.33	1.000	25.40						
1/2	3/8	2.375	60.33	1.000	25.40	3	1/2	3.875	98.43	2.125	53.98
						3	3/4	3.875	98.43	2.125	53.98
3/4	1/4	2.500	63.50	1.000	25.40	3	1	3.875	98.43	2.125	53.98
3/4	3/8	2.500	63.50	1.000	25.40	3	1 1/2	3.875	98.43	2.125	53.98
3/4	1/2	2.500	63.50	1.000	25.40	3	2	3.875	98.43	2.125	53.98
						3	2 1/2	3.875	98.43	2.125	53.98
1	1/4	2.625	66.68	1.125	28.58						
1	3/8	2.625	66.68	1.125	28.58	4	1/2	4.750	120.65	2.625	66.68
1	1/2	2.625	66.68	1.125	28.58	4	3/4	4.750	120.65	2.625	66.68
1	3/4	2.625	66.68	1.125	28.58	4	1	4.750	120.65	2.625	66.68
						4	1 1/2	4.750	120.65	2.625	66.68
1 1/2	1/2	2.875	73.03	1.375	34.93	4	2	4.750	120.65	2.625	66.68
1 1/2	3/4	2.875	73.03	1.375	34.93	4	2 1/2	4.750	120.65	2.625	66.68
1 1/2	1	2.875	73.03	1.375	34.93	4	3	4.750	120.65	2.625	66.68
2	1/2	3.375	85.73	1.625	41.28	6	1/2	7.125	180.98	3.625	92.08
2	3/4	3.375	85.73	1.625	41.28	6	3/4	7.125	180.98	3.625	92.08
2	1	3.375	85.73	1.625	41.28	6	1	7.125	180.98	3.625	92.08
2	1 1/2	3.375	85.73	1.625	41.28	6	1 1/2	7.125	180.98	3.625	92.08
						6	2	7.125	180.98	3.625	92.08
2 1/2	1/2	3.625	92.08	1.875	47.63	6	2 1/2	7.125	180.98	3.625	92.08
2 1/2	3/4	3.625	92.08	1.875	47.63	6	3	7.125	180.98	3.625	92.08
2 1/2	1	3.625	92.08	1.875	47.63	6	4	7.125	180.98	3.750	95.25

Table DT-4.1.2-10
Automatic Tube Weld: Instrument Tee



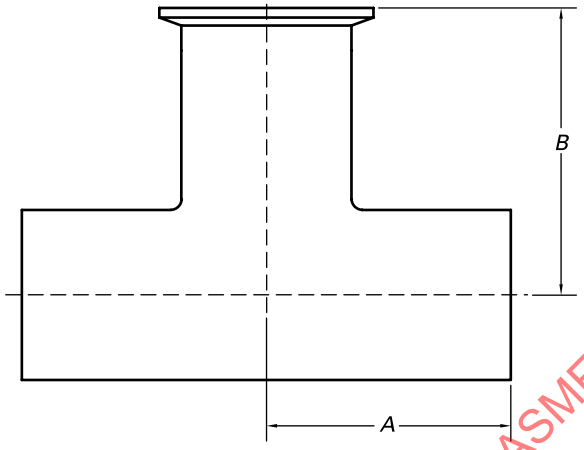
Nominal Size, in.			A		B	
X		Y	in.	mm	in.	mm
1/2	×	1 1/2	2.500	63.50	0.875	22.23
3/4	×	1 1/2	2.500	63.50	1.000	25.40
1	×	1 1/2	2.500	63.50	1.125	28.58
1/2	×	2	2.750	69.85	1.000	25.40
3/4	×	2	2.750	69.85	1.125	28.58
1	×	2	2.750	69.85	1.250	31.75
1 1/2	×	2	2.750	69.85	1.500	38.10

Table DT-4.1.2-11
Hygienic Clamp Joint: Instrument Tee



Nominal Size, in.			A		B	
X		Y	in.	mm	in.	mm
1/2	×	1 1/2	3.000	76.20	0.875	22.23
3/4	×	1 1/2	3.000	76.20	1.000	25.40
1	×	1 1/2	3.000	76.20	1.125	28.58
1/2	×	2	3.250	82.55	1.000	25.40
3/4	×	2	3.250	82.55	1.125	28.58
1	×	2	3.250	82.55	1.250	31.75
1 1/2	×	2	3.250	82.55	1.500	38.10

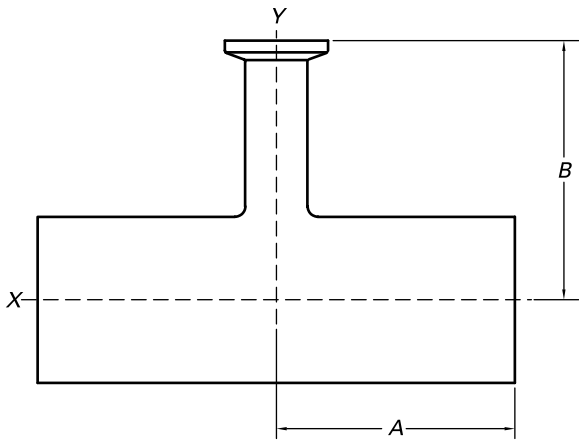
Table DT-4.1.2-12
Automatic Tube Weld:
Standard Outlet Hygienic Clamp Joint Tee



	A		B	
Nominal Size, in.	in.	mm	in.	mm
1/4	1.750	44.45	2.250	57.15
3/8	1.750	44.45	2.250	57.15
1/2	1.875	47.63	2.375	60.33
3/4	2.000	50.80	2.500	63.50
1	2.125	53.98	2.625	66.68
1 1/2	2.375	60.33	2.875	73.03
2	2.875	73.03	3.375	85.73
2 1/2	3.125	79.38	3.625	92.08
3	3.375	85.73	3.875	98.43
4	4.125	104.78	4.750	120.65
6	5.625	142.88	7.125	180.98

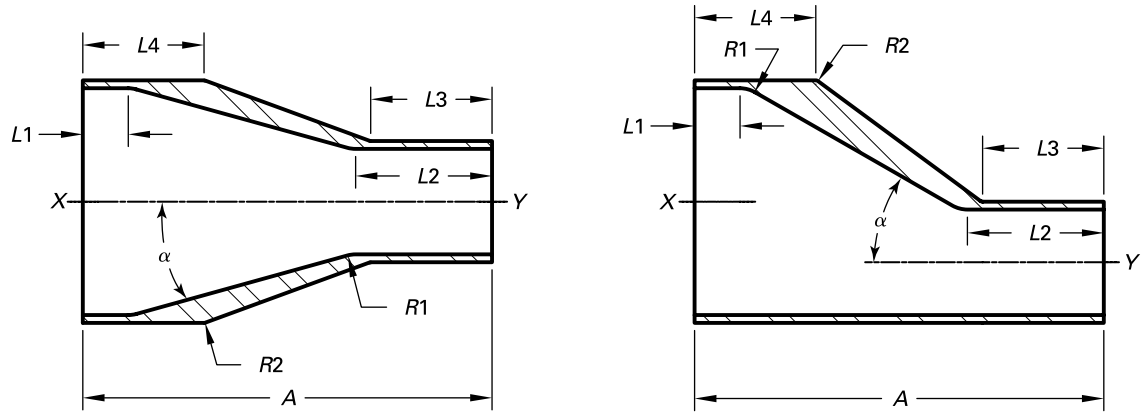
Table DT-4.1.2-13
Automatic Tube Weld: Standard Outlet Hygienic Clamp Joint Reducing Tee

(24)



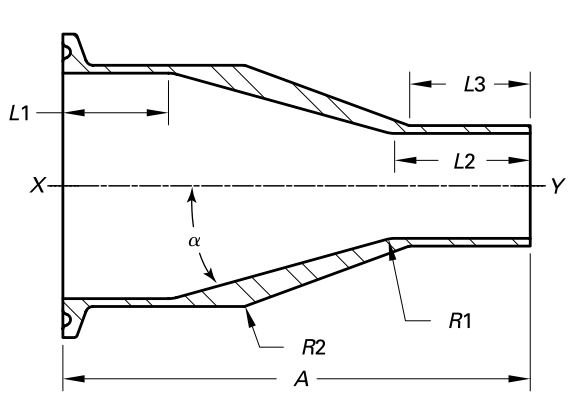
Nominal Size, in.		A		B		Nominal Size, in.		A		B	
X	Y	in.	mm	in.	mm	X	Y	in.	mm	in.	mm
3/8	1/4	1.750	44.45	2.250	57.15	2 1/2	1 1/2	3.125	79.38	3.375	85.73
						2 1/2	2	3.125	79.38	3.375	85.73
1/2	1/4	1.875	47.63	2.375	60.33						
1/2	3/8	1.875	47.63	2.375	60.33	3	1/2	3.375	85.73	3.625	92.08
						3	3/4	3.375	85.73	3.625	92.08
3/4	1/4	2.000	50.80	2.500	63.50	3	1	3.375	85.73	3.625	92.08
3/4	3/8	2.000	50.80	2.500	63.50	3	1 1/2	3.375	85.73	3.625	92.08
3/4	1/2	2.000	50.80	2.500	63.50	3	2	3.375	85.73	3.625	92.08
						3	2 1/2	3.375	85.73	3.625	92.08
1	1/4	2.125	53.98	2.625	66.68						
1	3/8	2.125	53.98	2.625	66.68	4	1/2	4.125	104.78	4.125	104.78
1	1/2	2.125	53.98	2.625	66.68	4	3/4	4.125	104.78	4.125	104.78
1	3/4	2.125	53.98	2.625	66.68	4	1	4.125	104.78	4.125	104.78
						4	1 1/2	4.125	104.78	4.125	104.78
1 1/2	1/2	2.375	60.33	2.875	73.03	4	2	4.125	104.78	4.375	111.13
1 1/2	4/3	2.375	60.33	2.875	73.03	4	2 1/2	4.125	104.78	4.375	111.13
1 1/2	1	2.375	60.33	2.875	73.03	4	3	4.125	104.78	4.375	111.13
2	1/2	2.875	73.03	3.125	79.38	6	1/2	5.625	142.88	5.125	130.18
2	3/4	2.875	73.03	3.125	79.38	6	3/4	5.625	142.88	5.125	130.18
2	1	2.875	73.03	3.125	79.38	6	1	5.625	142.88	5.125	130.18
2	1 1/2	2.875	73.03	3.125	79.38	6	1 1/2	5.625	142.88	5.125	130.18
						6	2	5.625	142.88	5.375	136.53
2 1/2	1/2	3.125	79.38	3.375	85.73	6	2 1/2	5.625	142.88	5.375	136.53
2 1/2	3/4	3.125	79.38	3.375	85.73	6	3	5.625	142.88	5.375	136.53
2 1/2	1	3.125	79.38	3.375	85.73	6	4	5.625	142.88	5.750	146.05

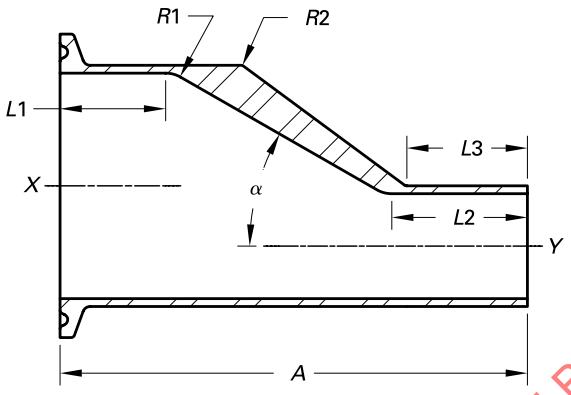
Table DT-4.1.3-1
Automatic Tube Weld: Concentric and Eccentric Reducer



Nominal Size, in.		Overall Length, *A*		I.D. Tangent, Large End, *L1*, min.		I.D. Tangent, Small End, *L2*, min.		O.D. Tangent, Small End, *L3*, min.		O.D. Tangent, Large End, *L4*, min.		Internal Taper, *α*, max., deg	Internal Radius, *R1*, min.		External Radius, *R2*, min.	
X	*Y*	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm		in.	mm	in.	mm
3/8	1/4	1.625	41.28	0.375	9.53	0.875	22.23	0.750	19.05	0.750	19.05	30	0.250	6.35	0.031	0.79
1/2	1/4	1.875	47.63	0.375	9.53	0.875	22.23	0.750	19.05	1.000	25.40	30	0.250	6.35	0.031	0.79
1/2	3/8	1.875	47.63	0.375	9.53	0.875	22.23	0.750	19.05	1.000	25.40	30	0.250	6.35	0.031	0.79
3/4	3/8	2.000	50.80	0.375	9.53	0.875	22.23	0.750	19.05	1.000	25.40	30	0.250	6.35	0.031	0.79
3/4	1/2	2.125	53.98	0.375	9.53	1.125	28.58	1.000	25.40	1.000	25.40	30	0.250	6.35	0.031	0.79
1	1/2	2.500	63.50	0.375	9.53	1.125	28.58	1.000	25.40	1.000	25.40	30	0.250	6.35	0.031	0.79
1	3/4	2.125	53.98	0.375	9.53	1.125	28.58	1.000	25.40	1.000	25.40	30	0.250	6.35	0.031	0.79
1 1/2	3/4	3.000	76.20	0.375	9.53	1.125	28.58	1.000	25.40	1.000	25.40	30	0.250	6.35	0.031	0.79
1 1/2	1	2.500	63.50	0.375	9.53	1.125	28.58	1.000	25.40	1.000	25.40	30	0.250	6.35	0.031	0.79
2	1	3.375	85.73	0.375	9.53	1.125	28.58	1.000	25.40	1.000	25.40	30	0.250	6.35	0.031	0.79
2	1 1/2	2.500	63.50	0.375	9.53	1.125	28.58	1.000	25.40	1.000	25.40	30	0.250	6.35	0.031	0.79
2 1/2	1 1/2	3.375	85.73	0.375	9.53	1.125	28.58	1.000	25.40	1.000	25.40	30	0.250	6.35	0.031	0.79
2 1/2	2	2.500	63.50	0.375	9.53	1.125	28.58	1.000	25.40	1.000	25.40	30	0.250	6.35	0.031	0.79
3	1 1/2	4.250	107.95	0.375	9.53	1.125	28.58	1.000	25.40	1.500	38.10	30	0.250	6.35	0.031	0.79
3	2	3.375	85.73	0.375	9.53	1.125	28.58	1.000	25.40	1.500	38.10	30	0.250	6.35	0.031	0.79
3	2 1/2	2.625	66.68	0.375	9.53	1.125	28.58	1.000	25.40	1.500	38.10	30	0.250	6.35	0.031	0.79
4	2	5.125	130.18	0.375	9.53	1.125	28.58	1.000	25.40	1.500	38.10	30	0.250	6.35	0.031	0.79
4	2 1/2	4.250	107.95	0.375	9.53	1.125	28.58	1.000	25.40	1.500	38.10	30	0.250	6.35	0.031	0.79
4	3	3.875	98.43	0.375	9.53	1.625	41.28	1.500	38.10	1.500	38.10	30	0.250	6.35	0.031	0.79
6	3	7.250	184.15	0.375	9.53	1.625	41.28	1.500	38.10	2.000	50.80	44	0.250	6.35	0.031	0.79
6	4	5.625	142.88	0.375	9.53	1.625	41.28	1.500	38.10	2.000	50.80	44	0.250	6.35	0.031	0.79

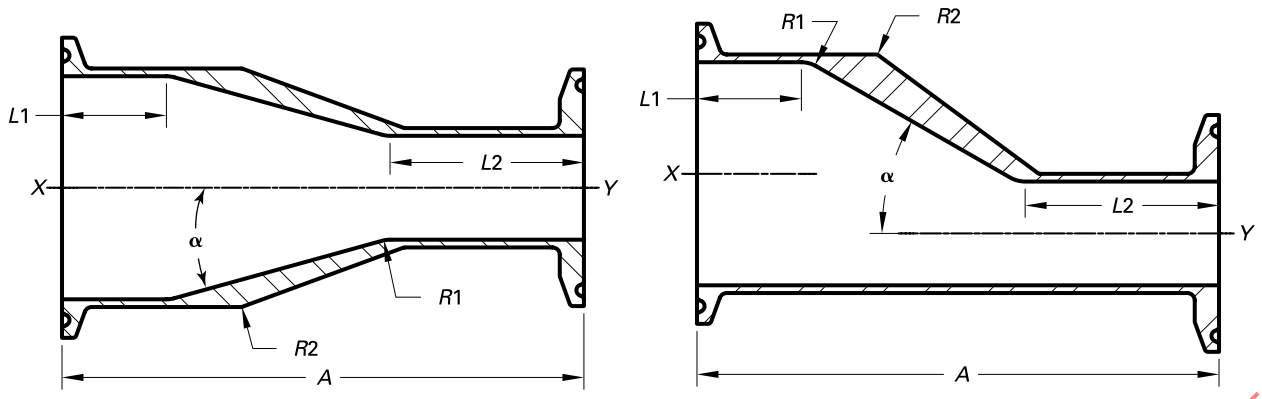
Table DT-4.1.3-2
Hygienic Clamp Joint: Tube Weld Concentric and Eccentric Reducer





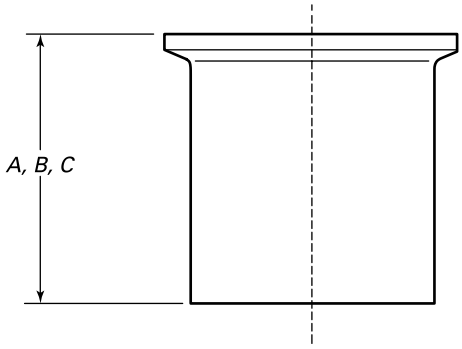
Nominal Size, in.		Overall Length, *A*		I.D. Tangent, Large End, *L*1, min.		I.D. Tangent, Small End, *L*2, min.		O.D. Tangent, Small End, *L*3, min.		Internal Taper, *α*, max., deg	Internal Radius, *R*1, min.		External Radius, *R*2, min.	
X	*Y*	in.	mm	in.	mm	in.	mm	in.	mm		in.	mm	in.	mm
3/8	1/4	2.125	53.98	0.375	9.53	0.875	22.23	0.750	19.05	30	0.250	6.35	0.031	0.79
1/2	1/4	2.375	60.33	0.375	9.53	0.875	22.23	0.750	19.05	30	0.250	6.35	0.031	0.79
1/2	3/8	2.375	60.33	0.375	9.53	0.875	22.23	0.750	19.05	30	0.250	6.35	0.031	0.79
3/4	3/8	2.500	63.50	0.375	9.53	0.875	22.23	0.750	19.05	30	0.250	6.35	0.031	0.79
3/4	1/2	2.625	66.68	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
1	1/2	3.000	76.20	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
1	3/4	2.625	66.68	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
1 1/2	3/4	3.500	88.90	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
1 1/2	1	3.000	76.20	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
2	1	3.875	98.43	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
2	1 1/2	3.000	76.20	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
2 1/2	1 1/2	3.875	98.43	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
2 1/2	2	3.000	76.20	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
3	1 1/2	4.750	120.65	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
3	2	3.875	98.43	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
3	2 1/2	3.125	79.38	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
4	2	5.750	146.05	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
4	2 1/2	4.875	123.83	0.375	9.53	1.125	28.58	1.000	25.40	30	0.250	6.35	0.031	0.79
4	3	4.500	114.30	0.375	9.53	1.625	41.28	1.500	38.10	30	0.250	6.35	0.031	0.79
6	3	8.000	203.20	0.375	9.53	1.625	41.28	1.500	38.10	44	0.250	6.35	0.031	0.79
6	4	6.375	161.93	0.375	9.53	1.625	41.28	1.500	38.10	44	0.250	6.35	0.031	0.79

Table DT-4.1.3-3
Hygienic Clamp Joint: Concentric and Eccentric Reducer



Nominal Size, in.		Overall Length, *A*		I.D. Tangent, Large End, *L*1, min.		I.D. Tangent, Small End, *L*2, min.		Internal Taper, *α*, max., deg	Internal Radius, *R*1, min.		External Radius, *R*2, min.	
X	*Y*	in.	mm	in.	mm	in.	mm		in.	mm	in.	mm
3/8	1/4	2.625	66.68	0.375	9.53	0.875	22.23	30	0.250	6.35	0.031	0.79
1/2	1/4	2.875	73.03	0.375	9.53	0.875	22.23	30	0.250	6.35	0.031	0.79
1/2	3/8	2.875	73.03	0.375	9.53	0.875	22.23	30	0.250	6.35	0.031	0.79
3/4	3/8	3.000	76.20	0.375	9.53	0.875	22.23	30	0.250	6.35	0.031	0.79
3/4	1/2	3.125	79.38	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
1	1/2	3.500	88.90	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
1	3/4	3.125	79.38	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
1 1/2	3/4	4.000	101.60	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
1 1/2	1	3.500	88.90	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
2	1	4.375	111.13	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
2	1 1/2	3.500	88.90	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
2 1/2	1 1/2	4.375	111.13	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
2 1/2	2	3.500	88.90	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
3	1 1/2	5.250	133.35	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
3	2	4.375	111.13	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
3	2 1/2	3.625	92.08	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
4	2	6.250	158.75	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
4	2 1/2	5.375	136.53	0.375	9.53	1.125	28.58	30	0.250	6.35	0.031	0.79
4	3	5.000	127.00	0.375	9.53	1.625	41.28	30	0.250	6.35	0.031	0.79
6	3	8.500	215.90	0.375	9.53	1.625	41.28	44	0.250	6.35	0.031	0.79
6	4	7.000	177.80	0.375	9.53	1.625	41.28	44	0.250	6.35	0.031	0.79

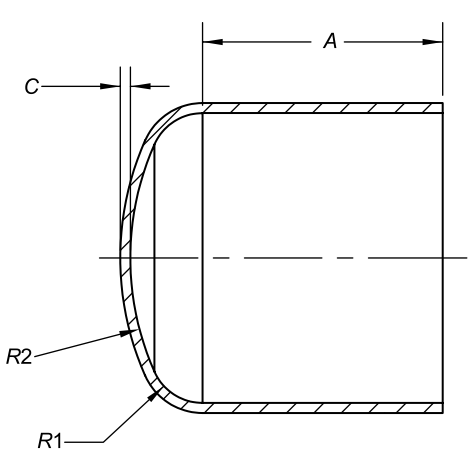
Table DT-4.1.4-1
Automatic Tube Weld: Ferrule



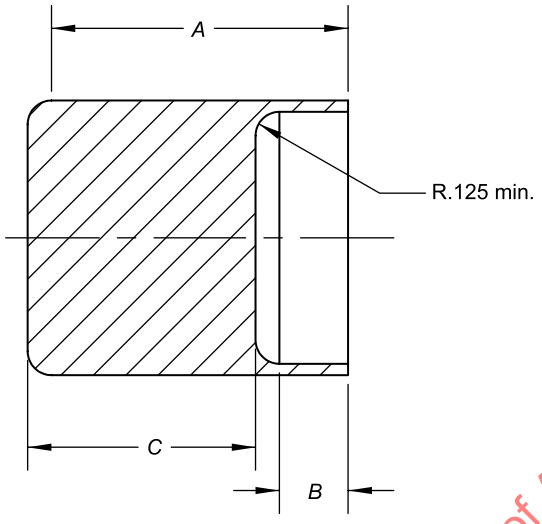
Nominal Size, in.	*A*		*B*		*C*	
	in.	mm	in.	mm	in.	mm
1/4	1.750	44.45	1.125	28.58	0.500	12.70
3/8	1.750	44.45	1.125	28.58	0.500	12.70
1/2	1.750	44.45	1.125	28.58	0.500	12.70
3/4	1.750	44.45	1.125	28.58	0.500	12.70
1	1.750	44.45	1.125	28.58	0.500	12.70
1 1/2	1.750	44.45	1.125	28.58	0.500	12.70
2	2.250	57.15	1.125	28.58	0.500	12.70
2 1/2	2.250	57.15	1.125	28.58	0.500	12.70
3	2.250	57.15	1.125	28.58	0.500	12.70
4	2.250	57.15	1.125	28.58	0.625	15.88
6	3.000	76.20	1.500	38.10	0.750	19.05

(24)

Table DT-4.1.5-1
Automatic Tube Weld: Cap



Type A [Notes (1), (2)]



Type B [Notes (3), (4)]

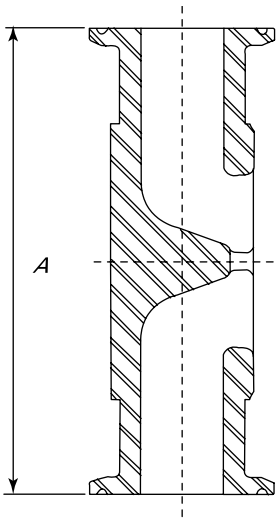
Nominal Size,	O.D. Tangent, *A*, min.		Type A Only: Inside Knuckle Radius (IKR), *R*1, min.		Type A Only: Inside Crown Radius (ICR), *R*2 Minimum		Type A Only: Inside Crown Radius (ICR), *R*2 Maximum		Types A and B: *C*, min.	
in.	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
½	1.500	38.10	0.063	1.60	0.250	6.35	0.600	15.24	0.065	1.65
¾	1.500	38.10	0.063	1.60	0.375	9.53	0.900	22.86	0.065	1.65
1	1.500	38.10	0.063	1.60	0.500	12.70	1.200	30.48	0.065	1.65
1½	1.500	38.10	0.090	2.29	0.750	19.05	1.500	38.10	0.067	1.70
2	1.500	38.10	0.120	3.05	1.000	25.40	2.000	50.80	0.092	2.34
2½	1.500	38.10	0.150	3.81	1.250	31.75	2.500	63.50	0.116	2.95
3	1.750	44.45	0.180	4.57	1.500	38.10	3.000	76.20	0.140	3.56
4	2.000	50.80	0.240	6.10	2.000	50.80	4.000	101.60	0.188	4.78
6	2.500	63.50	0.360	9.14	3.000	76.20	6.000	152.40	0.245	6.22

NOTES:
(1) For type A, minimum wall thickness in formed areas, *C*, shall conform to DT-3.
(2) For type A, other shapes are permitted as long as the design meets or exceeds the pressure and temperature ratings shown in Table DT-2-1 and dimension minimums *A*, *R*1, and *R*2 are met.
(3) For type B, minimum I.D. control portion length, *B*, is 0.375 in. (9.53 mm) for all sizes.
(4) For type B, other shapes are permitted as long as the dimension *C* minimum is maintained throughout the section.

Table DT-4.1.5-2
Hygienic Clamp Joint: Solid End Cap

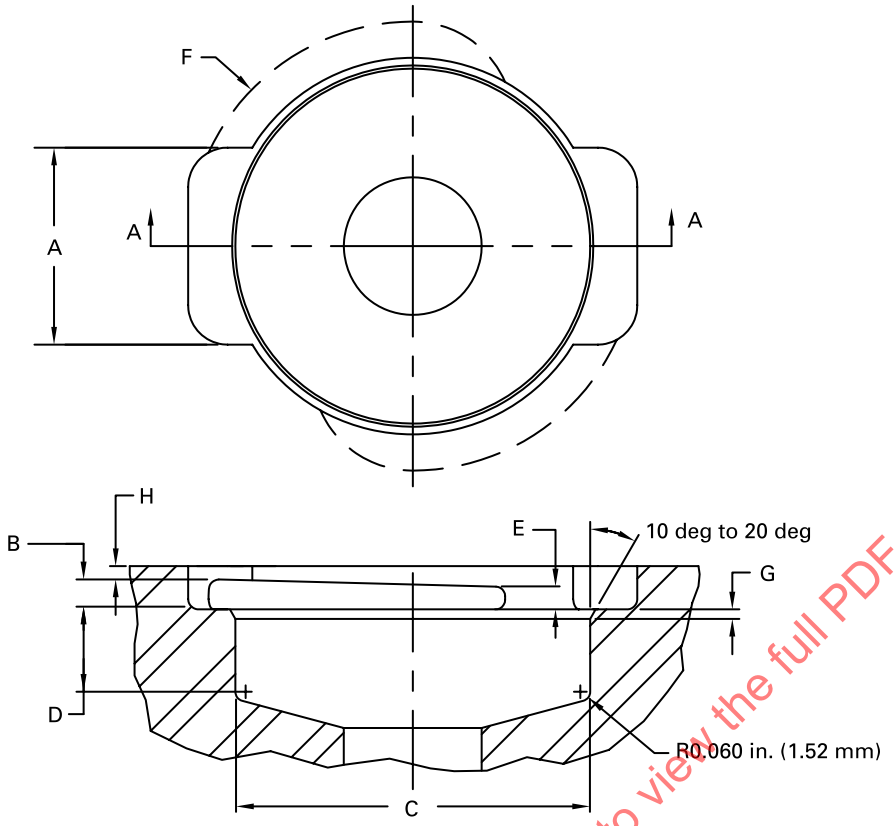
Nominal Size, in.	Type	*A*, min.	
		in.	mm
1/4	A	0.187	4.75
3/8	A	0.187	4.75
1/2	A	0.187	4.75
3/4	A	0.187	4.75
1	A	0.250	6.35
1	B	0.250	6.35
1 1/2	B	0.250	6.35
2	B	0.250	6.35
2 1/2	B	0.250	6.35
3	B	0.250	6.35
4	B	0.312	7.92
6	B	0.437	11.10

Table DT-4.4.1-1
Hygienic Clamp Joint: Two-Way, Weir-Style Diaphragm Valve



	A	
Nominal Size, in.	**in.**	**mm**
¼ fractional	2.500	63.50
⅜ fractional	2.500	63.50
½ fractional	2.500	63.50
½	3.500	88.90
¾	4.000	101.60
1	4.500	114.30
1½	5.500	139.70
2	6.250	158.75
2½	7.630	193.80
3	8.750	222.25
4	11.500	292.10

Table DT-4.5.1-1
Tapered Locking Tab Retainer: Recessed



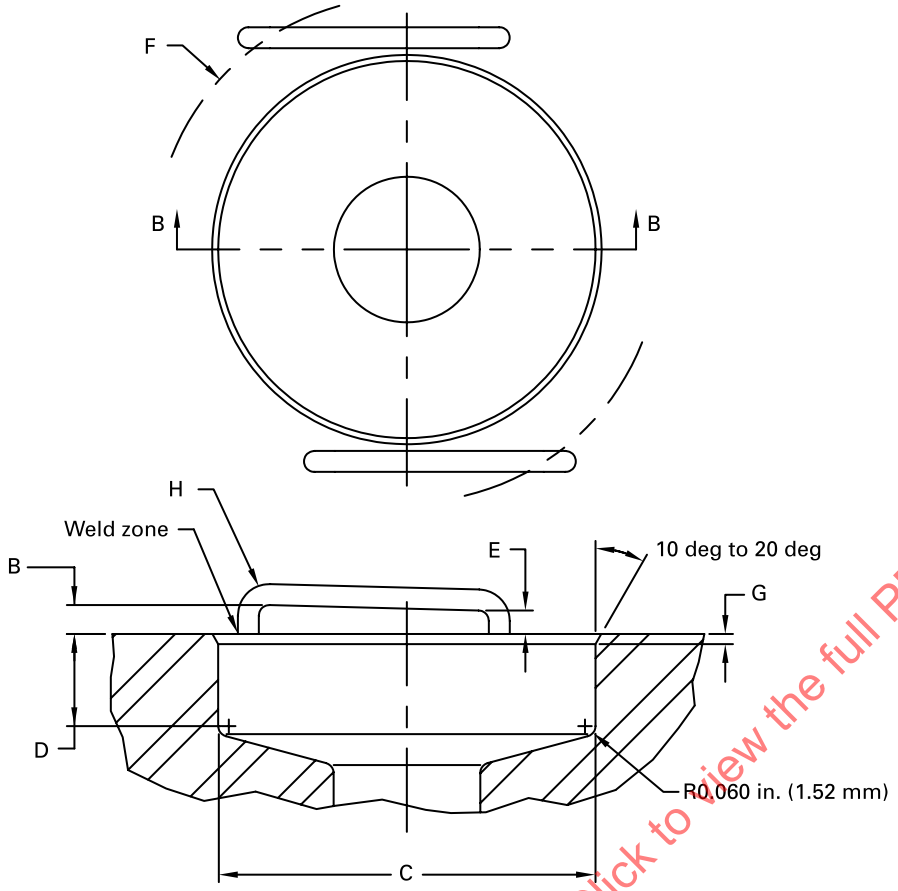
SECTION: A-A

	Dimension		Tolerance		
	in.	mm	in.	mm	Notes
A	1.250 (min.) 1.400 (max.)	31.75 (min.) 35.56 (max.)	...	...	(1)
B	0.173	4.39	±0.004	±0.10	...
C	2.250	57.15	+0.003/−0.000	+0.08/−0.00	...
D	0.550 (min.)	13.97 (min.)	...	...	...
E	0.134	3.40	±0.004	±0.10	...
F	R1.430	R36.32	±0.010	±0.25	(1)
G	0.060 (max.)	1.52 (max.)	...	...	(2)
H	0.125 (max.)	3.18 (max.)	...	...	...

GENERAL NOTES:
(a) Locking tab retainer options are shown as possible options and do not represent all possible designs.
(b) All surfaces shall meet the specified finish of wetted surfaces, excluding the weld zones.

NOTES:
(1) Clearance for locking tabs.
(2) O-ring lead-in chamfer.

Table DT-4.5.2-1
Tapered Locking Tab Retainer: External



SECTION: B-B

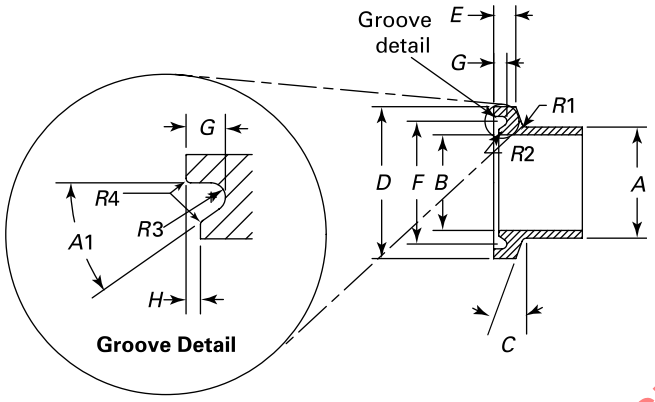
	Dimension		Tolerance		
	in.	mm	in.	mm	Notes
B	0.173	4.39	±0.004	±0.10	...
C	2.250	57.15	+0.003/−0.000	+0.08/−0.00	...
D	0.550 (min.)	13.97 (min.)	...	...	...
E	0.134	3.40	±0.004	±0.10	...
F	R1.430	R36.32	±0.010	±0.25	(1)
G	0.060 (max.)	1.52 (max.)	...	...	(2)
H	0.125 (max.)	3.18 (max.)	...	...	...

GENERAL NOTES:
(a) Locking tab retainer options are shown as possible options and do not represent all possible designs.
(b) All surfaces shall meet the specified finish of wetted surfaces, excluding the weld zones.

NOTES:
(1) Clearance for locking tabs.
(2) O-ring lead-in chamfer.

Table DT-7.1-1
Metallic Hygienic Clamp Ferrule Standard Dimensions and Tolerances

Type A

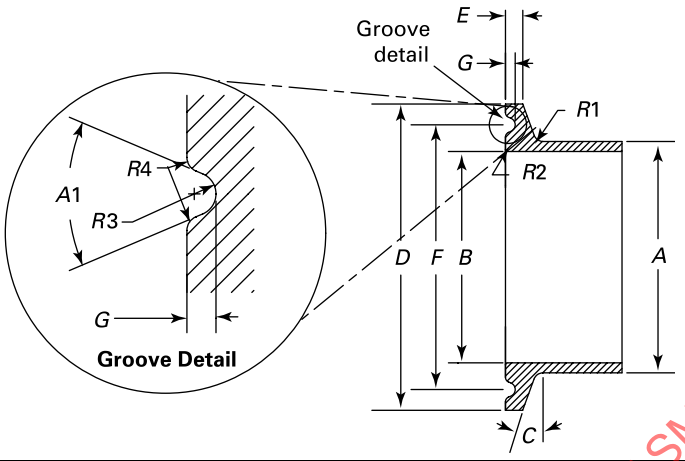


Nominal Size, in.	Type	Tube Diameter, *A*				I.D. Bore, *B*				Flange Angle, *C*, deg		Flange Diameter, *D*				Flange Thickness, *E*, ref.		Groove Diameter, *F*			
		Dimension		Tolerance, ±		Dimension		Tolerance, ±				Dimension		Tolerance, ±		Dimension		Dimension		Tolerance, ±	
		in.	mm	in.	mm	in.	mm	in.	mm	Dimension	Tolerance, ±	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
1/4	A	0.250	6.35	0.005	0.13	0.180	4.57	0.005	0.13	20	0.5	0.984	25.0	0.005	0.13	0.143	3.63	0.800	20.32	0.005	0.13
3/8	A	0.375	9.53	0.005	0.13	0.305	7.75	0.005	0.13	20	0.5	0.984	25.0	0.005	0.13	0.143	3.63	0.800	20.32	0.005	0.13
1/2	A	0.500	12.70	0.005	0.13	0.370	9.40	0.005	0.13	20	0.5	0.984	25.0	0.005	0.13	0.143	3.63	0.800	20.32	0.005	0.13
3/4	A	0.750	19.05	0.005	0.13	0.620	15.75	0.005	0.13	20	0.5	0.984	25.0	0.005	0.13	0.143	3.63	0.800	20.32	0.005	0.13
1	A	1.000	25.40	0.005	0.13	0.870	22.10	0.005	0.13	20	1.0	1.339	34.0	0.005	0.13	0.143	3.63	1.160	29.46	0.005	0.13

Nominal Size, in.	Type	Groove Depth, *G*				Face Offset, *H*				Groove Detail, *R3*				Groove Detail, *R4*				Groove Detail, *A1*, deg		Radius, *R1*, max.		Radius, *R2*			
		Dimension		Tolerance, ±		Dimension		Tolerance, ±		Dimension		Tolerance, ±		Dimension		Tolerance, ±						Maximum		Minimum	
		in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	Dimension	Tolerance, ±	in.	mm	in.	mm	in.	mm
1/4	A	0.085	2.16	0.005	0.13	0.031	0.79	0.005	0.13	0.031	0.79	0.005	0.13	0.020	0.51	0.005	0.13	35	1	0.031	0.79	0.031	0.79	0.005	0.13
3/8	A	0.085	2.16	0.005	0.13	0.031	0.79	0.005	0.13	0.031	0.79	0.005	0.13	0.020	0.51	0.005	0.13	35	1	0.031	0.79	0.031	0.79	0.005	0.13
1/2	A	0.085	2.16	0.005	0.13	0.031	0.79	0.005	0.13	0.031	0.79	0.005	0.13	0.020	0.51	0.005	0.13	35	1	0.031	0.79	0.031	0.79	0.005	0.13
3/4	A	0.085	2.16	0.005	0.13	0.031	0.79	0.005	0.13	0.031	0.79	0.005	0.13	0.020	0.51	0.005	0.13	35	1	0.031	0.79	0.031	0.79	0.005	0.13
1	A	0.085	2.16	0.005	0.13	0.031	0.79	0.005	0.13	0.031	0.79	0.005	0.13	0.020	0.51	0.005	0.13	35	1	0.031	0.79	0.031	0.79	0.005	0.13

Table DT-7.1-1
Metallic Hygienic Clamp Ferrule Standard Dimensions and Tolerances (Cont'd)

Type B



Nominal Size, in.	Type	Tube Diameter, *A*				I.D. Bore, *B*				Flange Angle, *C*, deg		Flange Diameter, *D*						Flange Thickness, *E*, ref.		Groove Diameter, *F*			
		Dimension		Tolerance, ±		Dimension		Tolerance, ±				Dimension		Tolerance, +		Tolerance, −		Dimension		Dimension		Tolerance, ±	
		in.	mm	in.	mm	in.	mm	in.	mm	Dimension	Tolerance, ±	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
1	B	1.000	25.40	0.005	0.13	0.870	22.10	0.005	0.13	20	1.0	1.984	50.39	0.008	0.20	0.005	0.13	0.112	2.84	1.718	43.64	0.005	0.13
1½	B	1.500	38.10	0.008	0.20	1.370	34.80	0.005	0.13	20	1.0	1.984	50.39	0.008	0.20	0.005	0.13	0.112	2.84	1.718	43.64	0.005	0.13
2	B	2.000	50.80	0.008	0.20	1.870	47.50	0.005	0.13	20	1.0	2.516	63.91	0.008	0.20	0.008	0.20	0.112	2.84	2.218	56.34	0.005	0.13
2½	B	2.500	63.50	0.010	0.25	2.370	60.20	0.005	0.13	20	1.0	3.047	77.39	0.008	0.20	0.008	0.20	0.112	2.84	2.781	70.64	0.005	0.13
3	B	3.000	76.20	0.010	0.25	2.870	72.90	0.005	0.13	20	1.0	3.579	90.91	0.010	0.25	0.010	0.25	0.112	2.84	3.281	83.34	0.005	0.13
4	B	4.000	101.60	0.015	0.38	3.834	97.38	0.005	0.13	20	1.0	4.682	118.92	0.015	0.38	0.015	0.38	0.112	2.84	4.344	110.34	0.005	0.13
6	B	6.000	152.40	0.030	0.76	5.782	146.86	0.005	0.13	20	1.0	6.570	166.88	0.030	0.76	0.030	0.76	0.220	5.59	6.176	156.87	0.005	0.13

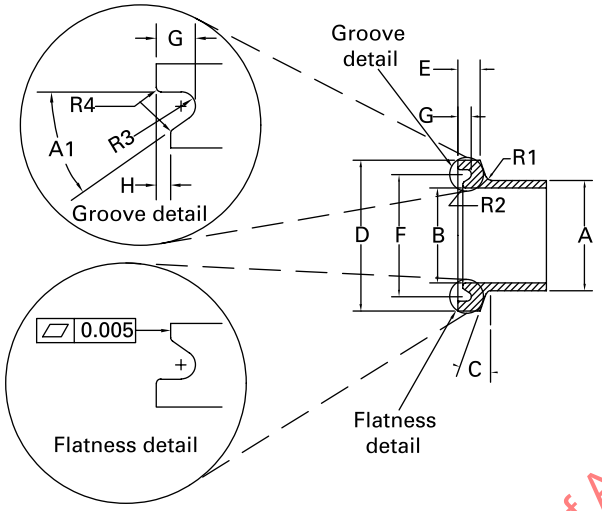
Nominal Size, in.	Type	Groove Depth, *G*				Face Offset, *H*		Groove Detail, *R*3				Groove Detail, *R*4				Groove Detail, *A*1, deg		Radius, *R*1, max.		Radius, *R*2			
		Dimension		Tolerance, ±				Dimension		Tolerance, ±		Dimension		Tolerance, ±						Maximum		Minimum	
		in.	mm	in.	mm	Dimension	Tolerance, ±	in.	mm	in.	mm	in.	mm	in.	mm	Dimension	Tolerance, ±	in.	mm	in.	mm	in.	mm
1	B	0.063	1.60	0.005	0.13	N/A	N/A	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
1½	B	0.063	1.60	0.005	0.13	N/A	N/A	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
2	B	0.063	1.60	0.005	0.13	N/A	N/A	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
2½	B	0.063	1.60	0.005	0.13	N/A	N/A	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
3	B	0.063	1.60	0.005	0.13	N/A	N/A	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
4	B	0.063	1.60	0.005	0.13	N/A	N/A	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
6	B	0.063	1.60	0.005	0.13	N/A	N/A	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13

Table DT-7.1-1
Metallic Hygienic Clamp Ferrule Standard Dimensions and Tolerances (Cont'd)

GENERAL NOTES:
(a) Dimensions and tolerances apply to machined finishes only.
(b) I.D. bore dimension *B* should be measured on the ferrule face side only.

Table DT-7.1-2
Polymeric Hygienic Clamp Ferrule Standard Dimensions and Tolerances

Type A

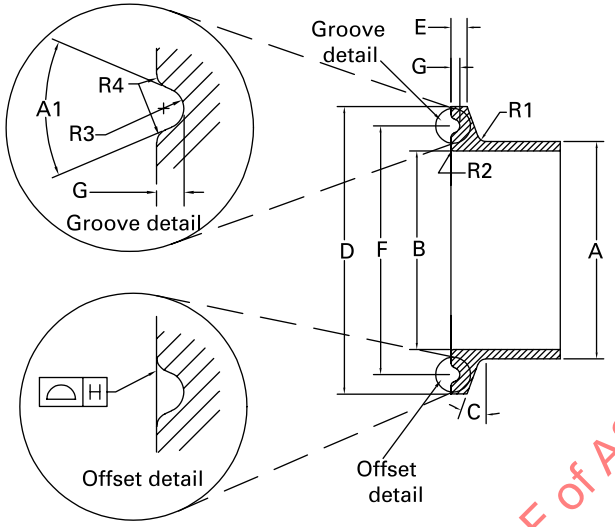


Nominal Size, in.	Type	Tube Diameter, *A*		I.D. Bore, *B*				Flange Angle, *C*, deg			Flange Diameter, *D*				Flange Thickness, *E*, ref.		Groove Diameter, *F*			
		Dimension		Dimension		Tolerance, ±					Dimension		Tolerance, ±		Dimension		Dimension		Tolerance, ±	
								Dimension	Tolerance ±	Tolerance −										
		in.	mm	in.	mm	in.	mm				in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
1/4	A	0.250	6.35	0.180	4.57	0.010	0.25	20	1.0	3.0	0.984	25.0	0.010	0.25	0.143	3.63	0.800	20.32	0.010	0.25
3/8	A	0.375	9.53	0.305	7.75	0.010	0.25	20	1.0	3.0	0.984	25.0	0.010	0.25	0.143	3.63	0.800	20.32	0.010	0.25
1/2	A	0.500	12.70	0.370	9.40	0.010	0.25	20	1.0	3.0	0.984	25.0	0.010	0.25	0.143	3.63	0.800	20.32	0.010	0.25
3/4	A	0.750	19.05	0.620	15.75	0.010	0.25	20	1.0	3.0	0.984	25.0	0.010	0.25	0.143	3.63	0.800	20.32	0.010	0.25
1	A	1.000	25.40	0.870	22.10	0.010	0.25	20	1.0	3.0	1.339	34.0	0.010	0.25	0.143	3.63	1.160	29.46	0.010	0.25

Nominal Size, in.	Type	Groove Depth, *G*				Face Offset, *H*				Groove Detail, *R3*				Groove Detail, *R4*				Groove Detail, *A1*, deg		Radius, *R1*, max.		Radius, *R2*			
		Dimension		Tolerance, ±		Dimension		Tolerance, ±		Dimension		Tolerance, ±		Dimension		Tolerance, ±						Maximum		Minimum	
		in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	Dimension	Tolerance, ±	in.	mm	in.	mm	in.	mm
1/4	A	0.085	2.16	0.005	0.13	0.031	0.79	0.005	0.13	0.031	0.79	0.005	0.13	0.020	0.51	0.005	0.13	35	1	0.031	0.79	0.031	0.79	0.005	0.13
3/8	A	0.085	2.16	0.005	0.13	0.031	0.79	0.005	0.13	0.031	0.79	0.005	0.13	0.020	0.51	0.005	0.13	35	1	0.031	0.79	0.031	0.79	0.005	0.13
1/2	A	0.085	2.16	0.005	0.13	0.031	0.79	0.005	0.13	0.031	0.79	0.005	0.13	0.020	0.51	0.005	0.13	35	1	0.031	0.79	0.031	0.79	0.005	0.13
3/4	A	0.085	2.16	0.005	0.13	0.031	0.79	0.005	0.13	0.031	0.79	0.005	0.13	0.020	0.51	0.005	0.13	35	1	0.031	0.79	0.031	0.79	0.005	0.13
1	A	0.085	2.16	0.005	0.13	0.031	0.79	0.005	0.13	0.031	0.79	0.005	0.13	0.020	0.51	0.005	0.13	35	1	0.031	0.79	0.031	0.79	0.005	0.13

Table DT-7.1-2
Polymeric Hygienic Clamp Ferrule Standard Dimensions and Tolerances (Cont'd)

Type B



Nominal Size, in.	Type	Tube Diameter, *A*		I.D. Bore, *B*				Flange Angle, *C*, deg			Flange Diameter, *D*				Flange Thickness, *E*, ref.		Groove Diameter, *F*			
		Dimension		Dimension		Tolerance, ±			Tolerance		Dimension		Tolerance, ±		Dimension		Dimension		Tolerance, ±	
		in.	mm	in.	mm	in.	mm	Dimension	±	−	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
1	B	1.000	25.40	0.870	22.10	0.010	0.25	20	1.0	3.0	1.984	50.39	0.010	0.25	0.112	2.84	1.718	43.64	0.010	0.25
1½	B	1.500	38.10	1.370	34.80	0.010	0.25	20	1.0	3.0	1.984	50.39	0.010	0.25	0.112	2.84	1.718	43.64	0.010	0.25
2	B	2.000	50.80	1.870	47.50	0.010	0.25	20	1.0	3.0	2.516	63.91	0.010	0.25	0.112	2.84	2.218	56.34	0.010	0.25
2½	B	2.500	63.50	2.370	60.20	0.010	0.25	20	1.0	3.0	3.047	77.39	0.010	0.25	0.112	2.84	2.781	70.64	0.010	0.25
3	B	3.000	76.20	2.870	72.90	0.010	0.25	20	1.0	3.0	3.579	90.91	0.010	0.25	0.112	2.84	3.281	83.34	0.010	0.25
4	B	4.000	101.60	3.834	97.38	0.010	0.25	20	1.0	3.0	4.682	118.92	0.015	0.38	0.112	2.84	4.344	110.34	0.010	0.25

Table DT-7.1-2
Polymeric Hygienic Clamp Ferrule Standard Dimensions and Tolerances (Cont'd)

Nominal Size, in.	Type	Groove Depth, *G*				Face Offset, *H*				Groove Detail, *R*3				Groove Detail, *R*4				Groove Detail, *A*1, deg		Radius, *R*1, max.		Radius, *R*2			
		Dimension		Tolerance, ±		Dimension		Tolerance, ±		Dimension		Tolerance, ±		Dimension		Tolerance, ±						Maximum		Minimum	
		in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	Dimension	Tolerance, ±	in.	mm	in.	mm	in.	mm
1	B	0.063	1.60	0.005	0.13	0.000	0.00	0.005	0.13	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
1½	B	0.063	1.60	0.005	0.13	0.000	0.00	0.005	0.13	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
2	B	0.063	1.60	0.005	0.13	0.000	0.00	0.005	0.13	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
2½	B	0.063	1.60	0.005	0.13	0.000	0.00	0.005	0.13	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
3	B	0.063	1.60	0.005	0.13	0.000	0.00	0.005	0.13	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13
4	B	0.063	1.60	0.005	0.13	0.000	0.00	0.005	0.13	0.047	1.19	0.005	0.13	0.020	0.51	0.005	0.13	46	1	0.063	1.60	0.031	0.79	0.005	0.13

GENERAL NOTES:

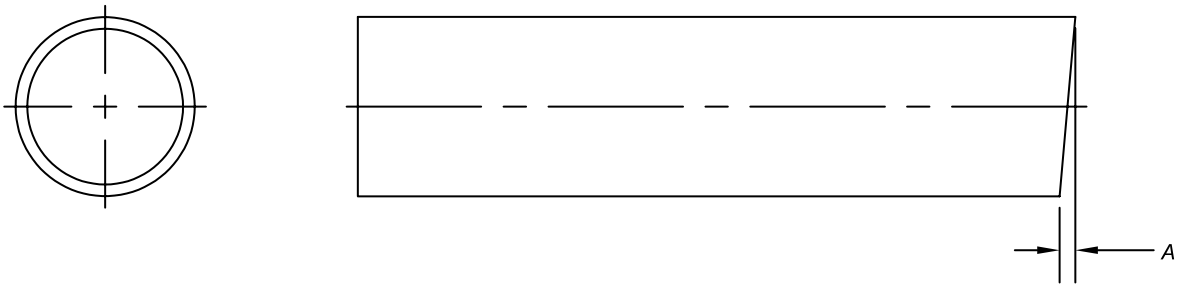
(a) Dimensions and tolerances apply to molded polymer materials only.

(b) I.D. bore dimension *B* should be measured on the ferrule face side only.

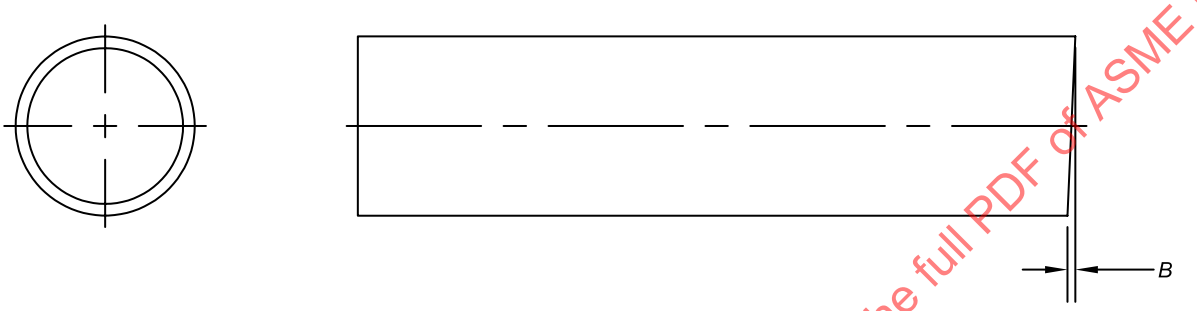
(c) Ferrules should only be used with elastomeric gaskets.

Table DT-7.2-1
Tubing End Square Cut Tolerances

(24)



(a) As Supplied [Note (1)]



(b) After Weld Joint Preparation [Note (2)]

	Square Cut Tolerances, Max.			
	A		*B*	
Nominal Size, in.	in.	mm	in.	mm
1/4	0.005	0.13	0.005	0.13
3/8	0.006	0.14	0.005	0.13
1/2	0.008	0.20	0.005	0.13
3/4	0.011	0.29	0.005	0.13
1	0.015	0.38	0.008	0.20
1 1/2	0.022	0.57	0.008	0.20
2	0.030	0.76	0.008	0.20
2 1/2	0.038	0.95	0.010	0.25
3	0.045	1.14	0.016	0.41
4	0.060	1.52	0.016	0.41
6	0.090	2.29	0.030	0.76

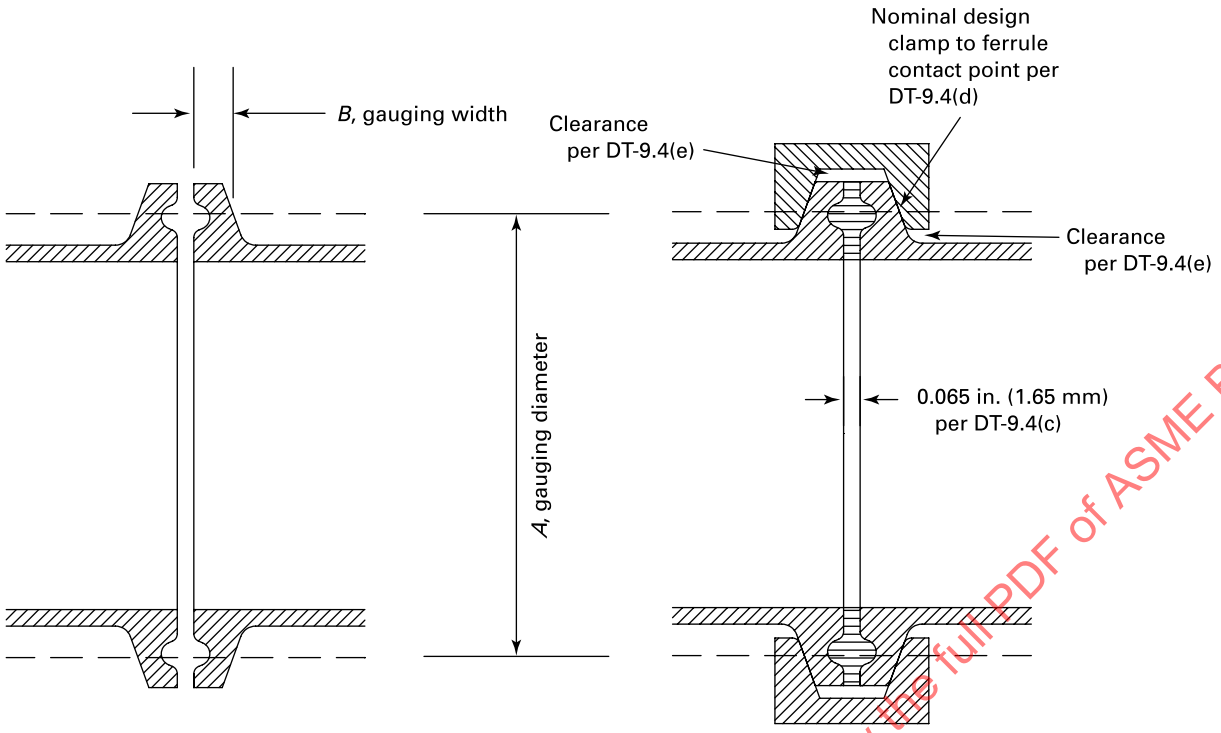
GENERAL NOTE: For weld joint preparation, see MJ-3.4.

NOTES:
(1) Maximum deviations from squareness, *A*, for tube face to outside diameter.
(2) Maximum deviations from squareness, *B*, for tube face to outside diameter.

Table DT-7.3-1
Transfer Panel and Jumper Tolerances

Connection Nominal Size,	Parallelism Tolerance (Tol.1) Maximum Gap Allowed		Position Tolerance (Tol.2) Maximum Deviation From the Design Distance Between Centerlines	
in.	in.	mm	in.	mm
½	0.010	0.25	0.015	0.38
¾	0.010	0.25	0.015	0.38
1	0.020	0.51	0.015	0.38
1½	0.020	0.51	0.015	0.38
2	0.025	0.64	0.015	0.38
2½	0.025	0.64	0.015	0.38
3	0.030	0.76	0.015	0.38
4	0.040	1.02	0.015	0.38

Table DT-9.3-1
Hygienic Clamp Ferrule: Design Criteria



Nominal Size, in.	Type	Basic Gauging and Contact Diameter, *A* (ref.) Dimension in.	Basic Gauging and Contact Diameter, *A* (ref.) Dimension mm	Gauging Width, *B* Dimension in.	Gauging Width, *B* Dimension mm	Gauging Width, *B* Tolerance, ± in.	Gauging Width, *B* Tolerance, ± mm	Hygienic Clamp Size, in.
1/4	A	0.867	22.02	0.164	4.17	0.004	0.10	3/4
3/8	A	0.867	22.02	0.164	4.17	0.004	0.10	3/4
1/2	A	0.867	22.02	0.164	4.17	0.004	0.10	3/4
3/4	A	0.867	22.02	0.164	4.17	0.004	0.10	3/4
1	A	1.222	31.04	0.164	4.17	0.004	0.10	ISO DN15
1	B	1.748	44.39	0.155	3.94	0.005	0.13	1 1/2
1 1/2	B	1.748	44.39	0.155	3.94	0.005	0.13	1 1/2
2	B	2.280	57.91	0.155	3.94	0.005	0.13	2
2 1/2	B	2.811	71.39	0.155	3.94	0.005	0.13	2 1/2
3	B	3.264	82.91	0.169	4.30	0.005	0.13	3
4	B	4.288	108.92	0.184	4.66	0.005	0.13	4
6	B	6.255	158.88	0.277	7.04	0.005	0.13	6

Figure DT-9.4-1
Clamp Conditions at Installation

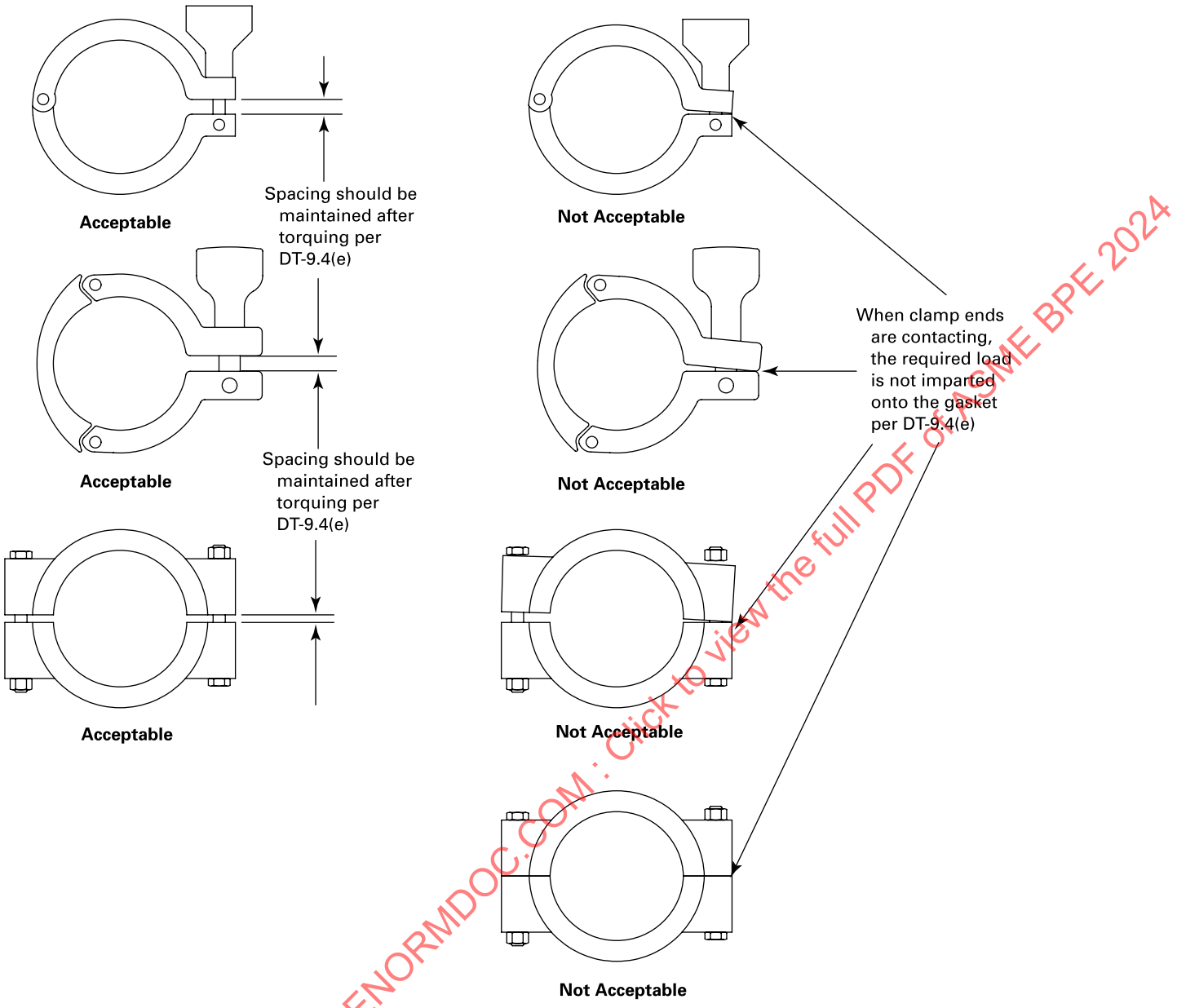


Table DT-11.1.1-1
Minimum Required Marking Information

Process Component	Heat Number or Unique Identifier	Material Type	Valve Pressure Rating	Manufacturer's Name, Logo. or Trademark	Reference to This Standard (ASME BPE)	Process Contact Surface Designation
Fittings	Required	Required	...	...	...	...
Valves	Required	Required	Required	...	...	...
Instrumentation	Required	...	...	Required	...	...

GENERAL NOTE: When the size of a component does not allow complete marking per DT-11.1, this table defines the marking requirements.

PART PI
PROCESS INSTRUMENTATION FOR MULTIUSE

PI-1 PURPOSE AND SCOPE

The purpose of this Part is to provide requirements for process instrumentation. This Part defines the minimum requirements for the application of process contact instrumentation in hygienic systems. This Part applies to instrument components that are in contact with the process.

PI-2 PROCESS INSTRUMENTATION GENERAL REQUIREMENTS

PI-2.1 General Considerations

PI-2.1.1 Installation. All process instrumentation should be installed per the manufacturer's instructions for proper operation. All process instrumentation should also be oriented to meet drainability requirements as specified in Part SD.

Indicating devices shall be oriented and located such that they can be easily viewed for maintenance and operation purposes. Instruments shall be located and oriented so connections can be easily made and adequate space is provided for calibration, maintenance, and replacement.

Instruments, connecting tubing, and systems shall be supported by mounting brackets as necessary to prevent potential stresses on the instrument and tubing system, and to allow for ease of removal without disturbing the adjacent components.

Remote-mounted devices (transmitters, etc.) shall be mounted with appropriate supports to a permanent structure. Ladders, handrails, guardrails, etc., shall not be acceptable mounting supports. If necessary, dedicated instrument supports shall be provided.

PI-2.1.2 Internal Design and Process Connections

(a) Sensors shall be designed in such a way that a failure will not cause contamination hazards to the process and environment.

(b) Liquid-filled elements in measuring devices should not contain materials that can potentially impact product quality.

(c) The internal volume of the liquid-filled elements should be minimized.

(d) Instruments should have integral hygienic fittings. Threaded ferrules are not acceptable to convert standard instrumentation to hygienic standards. Process connections shall be of hygienic design, per the requirements of Parts SD and MC, in order to ensure cleanability of the system.

(e) Gauge siphons (pigtails) shall not be used. Isolation valves should be used if required by the owner/user for routine maintenance or calibration.

(f) Where required for proper operation, all instruments, valves, and in-line devices shall be permanently marked for proper installation (flow direction or orientation).

PI-2.1.3 Exterior Design. Material selection considerations shall include all intended uses, ambient conditions, and cleaning agents as specified by the owner/user. Sensors and transmitters shall be housed in an enclosure with an appropriate protection rating as specified by the owner/user and shall conform to Parts SD and MC.

PI-2.2 Instrumentation Categories

Process instrumentation may be broadly categorized by process installation type as in-line, insertion, at-line, and off-line devices. Process instruments within these categories share some basic installation recommendations for hygienic design and in-process performance.

PI-2.2.1 In-Line Devices. In-line process instruments are self-contained devices installed directly into the process tubing system similar to a standard fitting. Basic installation requirements for hygienic operation as found in Part SD pertain to in-line process instrumentation.

In-line devices may be installed directly in the process stream or in a bypass line to facilitate periodic services (see Figure PI-2.2.1-1). Device-specific recommendations are defined later in this Part.

PI-2.2.2 Insertion Devices. Insertion devices are instruments that are inserted directly into the process tubing system or process vessel to measure a parameter.

Insertion devices generally require proper immersion in the process fluid for optimal performance. Installation of insertion devices must balance performance requirements and hygienic design. Refer to later sections of this Part and/or the manufacturer's recommended guidelines for specific recommendations (see Figure PI-2.2.2-1).

Figure PI-2.2.1-1
In-Line and At-Line Instrument Installation Examples

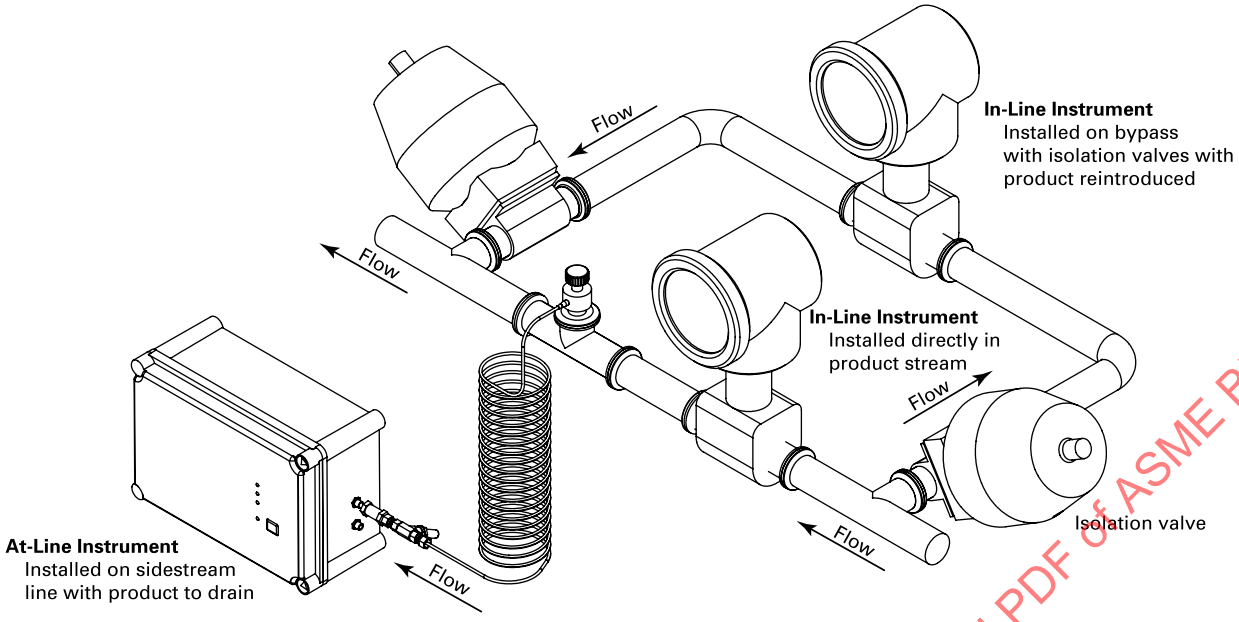
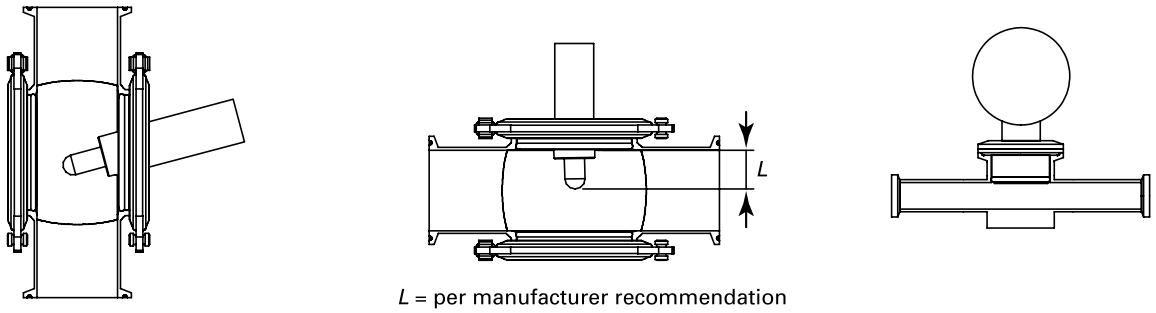
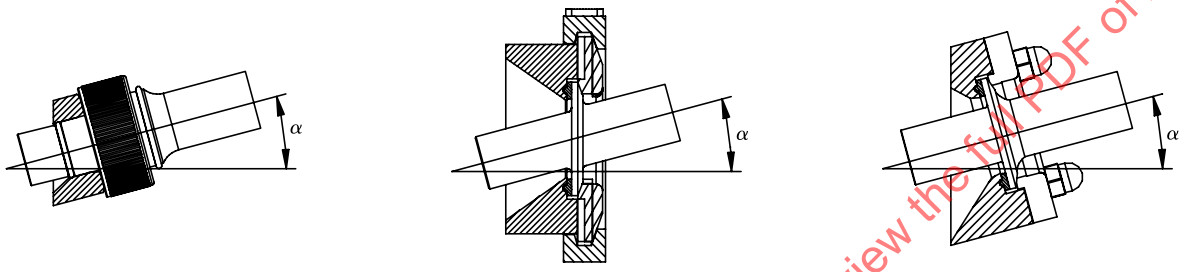


Figure PI-2.2.2-1
Accepted Insertion Device Installation Examples



L = per manufacturer recommendation

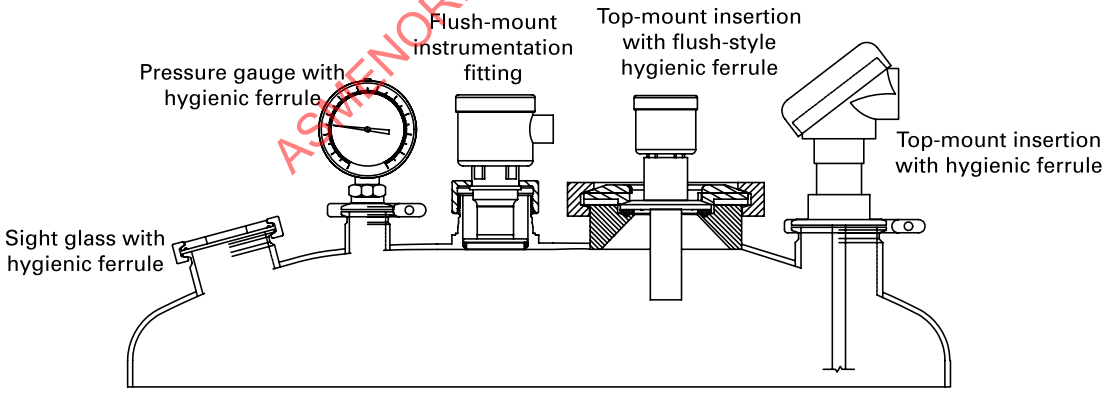


Instrument Socket With Beveled Interior

Sidewall With Angled Hygienic Ferrule

Angled Sidewall With Hygienic Ferrule

α = 15 deg type/device dependent



PI-2.2.3 At-Line Devices. At-line devices are instruments that measure various parameters by the means of a sidestream sampling loop, which is generally not reintroduced back into the process. Connection of the sampling stream shall conform to Part SD and shall be designed to ensure continuous sampling flow to maintain hygienic operation for optimal measurement (see Figure PI-2.2.1-1).

PI-2.2.4 Off-Line Devices. Off-line devices are instruments located away from the main process and are not covered in this Part.

PI-3 INSTRUMENT RECEIVING, HANDLING, AND STORAGE

PI-3.1 Introduction

Material compatibility and environmental storage conditions shall be considered when receiving, handling, and storing process instrumentation. All instruments shall have markings such as labels, tags, barcodes, or radio-frequency identification (RFID) to ease identification.

PI-3.2 Instrument Receiving

The instrument(s) shall be identified by part/model numbers.

PI-3.2.1 Original Packaging. The integrity of the original packaging of any component, with cleaning certifications such as passivated, cleaned for oxygen service, or hydrocarbon free, shall be maintained during inspection and storage.

PI-3.3 Instrument Handling: Protection of Process Connections and Surface Finish

Care shall be taken to protect the process connection(s) and surface finish of the instrument during receiving, handling, calibration, and storage.

PI-3.4 Instrument Storage

PI-3.4.1 Special Considerations. Special considerations for storage shall be made for certain instrumentation, such as analytical instruments, according to the manufacturer's recommendations.

PI-3.4.2 Instrument Shelf Life and Environmental Requirements. Instruments with limited shelf lives or environmental requirements (temperature, humidity, etc.) shall be identified.

Additional information regarding instrument receiving, handling, and storage is contained in Nonmandatory Appendix R.

PI-4 FLOWMETERS

PI-4.1 Coriolis Flowmeter

PI-4.1.1 General Considerations. This section provides the requirements for installation and operation of Coriolis flowmeters specific to bioprocessing and pharmaceutical industries as well as other applications with hygienic requirements.

The design, construction, and fabrication of Coriolis flowmeters are governed by other Parts of this Standard. PI-4.1.2 and PI-4.1.3 may be used as a general reference.

PI-4.1.2 Essential Components. Improper design and/or installation of a flowmeter can affect the drainability and cleanability of the system to which it is attached. Three components of Coriolis flowmeters affect drainability and cleanability: the flow tube(s), the manifold or flow splitter, and the process connections in combination with the installation angle.

The Coriolis flowmeter shall meet the process contact surface requirements as specified in Part SF for all the process-wetted components including flow tube(s), manifold/flow splitter, and process connection.

PI-4.1.3 Components

PI-4.1.3.1 Flow Tube(s). Coriolis flowmeters are either of single-tube or dual-tube construction. The tube(s) can be either straight or bent. The geometry of tube bends shall be considered when assessing drainability and determining installation requirements.

PI-4.1.3.2 Manifold or Flow Splitter. The manifolds or flow splitters for dual-tube construction flowmeters are the interface between the sensor process connections and the sensor measuring tubes and they can create product holdup as shown in Figure PI-4.1.3.2-1. The geometry of manifolds or flow splitters shall be considered when assessing drainability and determining installation requirements.

PI-4.1.3.3 Process Connections. The interface between the process connections and the sensor tube (s) may result in product holdup, even with single straight tube flowmeters. This is shown for concentrically reducing process connections in Figure PI-4.1.3.3-1. Eccentrically reducing process connections may allow a single-tube construction flowmeter, with a tube inside diameter differing from the process line inside diameter, to be mounted in horizontal piping. The geometry of process connections, including reductions in flow area, shall be considered when assessing drainability and determining installation requirements. The Coriolis flowmeter shall use acceptable hygienic connections and fittings as per Part MC.

Figure PI-4.1.3.2-1
Manifold or Flow Splitter for Dual-Tube Construction Flowmeters and Potential for Product Holdup

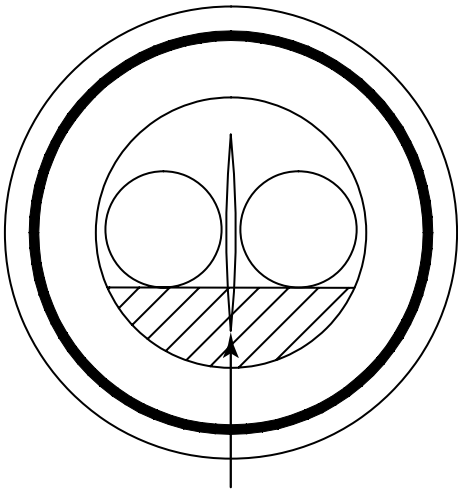
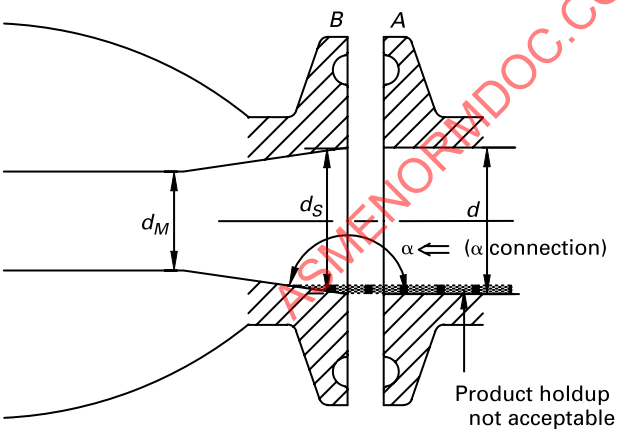


Figure PI-4.1.3.3-1
Concentrically Reducing Process Connection



A = customer ferrule
B = sensor process connection
d = customer pipe I.D.
d_M = sensor measuring tube I.D.
d_S = sensor process connection I.D.

PI-4.1.4 Installation. The manufacturer shall provide the owner/user with the mounting and cleanability requirements necessary to maintain, operate, and properly drain the flowmeter.

PI-4.1.4.1 Drainability. The flow tube or tubes, the manifold or flow splitter, and the process connections shall be considered a system. If a design can be supplied with different types of process connections, then the orientation shall consider the worst case for drainability, or each type of process connection shall be considered individually.

Coriolis flowmeters should be drainable with gravity. Coriolis flowmeters that are not drainable with gravity shall be indicated by the manufacturer and should be of single-tube or other system design to minimize product holdup. An additional motive force (e.g., air purge) may be required to ensure complete drainability.

Drainability requirements should be determined by process requirement and shall be defined by the owner/user.

PI-4.1.4.2 Cleanability. Coriolis flowmeters using a dual-tube construction with small-diameter tubes have a potential for plugging and can adversely affect the cleanability of the flowmeter. It is the responsibility of the owner/user to assess the risk of plugging and the effectiveness of cleaning processes, based on their process and the information provided by the manufacturer.

Requirements relating to cleanability, sterility, and drainability are addressed in Part SD.

PI-4.1.4.3 Mounting Location. It is recommended to install the Coriolis flowmeter vertically with the process fluid flowing upward through the flowmeter (see Figure PI-4.1.4.3-1). If the Coriolis flowmeter is to be installed horizontally, then drainability shall be considered (e.g., by gravity or air purge).

PI-4.1.4.4 Orientation. The Coriolis flowmeter will operate in any orientation as long as the flow tube(s) remain full of process fluid.

For Coriolis flowmeters that are drainable with gravity, the manufacturer shall provide the owner/user with information on how the flowmeter is to be installed to ensure effective drainability.

For flowmeters that are mounted in-plane with the process line, the information should include the minimum angle of inclination, α, and how to orient the flowmeter in that plane (see Figure PI-4.1.4.4-1 for definition of angle of inclination, α). It is recommended that the information be provided in pictorial format.

The manufacturer's recommendation for installation and support of Coriolis flowmeters should be followed.

PI-4.1.4.5 Special Considerations for Passivation of Coriolis Flowmeters. Coriolis flowmeter materials of construction vary significantly between manufacturers. Certain passivation procedures may damage Coriolis flowmeter materials. If the Coriolis flowmeter is to be passivated, the complete passivation procedure should be provided by the owner/user to the manufacturer for review and approval.

If the owner/user and the manufacturer cannot agree on an acceptable passivation procedure, the owner/user shall remove the flowmeter during passivation.

PI-4.1.5 Performance. The Coriolis flowmeter performance varies depending on the parameter to which it applies (e.g., mass, volume, density, temperature, or viscosity).

Guidelines and common terminology for selection, installation, calibration, and operation of Coriolis flowmeters are identified in ASME MFC-11 and ISO 10790.

PI-4.1.5.1 Accuracy. For Coriolis flowmeters, the accuracy specification usually includes the combined effects of linearity, repeatability, hysteresis, and zero stability.

PI-4.1.5.2 Process Influences. Coriolis flowmeters deliver their best performance when completely filled with a uniformly distributed process fluid. Entrained gas should be eliminated or minimized. Multiphase applications involving nonhomogeneous mixtures can cause measurement errors. The use of filters, air and/or vapor eliminators, or other protective devices to reduce errors in measurement should be placed upstream from the Coriolis flowmeter.

PI-4.1.5.3 Ambient Influences. Large differences in the temperature between the measuring tube(s) and the ambient temperature can cause errors in the temperature compensation (e.g., CIP/SIP). The use of insulation materials can reduce these effects.

PI-4.1.6 Selection. The major consideration when selecting and sizing a Coriolis flowmeter is the trade-off between pressure drop and flowmeter performance (accuracy).

The necessary engineering data shall be supplied by the owner/user to ensure correct sizing of the Coriolis flowmeter. The manufacturer shall use this information to provide all necessary calculations for minimum and maximum velocities, accuracy, and pressure drop. This will optimize the flowmeter performance over the flow rate range with a pressure drop that is acceptable for both CIP/SIP and normal operating conditions.

Chemical compatibility should be established between process-wetted materials [i.e., the flow tube(s), the manifold or flow splitter, the process connections] and the process fluid and the cleaning fluid (e.g., process, CIP, SIP, and passivation).

PI-4.1.7 Maintenance. There are no specific maintenance requirements for a Coriolis mass flowmeter.

Figure PI-4.1.4.3-1
Vertical Installation

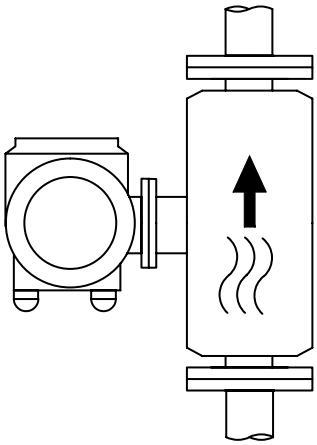
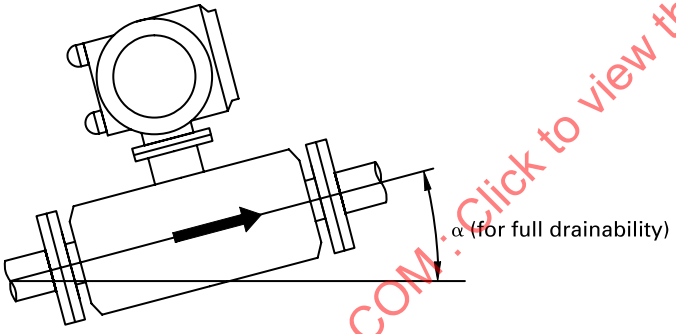


Figure PI-4.1.4.4-1
Minimum Angle of Inclination, α



PI-4.1.7.1 Seals/Gaskets. The manufacturer shall advise the owner/user if the process connections are not fully welded to the sensor body and if use of a seal/gasket assembly that requires periodic inspection is needed.

PI-4.1.7.2 Recalibration/Verification Schedule. A Coriolis flowmeter properly installed and operated within the manufacturer's guidelines on clean, noncorrosive, and nonabrasive fluids is stable. The frequency of recalibration or verification of the flowmeter is governed by the criticality of the measurement and the nature of the operating conditions. The frequency of calibration verification shall be determined by the owner/user.

As the Coriolis mass flowmeter is a mass flow device, it is preferable to perform the calibration verification against a mass traceable reference. Calibration against a volume traceable reference combined with a density traceable reference may be used where applicable. Master flowmeters may be used to verify calibration of Coriolis flowmeters.

Calibration of the mass reference or a master flowmeter shall be traceable to nationally recognized standards or another standard as agreed to by the owner/user and manufacturer.

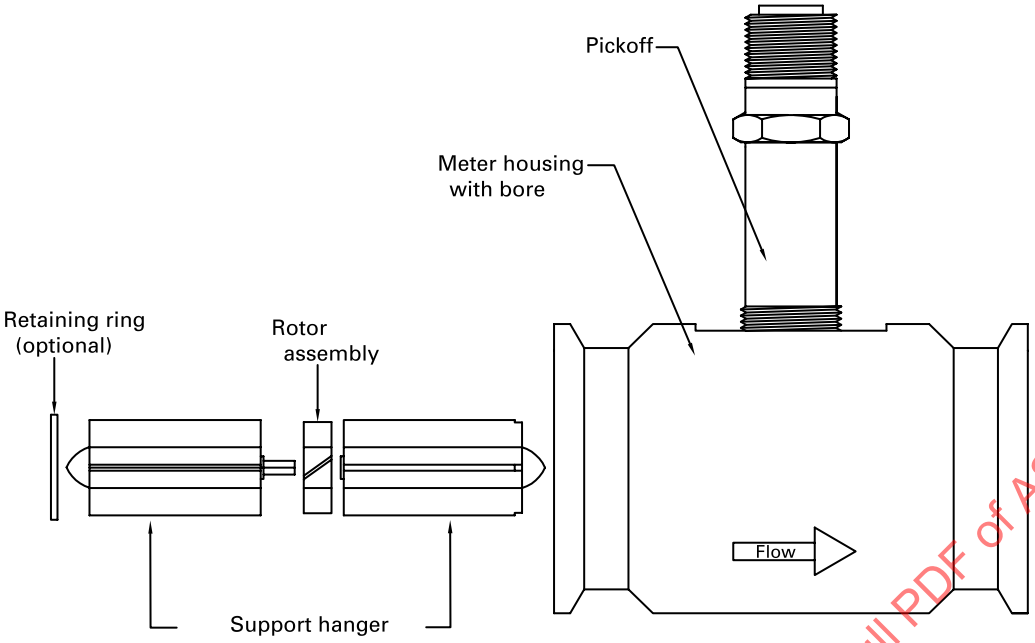
Calibration procedures can be found in ASME MFC-11.

PI-4.2 Turbine Flowmeter

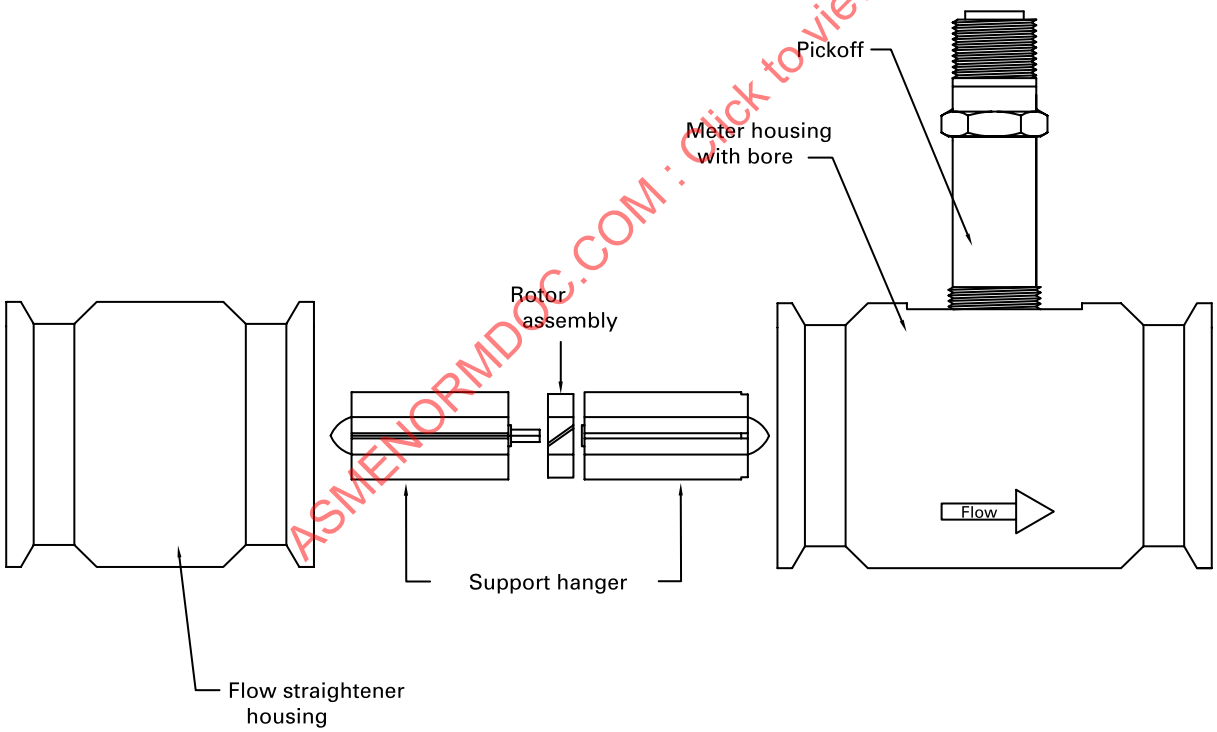
PI-4.2.1 General. This section provides for the hygienic design and installation requirements of turbine flowmeters specific to bioprocessing applications.

PI-4.2.2 Components. Turbine flowmeters typically consist of process contact and non-process contact components (see Figure PI-4.2.2-1 for examples of retaining versus non-retaining ring designs).

Figure PI-4.2.2-1
Typical Turbine Flowmeters



(a) Retaining Ring Design



(b) Nonretaining Ring Design

PI-4.2.2.1 Process Contact Components

(a) Meter Housing With Bore. The bore size shall be based on the manufacturers' specified flow range.

(b) Rotor Assembly. The rotor assembly shall be a solid rotor.

(c) Retaining Ring(s) (Optional). The retaining ring groove and retaining ring shall not contribute to process fluid holdup.

(d) Internal Support Hangers. Each support hanger shall be of a solid piece construction.

(e) Flow Straightener Housing (Optional). In a non-retaining ring design, the flow straightener housing shall be designed to keep the turbine flowmeter internals in place.

PI-4.2.2.2 Non-Process Contact Components. The pickoff shall not contact the process.

PI-4.2.3 Installation. The flowmeter shall be installed with a minimum straight run of 10 pipe diameters upstream of the inlet and 5 pipe diameters downstream of the outlet.

PI-4.2.3.1 Orientation. Turbine flowmeters shall be oriented to ensure that the meter is completely filled with the process fluid during operation.

The manufacturer's recommendations for the orientation and the structural support of turbine flowmeters shall be followed.

PI-4.2.4 Performance. Turbine flowmeter performance details are provided in ASME MFC-22.

PI-4.2.4.1 Accuracy. Turbine flowmeter accuracy details are provided in ASME MFC-22.

PI-4.2.4.2 Process Influences. Entrained gas shall be eliminated by having sufficient back pressure downstream of the flowmeter to prevent cavitation, or by the use of a vapor eliminator upstream of the meter.

The owner/user should consult the manufacturer for recommendations on the minimum operational pressure, as the meter outlet pressure is dependent upon the process fluid conditions, specific gravity, and viscosity.

For process liquids where abrasives or other entrained particles may exist, hygienic filters, strainers, or other devices shall be installed upstream of the flowmeter to prevent damage.

PI-4.2.4.3 Ambient Influences. External environmental conditions do not affect the performance of the turbine flowmeter when the flowmeter is operated within the manufacturer's specifications.

PI-4.2.5 Selection. Maximum process fluid velocity should be taken into consideration during air purge or clean steam sanitization to prevent over ranging of the bearings and damaging the rotor assembly. Turbine flowmeter selection details are provided in ASME MFC-22.

PI-5 LEVEL INSTRUMENTS (24)

PI-5.1 Free-Space Radar Level Instruments

PI-5.1.1 General. This section provides device-specific requirements related to free-space radar level instruments. See PI-2.1 for information on general requirements. Free-space radar level instruments are also referred to as *noncontact radar* and *through-air radar level instruments*.

PI-5.1.2 Components. A free-space radar level instrument is comprised of an antenna and a process connection. The antenna of a free-space radar level instrument is typically available as a bulb, horn, isolated horn, or rod (see Figure PI-5.1.2-1)

PI-5.1.2.1 Process Contact Components. The antenna shall not be submerged in a process liquid but it is exposed to the gas phase above the process liquid.

PI-5.1.2.2 Non-Process Contact Components. No requirements or recommendations apply.

PI-5.1.3 Installation

PI-5.1.3.1 Mounting Location

(a) The process connection shall be located on top of the vessel.

(b) The mounting location should be selected to avoid or minimize obstructions below the antenna.

(c) The mounting location should be one-third to two-thirds of the vessel radius, as measured from the vessel centerline (see Figure PI-5.1.3.1-1).

PI-5.1.3.2 Orientation. The free-space radar antenna should be mounted perpendicular to the surface of the process fluid.

PI-5.1.3.3 Immersion Length and Depth. A vessel's maximum working level shall be below the insertion depth of the free-space radar antenna.

PI-5.1.3.4 Special Installation Considerations

(a) Each instrument has a specific minimum measuring distance (also referred to as *blocking distance* or *dead band*) (see Figure PI-5.1.3.1-1) immediately below the antenna, in which measurements are not possible.

(b) Considerations should be made for free-space radar level instruments installed in nonmetallic vessels. Radar level instruments installed in nonmetallic vessels can detect objects outside the vessel.

(c) For effective cleanability, shadowing effects, recessed areas, and annular spaces created by the installed antenna should be evaluated.

PI-5.1.4 Performance

PI-5.1.4.1 Accuracy. No requirements or recommendations apply.

Figure PI-5.1.2-1
Bulb, Horn, Isolated Horn, and Rod-Style Antenna

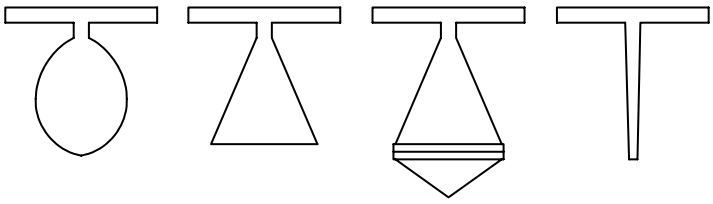
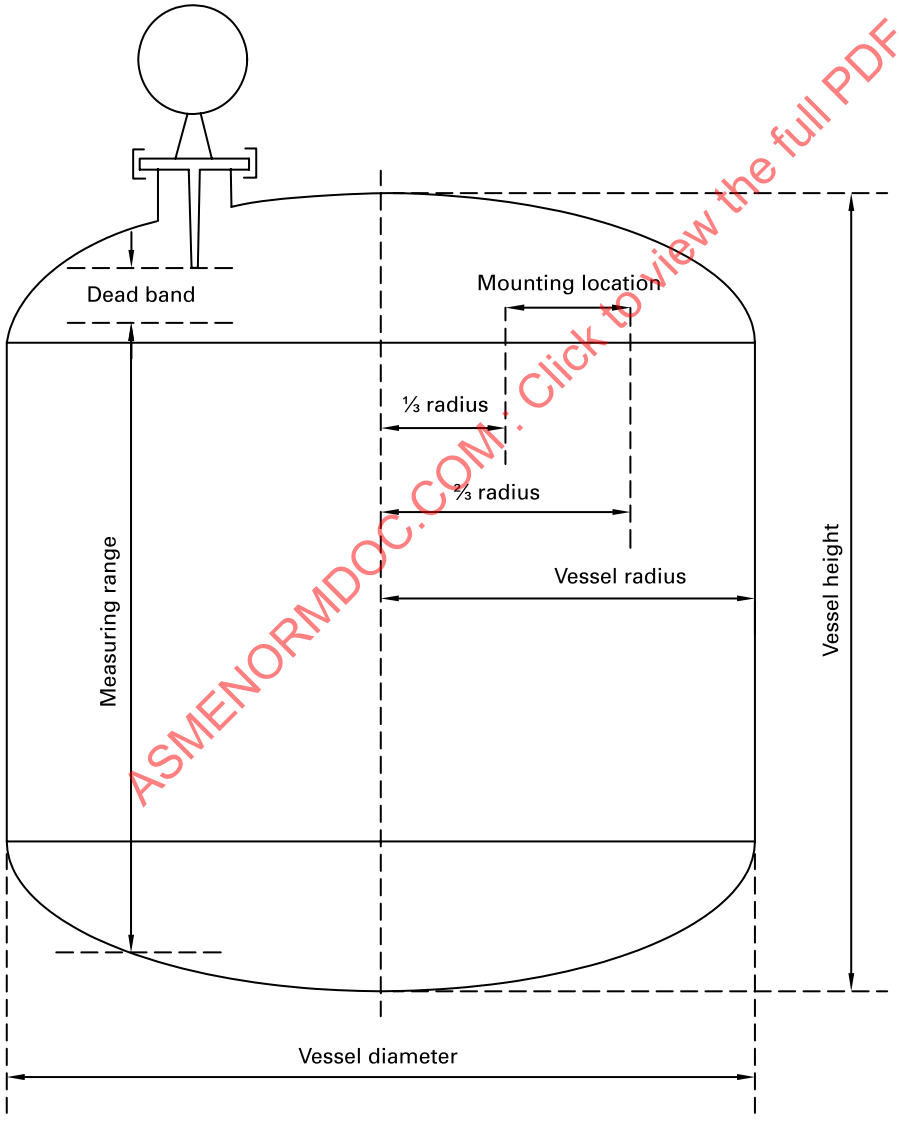


Figure PI-5.1.3.1-1
Dead Band, Measuring Range, and Mounting Location



PI-5.1.4.2 Response Time. No requirements or recommendations apply.

PI-5.1.4.3 Process Influences. The following process conditions may reduce the radar signal strength returned to the antenna, which may impact the measuring performance:

(a) a wavy or rippled surface
(b) vortices in the process fluid
(c) large changes of the reflective properties of the process fluid
(d) foam, steam, or mist on top of the process fluid
(e) buildup on the antenna

PI-5.1.4.4 Ambient Influences. Mounting of the free-space radar level instrument in areas of high electromagnetic interference should be avoided.

PI-5.1.4.5 Special Performance Considerations. No requirements or recommendations apply.

PI-5.1.5 Selection. Antenna construction type (see Figure PI-5.1.5-1) and its material of construction shall be compatible with the stated process conditions, cleaning solutions, and sanitized conditions.

PI-6 PRESSURE INSTRUMENTS

PI-6.1 Pressure Sensors

PI-6.1.1 General. Pressure sensors used in bioprocessing applications shall be isolated from the process by means of an integral diaphragm. The pressure may be transmitted between the isolation diaphragm and the sensing element using a fill fluid.

PI-6.1.2 Installation. Pressure sensor installation methods include flush tee, in-line instrument tee, and short-outlet tee. See Figure PI-6.1.2-1. To minimize branch legs, flush tee or in-line installations are preferred. See Figure PI-6.1.2-1, illustrations (a) through (d).

PI-6.1.2.1 Mounting Location. Pressure sensors should be mounted away from flow restrictions to reduce the impact of pressure fluctuations on the measurement.

PI-6.1.2.2 Special Considerations. Diaphragms shall be protected and handled in accordance with the manufacturer's guidelines to prevent damage.

The owner/user should follow the manufacturer's guidelines regarding installation measurement adjustments.

Welds on diaphragms may not meet the R_a max. surface finish requirements of Part SF due to unique design requirements for instrument sensitivity. The welds on diaphragms shall meet all the other requirements of Part SF.

All other process contact surfaces shall meet the requirements of Part SF.

PI-6.1.3 Performance. The owner/user should supply the manufacturer with process operational parameters to ensure the performance of the measurement.

PI-6.1.4 Selection. Pressure sensor range shall encompass the required measurement ranges. The vacuum generated through a SIP cycle shall be considered in sensor range selection.

Pressure sensor operational temperature limits shall meet the requirements of the process and ambient environment.

The owner/user shall select the fill fluid for their process to minimize the impact on the process fluid, in case the diaphragm fails and the fill fluid leaks into the process.

PI-7 TEMPERATURE SENSORS AND ASSOCIATED COMPONENTS

PI-7.1 General

This section presents requirements for commonly used temperature-sensing instruments. Additional information on temperature sensors and influences on sensor performance can be found in Nonmandatory Appendix Q.

PI-7.2 Components

PI-7.2.1 Sensors. Temperature sensors addressed in this section include resistance temperature detectors (RTDs) and thermocouples. RTDs are the preferred sensing technology. Thermocouples are acceptable with owner/user approval.

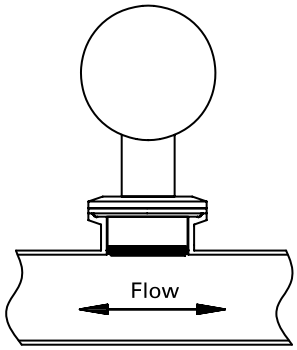
PI-7.2.2 Thermowells. Thermowells are used to protect the sensor and enable calibration or replacement without stopping the process or breaching the system boundary. Common thermowell styles are straight thermowells and elbow thermowells.

PI-7.3 Installation

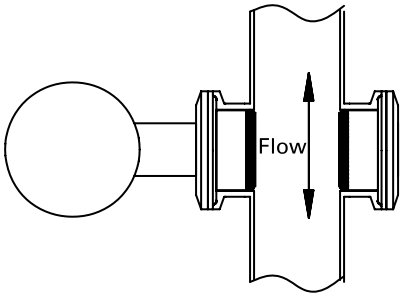
Installation methods include tee style, elbow style, or nonintrusive (see Figure PI-7.3-1). Tee- and elbow-style installations can be direct insertion (sensor is in direct contact with the process fluid) or indirect insertion (sensor is isolated from the process by an installed thermowell). Nonintrusive sensors covered in this section are integral sensors with a section of process tubing. Clamp-on-style nonintrusive sensors are not addressed in this section.

(a) Tee-Style Installations. When tee-style installations are used for direct or indirect insertion, a hygienic process connection or weld end shall be used.

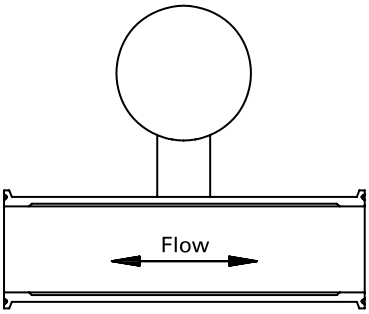
Figure PI-6.1.2-1
Accepted Orientation and Flow



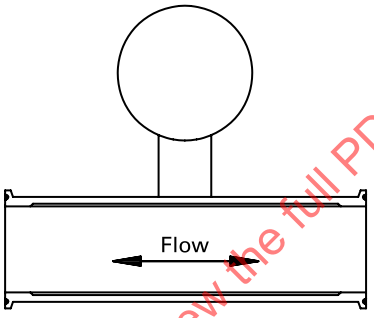
(a) Flush Tee Horizontal Installation



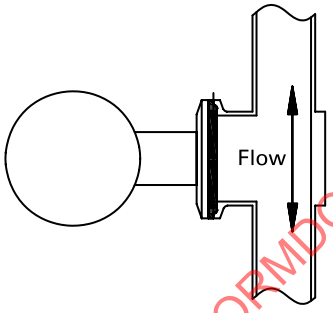
(b) Flush Tee Vertical Installation



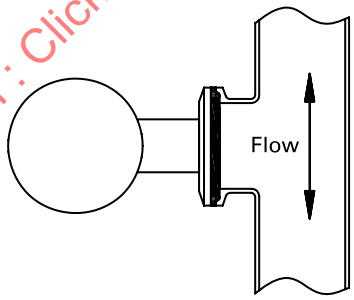
(c) In-line Horizontal Installation



(d) In-line Vertical Installation

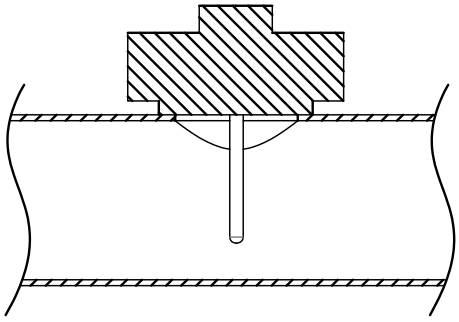


(e) Sanitary Instrument Tee Vertical Installation

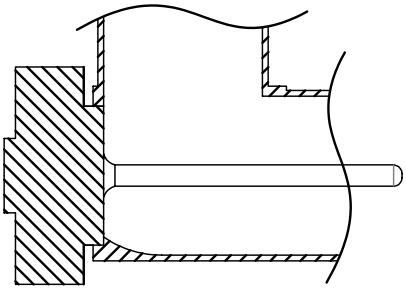


(f) Short Outlet Tee Vertical Installation

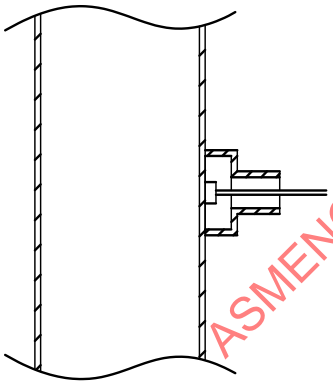
Figure PI-7.3-1
Typical Installation Styles



(a) Direct or Indirect Insertion in Tee



(b) Direct or Indirect Insertion in an Elbow



(c) Nonintrusive

GENERAL NOTE: Shown with nonspecific hygienic connections.

(b) Elbow-Style Installations. When elbow installations are used, the process connections shall be hygienic connections or weld ends. When using a direct insertion sensor in an elbow, the instrument connection shall be a hygienic connection.

(c) Nonintrusive-Style Installations. The process connections for nonintrusive sensors shall be hygienic connections or weld ends.

PI-7.3.1 Drainability. The installed sensor shall meet the drainability requirements of Part SD.

PI-7.3.2 Cleanability. The installed sensor shall meet the cleanability requirements of Part SD.

PI-7.3.3 Mounting Location. The sensor mounting location shall be specified by the owner/user to ensure the measurement meets the process system requirements. Locations near process influences per PI-7.4.3 and ambient influences per PI-7.4.4 should be avoided whenever possible as they can affect the accuracy of the measurement.

When selecting mounting locations in vessels, the minimum working volume of the vessel shall be considered. The inserted sensor shall not interfere with operations, such as filling and draining of the vessel. In vessels with agitators, consideration should be given to the effect of the sensor location on the mixing pattern.

PI-7.3.4 Orientation

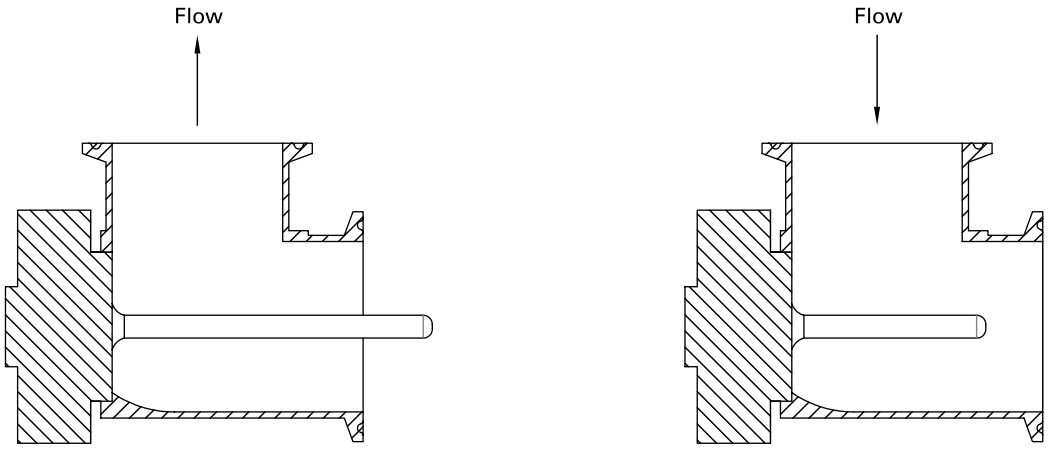
(a) All Insertion-Style Sensors. The installation orientation shall ensure that the insertion length (see PI-7.3.5) is in contact with the process fluid under all operating conditions.

(b) Elbow Thermowells. For process systems with tubing size less than 2.5 in. (64 mm), the flow shall be toward the sensor tip [see Figure PI-7.3.4-1, illustration (a)].

For systems with tubing size of 2.5 in. (64 mm) or greater, flow toward the sensor tip or perpendicular to the sensor is acceptable as long as the full insertion length is covered by the process fluid under all operating conditions [see Figure PI-7.3.4-1, illustration (b)].

(c) Nonintrusive Sensors. Nonintrusive sensors shall be mounted such that the process fluid is always in contact with the instrument wall/tube where the sensing element is located. The preferred orientation is vertical, in a vertical section of the process tubing where the flow direction is upward. For alternate orientations, the sensor manufacturer's installation recommendations shall be followed (see Figure PI-7.3.4-2).

Figure PI-7.3.4-1
Accepted Elbow Orientations and Flow Directions

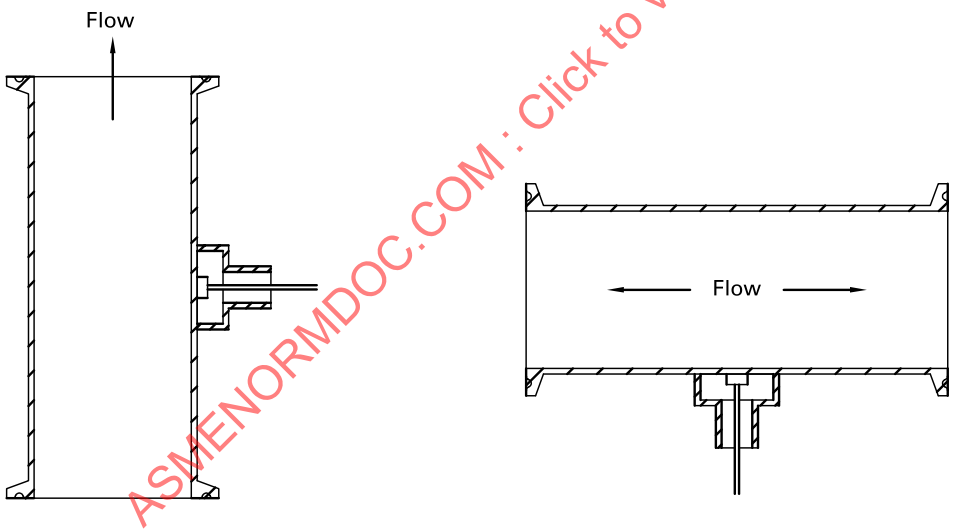


(a) For All Tube Sizes

(b) For Tube Sizes 2.5 in. (64 mm) and Larger

GENERAL NOTE: Shown with nonspecific hygienic connections.

Figure PI-7.3.4-2
Accepted Nonintrusive Orientations and Flow Directions



(a) Vertical Orientation With Flow Upward

(b) Horizontal Orientation With Sensor Located on Bottom Side of Installation

GENERAL NOTE: Shown with nonspecific hygienic connections.

PI-7.3.5 Insertion Length/Depth

(a) Insertion and Sensitive Lengths. "Insertion length" is the length of the sensor or thermowell in contact with the process fluid. "Sensitive length" is the length of the measuring element, internal to the sensor.

NOTE: These terms are not applicable for nonintrusive-type sensors.

(b) Tee Installations. The insertion length should be 10 times the diameter of the sensor tip or thermowell tip, plus the element sensitive length (see Figure PI-7.3.5-1).

Alternate insertion lengths are acceptable with proper consideration of the installation details and sensor design (consult the manufacturer) and with owner/user approval.

The minimum insertion shall locate the midpoint of the sensitive length at the centerline of the process tube.

The maximum insertion shall maintain a minimum of one sensor tip diameter or thermowell tip diameter spacing between the instrument tip and tube wall opposite the installation point.

(c) Insertion Length in Elbow Thermowells. The insertion length should be 10 times the diameter of the sensor tip or thermowell tip, plus the measuring element sensitive length (see Figure PI-7.3.5-2). Alternate insertion lengths are acceptable with owner/user approval.

PI-7.3.6 Special Considerations

(a) Thermowells

(1) Response Time. When the temperature measurement response time (see PI-7.4.2) is critical to the process system operation, thermowells can be constructed using thin walls and smaller diameters. The owner/user shall consult with the sensor/thermowell manufacturer regarding design and material selection to ensure proper operation under the required system operating conditions.

(2) Measurement Accuracy. Proper thermal contact between the sensor and thermowell is important to ensure measurement accuracy. The thermowell bore diameter should be designed to be 0.01 in. (0.25 mm) greater than the sensor diameter. A spring-loaded sensor design should be used to ensure sensor tip contact with the inside end of the thermowell. Use of thermally conductive compound between the outer sensor wall and internal surface of the thermowell and/or metal-to-metal contact is recommended. Consult with the sensor manufacturer regarding the application of thermal compound.

(b) Nonintrusive Sensors. Nonintrusive-style sensors will typically provide a slower response time than most insertion-style sensors.

PI-7.4 Performance

PI-7.4.1 Accuracy. The measurement accuracy will be influenced by the characteristics of the selected sensor, sensor insertion depth, ambient temperature, installation location, flow condition, and wiring.

(a) Sensor Accuracy. ASTM E1137 and IEC 60751 define the nominal resistance vs. temperature relationship and standard sensor interchangeability criteria for RTD-type sensors.

ASTM E230 defines the nominal millivolts vs. temperature relationship and accuracy for various thermocouple-type sensors.

(b) Wiring and Cabling. Sensor wiring lengths and configuration shall be considered when assessing measurement accuracy.

PI-7.4.2 Response Time. When temperature transients are important to monitor or control, the response time specification for the selected sensor (or sensor with a thermowell) shall be less than one-half the desired or anticipated process system response time.

PI-7.4.3 Process Influences. Entrained gas bubbles shall be minimized near the fluid temperature measurement location as gas can cause a delay in sensor response due to variations in thermal conductivity and/or instability in the temperature measurement.

PI-7.4.4 Ambient Influences. The insertion criteria should be followed to reduce the stem conduction effects caused by the temperature differences between the process and ambient area. When the recommended insertion length per PI-7.3.5 is not feasible, insulating the exterior portion of the sensing instrument is recommended.

Nonintrusive-style sensor accuracy can be affected by the temperature difference between the process and ambient area. Insulating the exterior portion of the sensor can reduce this effect.

PI-7.5 Selection

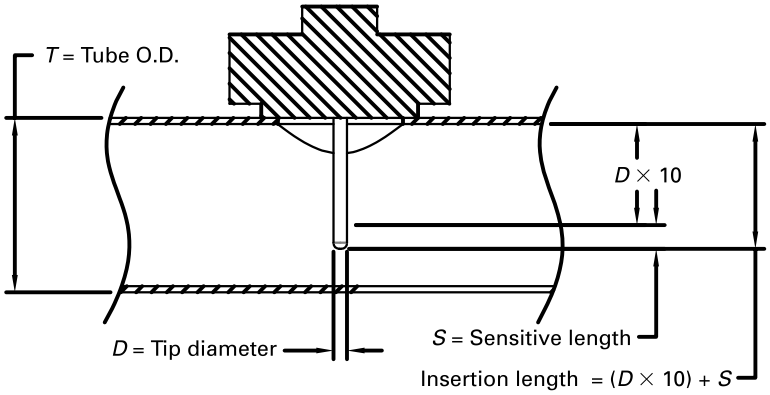
PI-7.5.1 Sensor Selection. Sensor type, materials, construction methods, and performance criteria (stability, repeatability, hysteresis, and self-heating) shall be considered when choosing a sensor.

(a) Insertion-style sensors are preferred as they provide the best measurement accuracy and responsiveness.

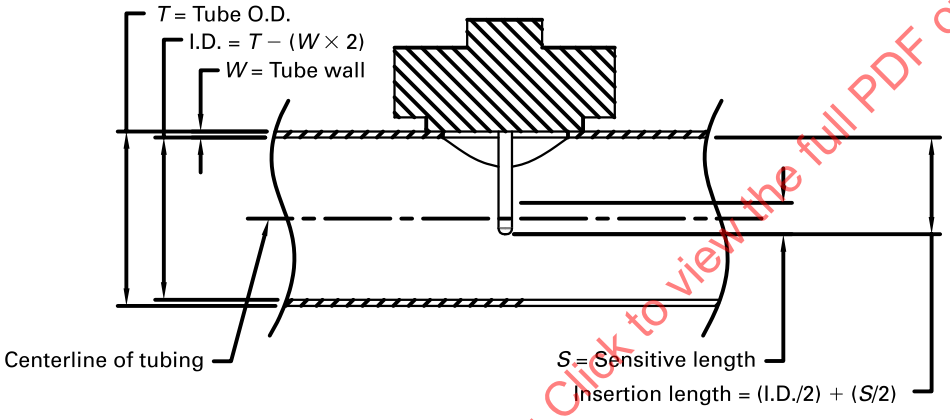
(b) Nonintrusive sensors are acceptable when insertion-type sensors are not feasible due to potential flow restrictions or small-diameter process tubing.

PI-7.5.2 Thermowell Selection. A thermowell shall be used for insertion-type temperature sensors that require sensor removal without breaching the process system boundary.

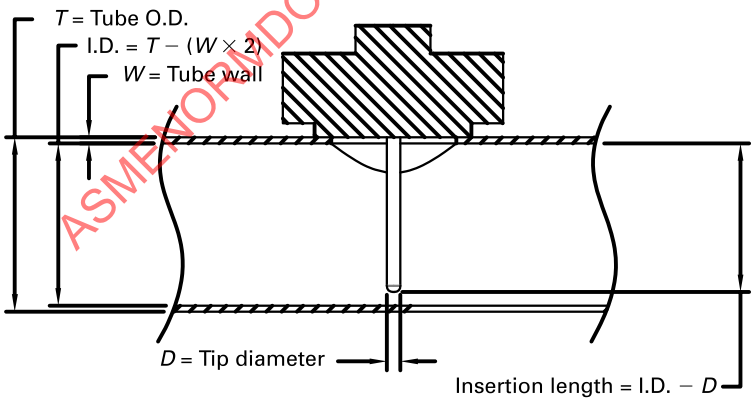
Figure PI-7.3.5-1
Sensor Insertion Lengths for Tee Installations



(a) Optimum Insertion Length



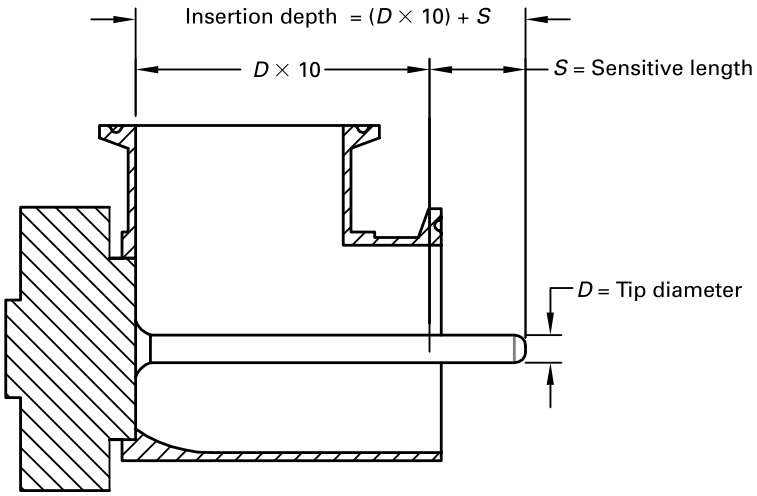
(b) Minimum Insertion Length



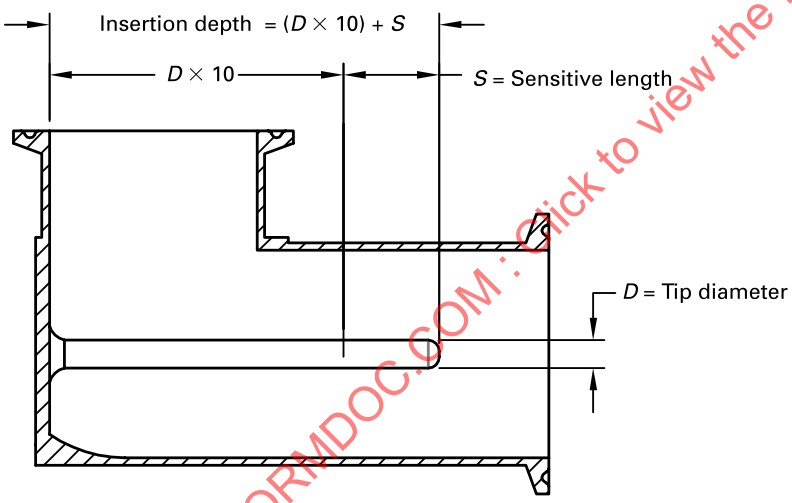
(c) Maximum Insertion Length

GENERAL NOTE: Shown with nonspecific hygienic connections.

Figure PI-7.3.5-2
Sensor Insertion Lengths for Elbow Installations



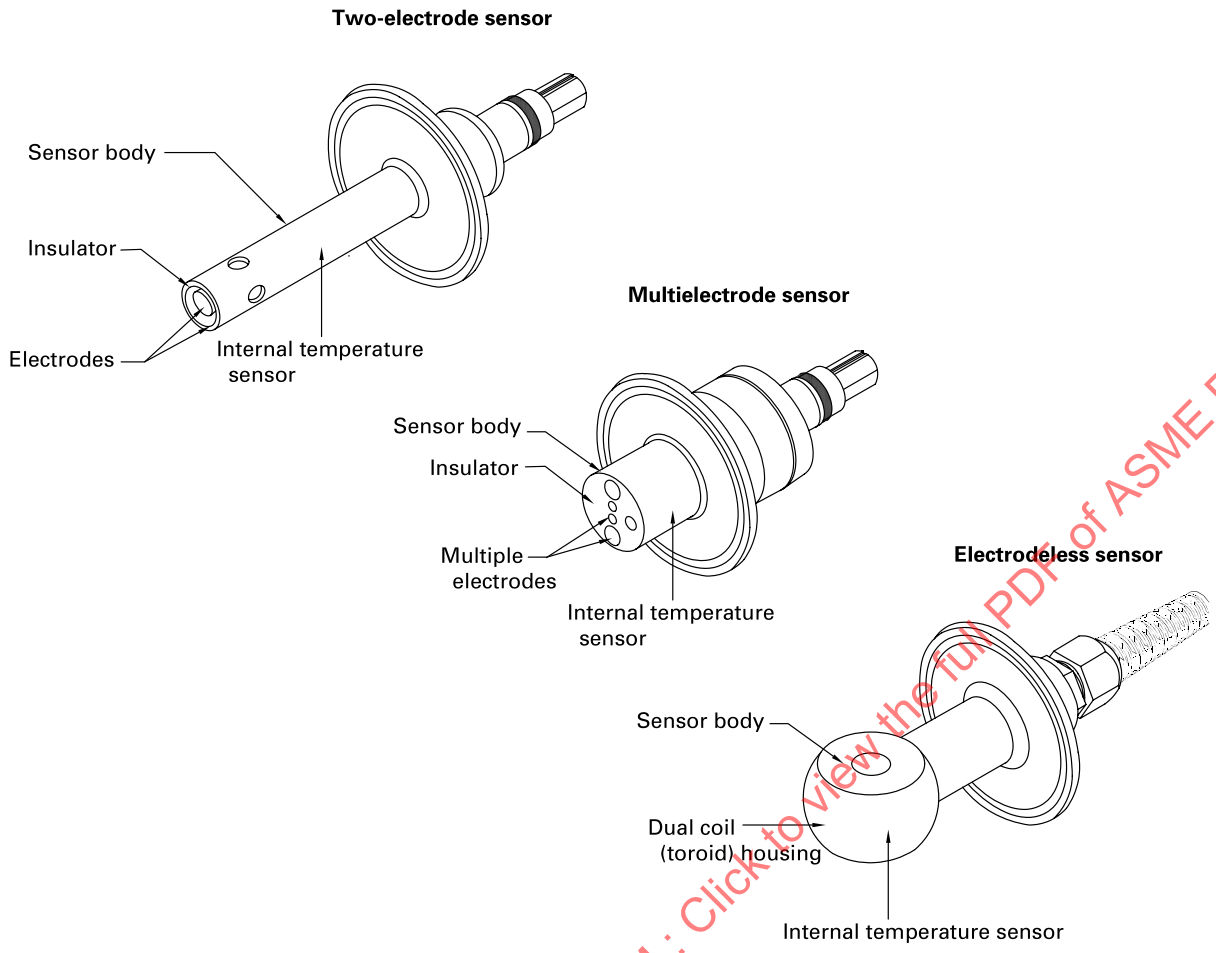
(a) Direct Insertion Elbow



(b) Indirect Insertion Elbow Thermowell

GENERAL NOTE: Shown with nonspecific hygienic connections.

Figure PI-8.1.2-1
Conductivity Sensor Components



(a) Thermowells installed within the process system boundary shall be fabricated with hygienic connections or be welded to the process tubing.

(b) ASME PTC 19.3 TW, where applicable, shall be considered to ensure sufficient thermowell strength under all process conditions.

(c) Thermowell design and style (straight or elbow type) shall be specified based on line size, process conditions, and installation location. Elbow thermowells are preferred for line sizes that are 0.5 in. (13 mm) in diameter or less. Straight thermowells are acceptable when the insertion length criteria can be achieved.

(d) Thermowell installations may cause a pressure drop, which shall be considered in the system design.

PI-7.6 Sensor Calibration Verification

Calibration methods for temperature sensors are described in ASTM E644 and ASTM E220.

PI-8 ANALYTICAL INSTRUMENTS

PI-8.1 Conductivity

PI-8.1.1 General. This section only provides device-specific requirements related to conductivity sensors. See PI-2.1 for information on general requirements.

PI-8.1.2 Components. Conductivity sensor components combined in one body vary depending on the sensor type (see Figure PI-8.1.2-1).

PI-8.1.2.1 Process Contact Components

(a) Two-Electrode. A two-electrode-type conductivity sensor typically consists of an outer shaft/body and inner electrode. Conductivity measurements are made in this interstitial space and require this area to be fully wetted.

(b) Multielectrode. A multielectrode-type conductivity sensor typically consists of a wetted body with inner and outer electrodes generally arranged on the same plane.

Conductivity measurements are made immediately in front of and in between the electrodes and require this area to be fully wetted. A nonconductive material of construction is required between the electrodes with the sensor body generally used as the insulator.

(c) Electrodeless. An electrodeless-type conductivity sensor typically consists of two encapsulated coils. One coil generates a current and the second coil detects changes proportional to the conductivity of the process fluid. An electrodeless sensor requires process fluid through and around the coils for proper measurements.

PI-8.1.2.2 Non-Process Contact Components. The internal temperature sensor is an integral non-process contact component that is typical for all types of conductivity sensors.

PI-8.1.3 Installation

PI-8.1.3.1 Mounting Location. Special installation considerations and process influences should be an integral part of the decision for conductivity sensor mounting locations. See PI-8.1.3.2 through PI-8.1.3.4 for details.

PI-8.1.3.2 Orientation. Conductivity sensors should not be mounted in locations or orientations that promote gas bubble collection around the sensor. Gas bubbles can affect sensor performance. Figure PI-8.1.3.2-1 provides examples of acceptable orientations.

PI-8.1.3.3 Immersion Length/Depth. All conductivity sensors require full immersion of their measurement electrodes or coils into the process fluid for proper functionality. Conductivity sensors should be inserted to allow for sufficient clearance of electrodes and coil fields (see PI-8.1.3.4 for details).

PI-8.1.3.4 Special Installation Considerations

(a) Sensor electrodes mounted too close to tube or vessel walls can cause conductivity field distortions resulting in measurement inaccuracies. The owner/user shall consult the manufacturer's clearance requirements and recommendations (see Figure PI-8.1.3.4-1).

(b) Conductivity sensors shall not be located directly in the flow path of another sensor or inlet that causes a significant change in conductivity (e.g., following a glass measuring electrode pH sensor or injection port).

(c) Installation of conductivity sensors in locations where incomplete liquid mixing and reactions can occur should be avoided. Incomplete liquid mixing and reactions can result in measurements that are not representative of the average conductivity.

(d) Stagnant zones should be avoided. Stagnant zones can result in measurements that are not representative of the average conductivity and increase sensor maintenance.

See PI-8.1.4.3 for other relevant information.

PI-8.1.4 Performance

PI-8.1.4.1 Accuracy. In-line installations shall ensure continuous process fluid flow around sensor electrodes or coils to maximize measurement accuracy.

PI-8.1.4.2 Response Time. Conductivity sensor response times are impacted predominately by the response time of the temperature-sensing element. Details can be found in Nonmandatory Appendix DD.

PI-8.1.4.3 Process Influences

(a) Entrained air impacts conductivity measurements.

(b) Change of product and process temperature impact conductivity measurements.

All conductivity sensors shall use either an internal or external temperature sensor for compensation, as required.

PI-8.1.4.4 Ambient Influences. Electromagnetic interferences that affect conductivity sensor performance should be avoided.

PI-8.1.5 Selection. Conductivity sensors shall be selected based on process conditions and specific performance requirements (e.g., conductivity range and chemical compatibility). Guidance for application-based sensor selection can be found in Nonmandatory Appendix DD.

PI-8.2 pH Sensors

PI-8.2.1 General. This section provides device-specific requirements for pH sensors incorporating a glass measuring electrode.

PI-8.2.2 Components. pH sensors typically include a measuring electrode, a reference electrode, a reference junction, and an internal temperature sensor, combined in one body (see Figure PI-8.2.2-1).

The measuring electrode and reference junction are process contact components. The reference electrode and internal temperature sensor are non-process contact components.

PI-8.2.3 Installation. Criteria described in PI-8.2.3.1 through PI-8.2.3.5 should be taken into consideration for pH sensor installation.

PI-8.2.3.1 Cleanability. pH sensors shall be selected to be compatible with cleaning procedures. Some cleaning procedures will not effectively clean the sensor, which will affect sensor performance.

PI-8.2.3.2 Mounting Location. Special installation considerations and process influences should be an integral part of the decision for sensor mounting location. See PI-8.2.3.5 and PI-8.2.4.2 for details.

Figure PI-8.1.3.2-1
Acceptable Orientations for Conductivity Sensors

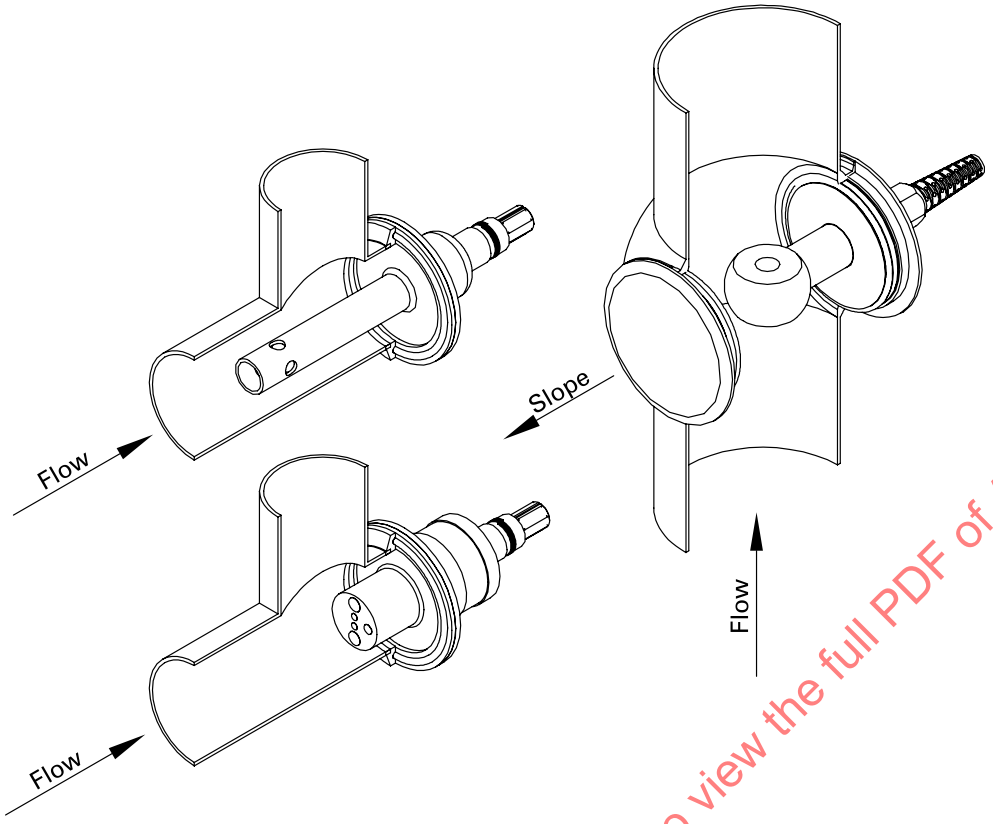
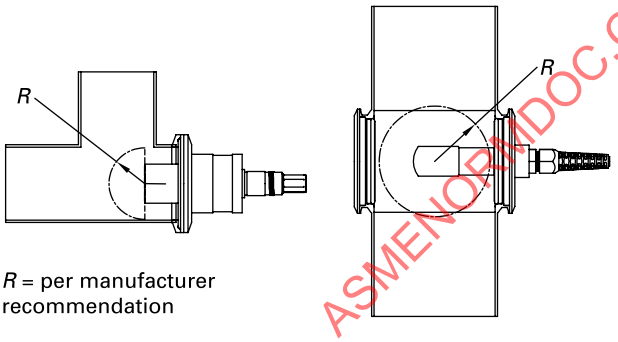


Figure PI-8.1.3.4-1
Installation Clearance Requirements



PI-8.2.3.3 Orientation. pH sensors that have air bubbles in the measuring electrode or reference electrode shall be installed at a minimum angle of 15 deg from the horizontal (see Figure PI-8.2.3.3-1).

PI-8.2.3.4 Insertion Length/Depth. pH sensors should be inserted only as far as needed to ensure the measuring electrode and reference junction are submerged into the process liquid.

PI-8.2.3.5 Special Installation Considerations. Installation of pH sensors in locations where incomplete liquid mixing and reactions may occur should be avoided. Incomplete liquid mixing and reactions can result in measurements that are not representative of the average pH.

PI-8.2.4 Performance. pH sensor performance can be influenced by the conditions described in PI-8.2.4.1 through PI-8.2.4.4.

PI-8.2.4.1 Response Time. pH sensor response time is affected by sensor design and process conditions. Sensor selection shall take into account process conditions and required response times.

PI-8.2.4.2 Process Influences

(a) High process liquid velocity should be avoided. Process liquid velocity in excess of 8 ft/sec (2.4 m/s) can cause excessive measurement noise and physical damage to the pH sensor.

(b) Pressure fluctuations should be avoided. Pressure fluctuations can cause measurement instability.

Figure PI-8.2.2-1
pH Sensor Components

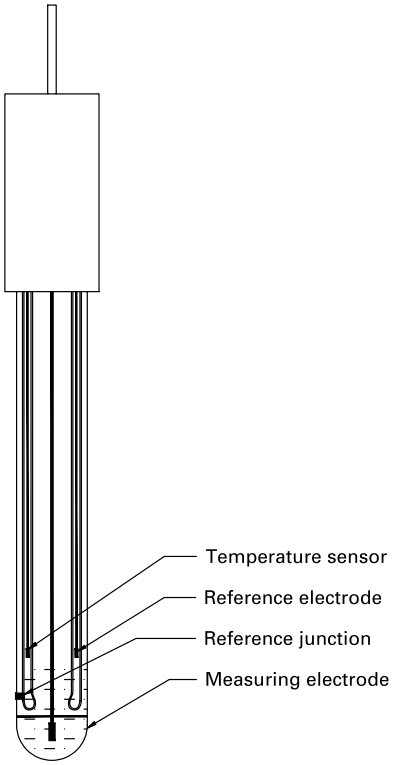
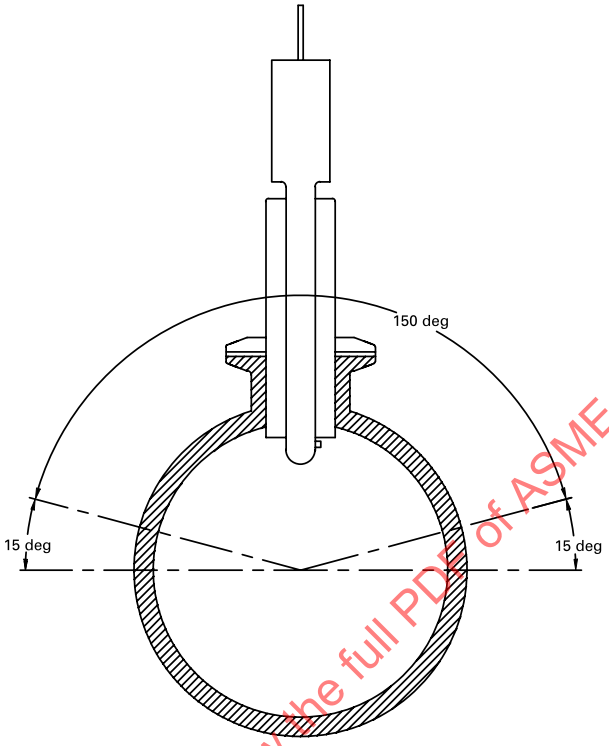
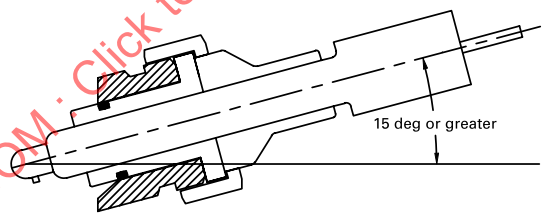


Figure PI-8.2.3.3-1
Accepted Mounting Orientations



(a) Horizontal Flow Orientation



(b) Upward Flow or Vessel Orientation

(c) Stagnant zones should be avoided. Stagnant zones can result in measurements that are not representative of the average pH and increase sensor maintenance.

PI-8.2.4.3 Ambient Influences. Electromagnetic interference that affects pH sensor performance should be avoided.

PI-8.2.4.4 Special Performance Considerations

(a) pH sensors shall be kept hydrated at all times to ensure design performance; sensors will be nonresponsive if allowed to dry out.

(b) After any process stability upset (e.g., cleaning), the reference electrode shall be allowed recovery time. Recovery times after an upset can vary depending on upset conditions and sensor design. pH sensor readings will drift during recovery.

(c) After recovery from a process stability upset, pH sensors should be checked for appropriate span, response, offset, and stability. Sensors that do not meet performance requirements shall be recalibrated or replaced.

PI-8.2.5 Selection. pH sensors shall be selected based on the process conditions and specified performance requirements (e.g., measuring electrodes shall be compatible with design pH ranges).

(24)

PI-8.4 Total Organic Carbon Instruments

PI-8.4.1 General. This subsection provides device-specific requirements related to total organic carbon (TOC) instruments. See PI-2.1 for information on general requirements.

TOC measurement is used to quantify the presence of organic carbon in aqueous media. Online monitoring of TOC is an integral component of compendial water as defined by the Global Pharmacopeias (e.g., USP <643>, JP 2.59, EP 2.2.44).

PI-8.4.2 Components. TOC measurement is achieved via oxidation by untraviolet (UV) radiation measured by differential conductivity. TOC measurement uses conductivity sensors in the following two ways:

(a) with internal reactor for batch measurement

(b) with internal reactor for continuous measurement

The TOC measurement method should be selected based on the application.

PI-8.4.2.1 Process Contact Components. A TOC analyzer shall include a sample valve of hygienic design.

PI-8.4.2.2 Non-Process Contact Components. TOC analyzer sampling systems should include, but are not limited to, sample tubing, one or more drain valves, flow control, and sample coolers. The sampling system shall not contribute to the contamination of the compendial water system. The slipstream flow to the TOC analyzer shall be continuous while the sample valve is open to avoid stagnant conditions.

PI-8.4.3 Installation. Installation shall be performed in accordance with Figure PI-8.4.3-1.

PI-8.4.3.1 Mounting Location. TOC sensors shall be mounted at an elevation below the sample valve of the compendial water system.

PI-8.4.3.2 Orientation. No requirements or recommendations apply.

PI-8.4.3.3 Immersion Length and Depth. No requirements or recommendations apply.

PI-8.4.3.4 Special Installation Considerations. The TOC sample valve shall be closed during CIP or SIP to prevent damage to the sensor. TOC instruments are not designed for CIP or SIP operations.

PI-9 OPTICAL

PI-9.1 Optical Devices

PI-9.1.1 General. Optical devices are used to measure various process characteristics parameters including color, turbidity, concentration, percent suspended solids, optical density, particle and cell size/shape, cell density, and cell viability. Applications include filtration, chromatography, cell culture fermentation, and water systems.

PI-9.1.2 Components

PI-9.1.2.1 Light Source(s). Optical devices include a light source(s) such as visible (VIS), ultraviolet (UV), near infrared (NIR), or infrared (IR), which is transmitted into the process fluid.

PI-9.1.2.2 Sensor. Sensor types include photo detectors, photomultipliers, and CCD (charge-coupled device) imaging chips. The system can involve various optical components to focus, filter, and enhance the light beam either one-dimensionally or multidimensionally.

PI-9.1.2.3 Sight Glass. Sight glasses are one of the key components of an optical device. Process fluid-contacting components of the sight glass assembly shall conform to Parts MM and PM.

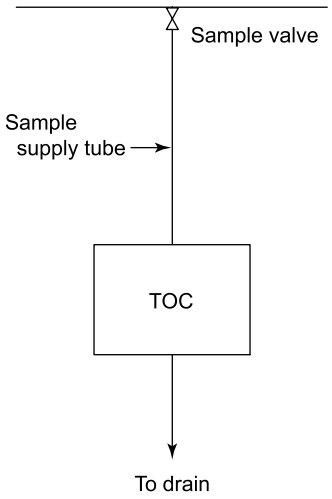
(a) When glass is used as a sight glass for viewing (viewport), a glass fused to a metal hermetic compression seal shall be used. The fused glass shall be circular in shape within the metal frame.

(b) Bubbles in the fused sight glass are acceptable but the size and quantity should be kept to a minimum. Bubbles shall not be present on the glass surface.

(c) The seal point of the glass fused to metal sight glass is at the surface. The surface of the sight glass shall be integral, continuous, and free of defects such as crevices and pits.

(d) Cracked glass shall not be used.

Figure PI-8.4.3-1
Accepted Installation for a TOC Instrument



(e) Sight glasses shall be marked with the glass type, maximum pressure, and temperature rating as per Part DT.

(f) Typical sight glass mountings are shown in Figure SD-3.4.6-1.

PI-9.1.3 Installation. The measuring probe should be installed past the boundary layer. Seals used for installation of viewport sight glass shall meet the requirements of Part MC.

PI-9.1.3.1 Cleanability. Process fluid–contacting surfaces of optical devices shall be cleanable as required per Part SD.

PI-9.1.3.2 Mounting Location. Optical devices shall be mounted in a pipe or vessel where a representative measurement can be made.

A light or combined light and sight glass for viewing shall be mounted as shown in Figure PI-9.1.3.2-1.

PI-9.1.3.3 Orientation. The preferred mounting of in-line optical devices is in the vertical section of tubing to avoid particle segregation. The probe should be in constant contact with the process fluid.

PI-9.1.3.4 Insertion Length. For tube diameters less than 1 in. (25 mm), experimental test data should be used to assess performance.

For in-line installation of tube diameters ranging from 1 in. (25 mm) to 4 in. (100 mm), optical probes should be mounted a minimum (L_{min}) of 0.3 in. (8 mm) away from any interior tube wall (reference Figure PI-9.1.3.4-1).

For vessels and tubing in excess of 4 in. (100 mm) diameter, optical probes should be mounted where the glass measurement surface is a minimum (L_{min}) of 1.5 in. (38 mm) from any interior tube wall (reference Figure PI-9.1.3.4-2).

PI-9.1.3.5 Special Considerations. Special care should be taken for process fluids that are adversely impacted by temperature to avoid high temperatures on the process side of the sight glass or optical window caused by the optical devices. Testing of the optical device at the maximum operating wattage of the probe or probes should not result in still water within 0.5 in. (13 mm) of the probe rising more than 2°F (1°C) in 1 hr.

For light sources used for viewing only, a thermal switch, timer, momentary switch, IR filter, or some other suitable means should be considered to control overheating.

PI-9.1.4 Performance. In-line optical devices generally require the tube to be full of liquid and free of excess air pockets. Certain optical devices can tolerate the presence of some air bubbles. The owner/user should consult with the optical device manufacturer for guidance.

PI-9.1.4.1 Accuracy. Optical devices are inherently accurate and repeatable but dependent on device-specific calibration.

PI-9.1.4.2 Response Time. Optical sensing elements provide instantaneous readings with no delays due to process conditions such as temperature or flow. The owner/user should consult the manufacturer if a specific response time is required.

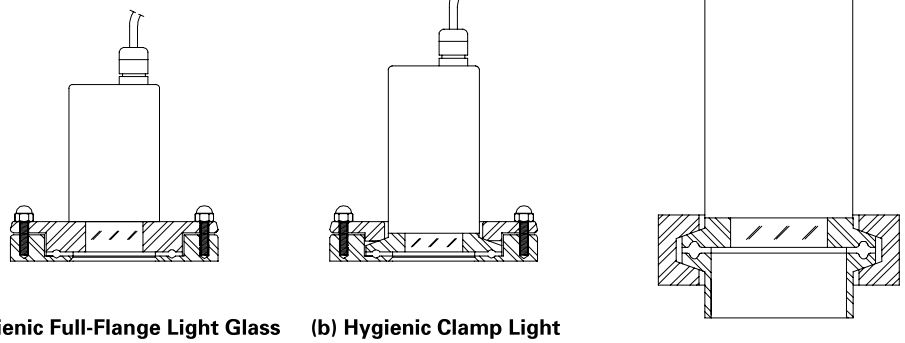
PI-9.1.4.3 Process Influences. Velocity and particulate content in the process fluid may impact the cleaning frequency requirement of the optical device.

PI-9.1.4.4 Ambient Influences. Some optical sensing electronics have limited process and ambient temperature ranges. The owner/user should consult the manufacturer to ensure the selection is compatible with the temperature conditions.

PI-9.1.5 Selection. Optical device sensing technologies vary based on the intended application and suitable measurement ranges. The owner/user shall determine the desired measurement range and unit of measurement before selecting the optical device and associated technology.

Figure PI-9.1.3.2-1
Vessel Light Glass Design and Mounting

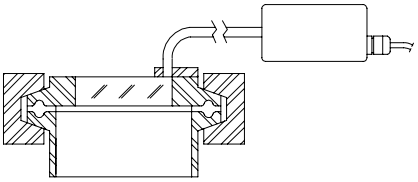
(Accepted)



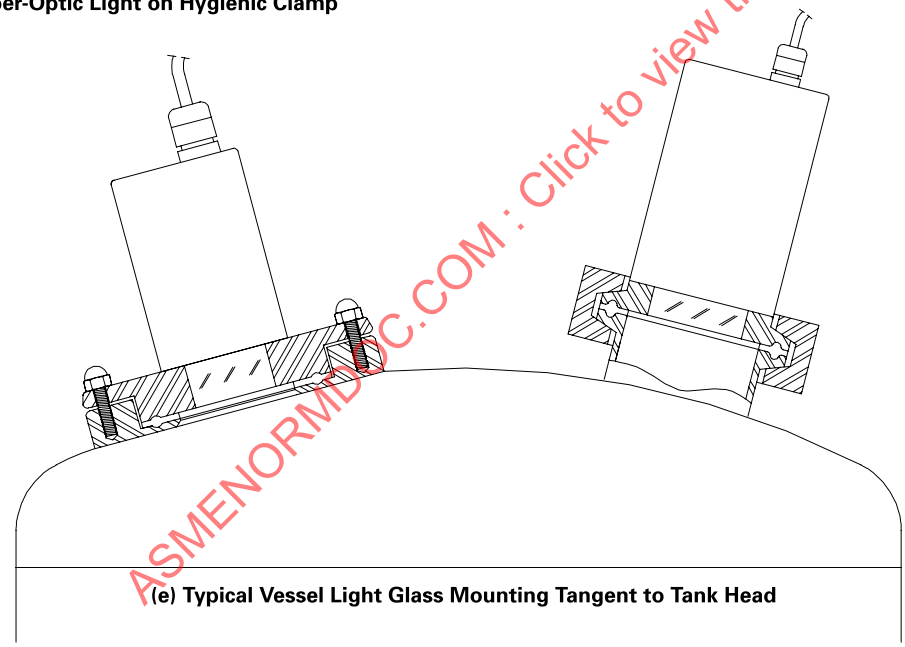
(a) Hygienic Full-Flange Light Glass on Hygienic Clamp Pad

(b) Hygienic Clamp Light on Hygienic Clamp Pad

(c) Hygienic Clamp Light



(d) Fiber-Optic Light on Hygienic Clamp



(e) Typical Vessel Light Glass Mounting Tangent to Tank Head

Figure PI-9.1.3.4-1
In-Line Insertion Length

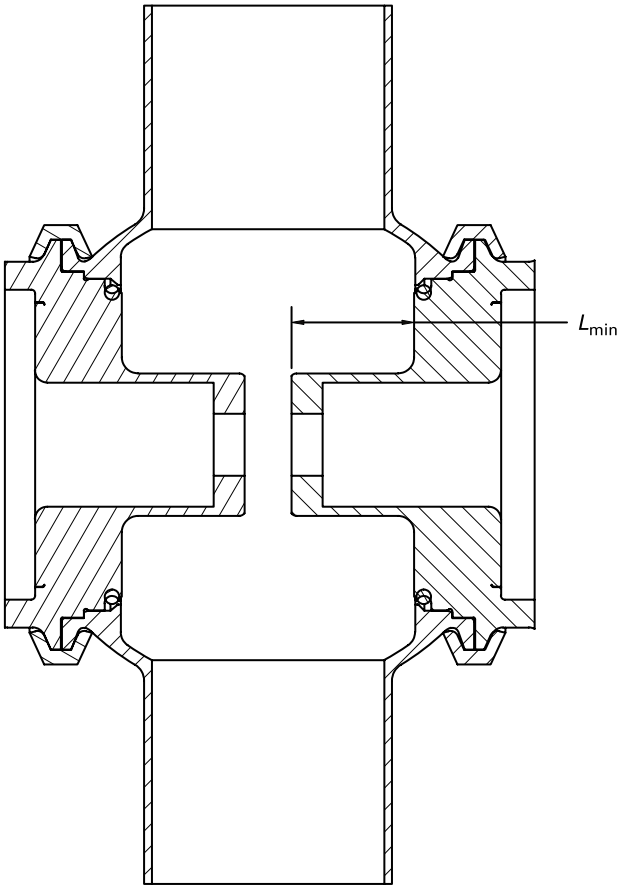
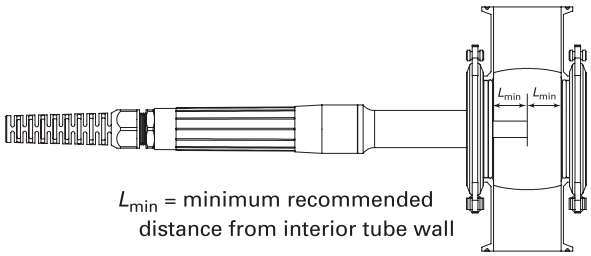


Figure PI-9.1.3.4-2
Insertion Probe Length



L_{min} = minimum recommended distance from interior tube wall

PART MC
COMPONENTS FOR MULTIUSE

MC-1 PURPOSE AND SCOPE

The purpose of this Part is to provide the requirements for the sealing components of seals, valves, and fittings used in the bioprocessing industry. These sealing components create or maintain process boundaries between system components and/or subassemblies to ensure multiuse process system integrity. This Part defines the design of seals, valves, and fittings. This Part also enables equipment manufacturers, system designers, and owner/users to specify the required seal, valve, and fitting type and performance for specific applications. It is not the intent of this Part to inhibit the development or use of new technologies.

MC-2 SEALING COMPONENT TYPES

MC-2.1 General

Sealing components used in bioprocessing equipment take a variety of forms based on their function within the system and the process boundaries to the atmosphere and other systems, which they must maintain. The following sections define the main types of sealing components and their acceptability for use in the bioprocessing industry. For this section, seals are divided into static and dynamic seals. All acceptable seals shall meet the design criteria, materials, and performance characteristics contained in this Standard.

MC-2.2 Static Seals

MC-2.2.1 General. A static seal is characterized by the absence of relative motion between sealing surfaces, or between the sealing surface and a mating surface, after initial installation. Small amounts of movement that might be caused by thermal expansion, vibration, bolt stretch, or seal response to fluid pressure do not alter the static definition.

(24) **MC-2.2.2 Hygienic Unions.** Hygienic unions provide connections between process components (e.g., pipe fittings, tank fittings, instruments, and hoses) to ensure the process integrity is maintained. They include seals between two ferrules.

The geometry of the most common hygienic union is governed by Table DT-7.1-1 or Table DT-7.1-2 and is shown in Figures MC-2.2.2-1 and MC-2.2.2-2. Other geometries for the opposing ferrules are also used in the industry and are controlled by relevant industry standards [e.g., ISO 2852, DIN 11864 (-1, -2, -3, O-rings)]. (See Figures MC-2.2.2-3 and MC-2.2.2-4.)

Polymeric ferrules and clamps should be designed and manufactured to ensure proper fit-up and avoid leakage. Material of construction and the molding process impact the tolerances of polymeric ferrules; consequently, tolerances are not the same as they are for metallic ferrules. Polymeric ferrules shall meet the nominal dimensions and tolerances of Table DT-7.1-2 and shall achieve clearance as per DT-9.4(e).

When using polymeric hygienic unions, several application variables should be considered to ensure optimum performance. Variables include fluid type, process temperature, system pressure, vibration, materials of construction, sterilization method (where appropriate), cleaning methods (where appropriate), and duration of use. Pressure and temperature ratings of polymeric hygienic unions shall be provided by the manufacturer.

Other hygienic unions and cross-sectional geometries shall meet all of the requirements of this Standard, except for the ferrule dimensions.

Nonhygienic connections shown in Figure MC-2.2.2-5 are not recommended (e.g., threaded fittings exposed to process fluid).

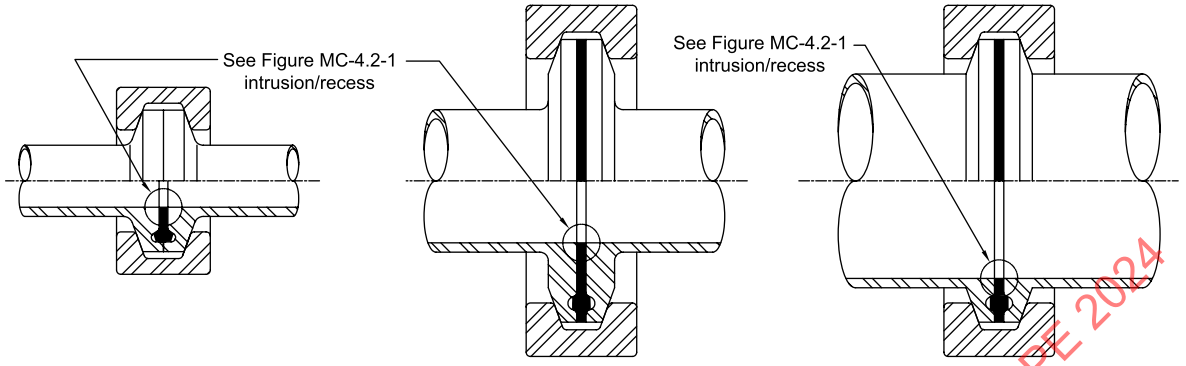
MC-2.2.3 O-Ring Seals. An O-ring is a ring seal with a circular cross section (a toroid), designed to be seated in a groove and compressed during assembly. O-rings are most often used as static seals. These are used extensively in hygienic applications and can seal both radially and axially opposed faces. Common static O-ring applications include sealing fasteners, shaft couplings, and pump and filtration components.

Other ring seal geometries of varying cross sections (e.g., manway gaskets) may be used in hygienic applications. However, significant differences may exist in their performance (e.g., pressure and cleanability), and they should be evaluated accordingly.

Examples of O-ring industry standards include SAE AS568, Aerospace Size Standard for O-Rings, and ISO 3601, Fluid Power Systems — O-Rings.

For use in bioprocessing applications, O-rings and their mating surfaces shall meet the requirements of this Standard.

(24) **Figure MC-2.2.2-1**
Hygienic Union, Ferrules per Table DT-7.1-1 or Table DT-7.1-2

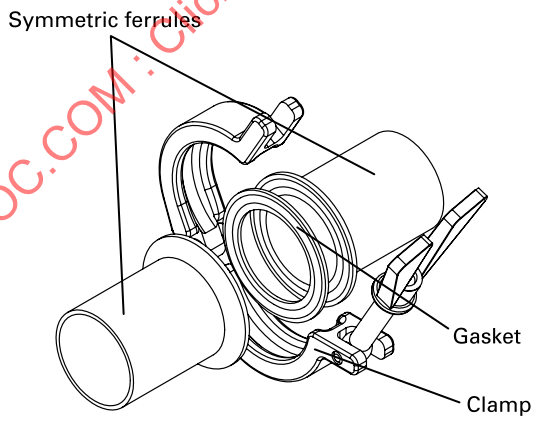


(a) Typical Hygienic Clamp Union — 1 in. and Smaller (Type A) per Table DT-7.1-1 or Table DT-7.1-2 (Accepted)

(b) Typical Hygienic Clamp Union — 1 in. (Type B) per Table DT-7.1-1 or Table DT-7.1-2 (Accepted)

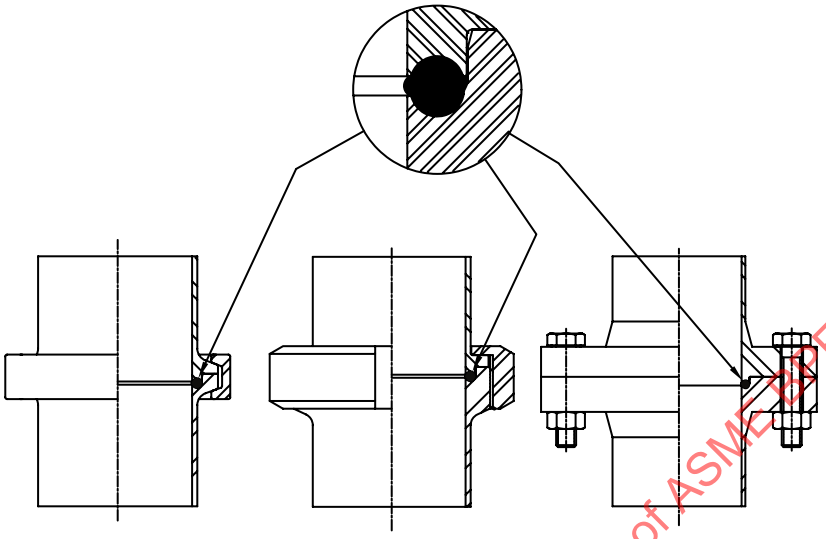
(c) Typical Hygienic Clamp Union — 1.5 in. and Larger (Type B) per Table DT-7.1-1 or Table DT-7.1-2 (Accepted)

(24) **Figure MC-2.2.2-2**
Hygienic Clamp Union, Ferrules per Table DT-7.1-1 or Table DT-7.1-2



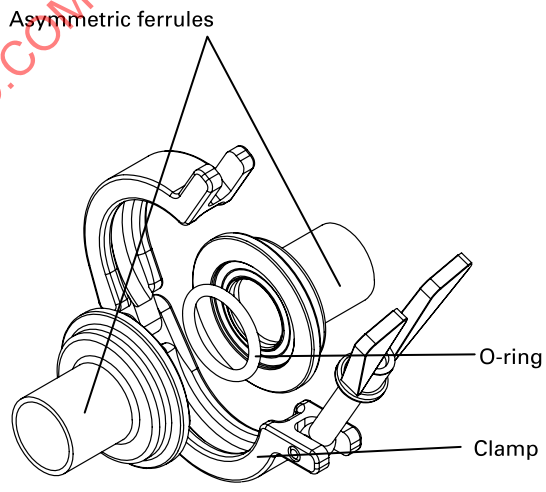
(Accepted)

Figure MC-2.2.2-3
Hygienic Union per DIN 11864



(Accepted)

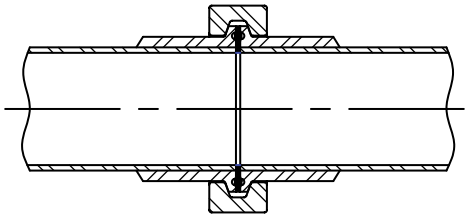
Figure MC-2.2.2-4
Hygienic Clamp Union per DIN 11864



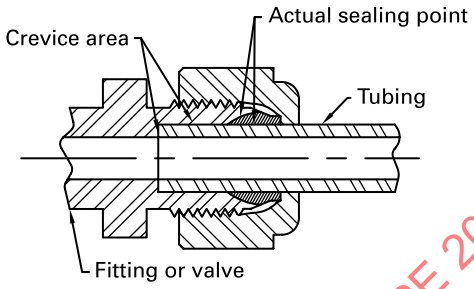
(Accepted)

Figure MC-2.2.2-5
Nonhygienic Connections

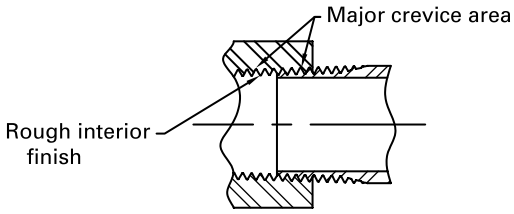
(Not Accepted for Hygienic Service)



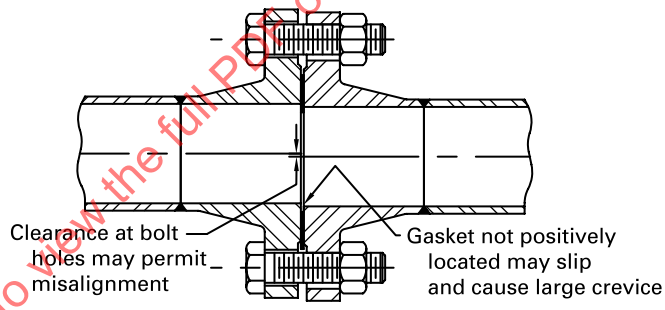
(a) Roll-On Fitting



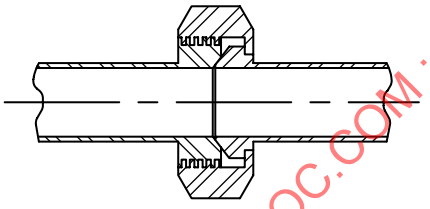
(b) Compression Fitting



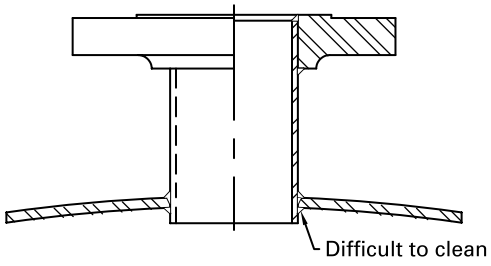
(c) Threaded Joint



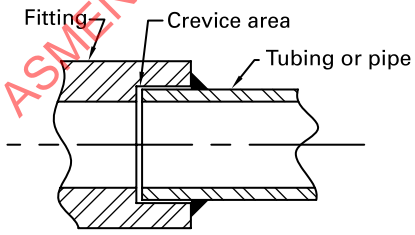
(d) Flanged Joint



(e) Bevel Seat



(f) Nozzle Detail



(g) Socket Joint

MC-2.2.4 Other Static Seals. Other static seals used in bioprocessing applications shall meet the requirements of this Standard (e.g., flat gaskets, L-cups, U-cups, stoppers, septums, and bioseals).

Inflatable static seals are static seals where gas is supplied to the inner part of the seal, providing a pillow barrier between the process and the atmosphere. They are commonly used in large process components, and in connections to support structures.

MC-2.3 Dynamic Seals

A dynamic seal is characterized by the movement of the seal surface and a mating surface after initial installation.

MC-2.3.1 Valves

MC-2.3.1.1 General. Valves are process components that provide dynamic seals within the process. They also provide seals between the process and the atmosphere.

MC-2.3.1.2 Diaphragm Valves

(a) Weir Diaphragm Valve, Weir Diaphragm Tank Bottom Valve. The diaphragm seal is a flexible membrane that forms positive closure when compressed against the weir (see Figure MC-2.3.1.2-1). The diaphragm is a product/process contact seal creating both static (atmospheric) and dynamic (differential) seals.

(b) Radial Diaphragm Valve, Radial Diaphragm Tank Bottom Valve. The diaphragm seal is a flexible membrane that forms positive closure when compressed against a radial seat (see Figure MC-2.3.1.2-2). The diaphragm is typically a product/process contact seal creating both static (atmospheric) and dynamic (differential) seals. However, in some designs static seals may be used between body components.

(c) Weirless Diaphragm Valve. The diaphragm seal is a flexible membrane that modulates flow across a weirless valve body and also forms positive closure when compressed against the weirless valve body (see Figure MC-2.3.1.2-3). The diaphragm is a product contact seal creating both atmospheric and differential seals.

(d) Linear Control Valve. A sliding seal (such as an O-ring) or nonsliding seal (such as a diaphragm) is used to seal a linear stem (see Figure MC-2.3.1.2-4). For closure, the linear control valve may use a soft seal such as an O-ring or diaphragm or a metal-to-metal seal/seat.

(e) Regulator Valve. A control diaphragm is a flexible membrane that typically is used as a pressure barrier and also forms a static seal to the atmosphere. A plug-type dynamic seal may be used for closure. Static seals are used between body components. To regulate the flow, the operating diaphragm responds to pressure to control the regulating plug and functions as a static seal around its perimeter (see Figure MC-2.3.1.2-5).

MC-2.3.1.3 Ball Valve and Ball Tank Bottom Valve. The seat/seal functions as a dynamic seal against the rotating ball. Static seals are used between body components. A dynamic seal is used on a rotary stem (see Figure MC-2.3.1.3-1).

MC-2.3.1.4 Rising Stem Single, Double-Seat Mix-Proof, and Needle Valves. Plug(s) are used to close flow against seat(s). Dynamic seal(s) are used on linear stem(s). Static seals are used between body components (see Figure MC-2.3.1.4-1).

MC-2.3.1.5 Butterfly Valves. The seat/seal creates a dynamic seal when the disk is rotated into the closed position (see Figure MC-2.3.1.5-1). The seat/seal also forms the primary stem seal to prevent leakage through the stem journal.

MC-2.3.1.6 Thermostatic Steam Trap. The valve seat is closed by a plug attached to a dynamic bellows seal. The body cavity for a serviceable steam trap is typically sealed by a static seal (see Figure SD-3.1.2.2-1).

MC-2.3.1.7 Back Pressure Control Valve. A nonsliding seal (such as a diaphragm) is used to seal a linear stem. For closure, the valve may use a soft seal, such as an O-ring or diaphragm, or a metal-to-metal seal/seat (see Figure MC-2.3.1.7-1). To regulate the flow, the operating diaphragm responds to pressure to control the regulating plug and functions as a static seal around its perimeter.

MC-2.3.1.8 Pinch Valve. Pinch valves use a flexible tube or sleeve that forms a differential seal when closed (see Figure MC-2.3.1.8-1).

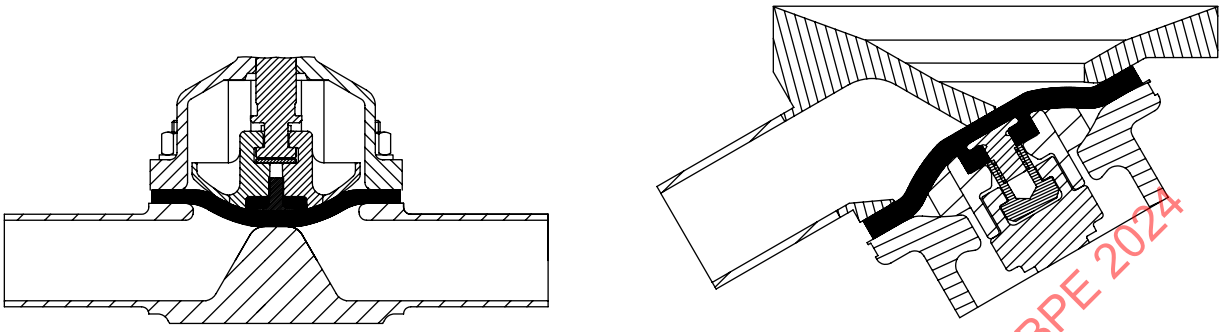
MC-2.3.1.9 Check, Pressure Relief, and Safety Pressure Relief Valves

(a) A check valve is a unidirectional flow device (see Figure MC-2.3.1.9-1). When the application requires drainability, a check valve may include provisions for draining, such as flats, drain holes, or a drain port.

(b) A pressure relief valve is a type of valve that relieves pressure in a system in order to protect against mechanical damage of equipment. An override device may be used to allow flow through the valve for the purpose of cleaning. Pressure relief valves allow bypassing of the overpressured fluid back into the process line or a safe location (e.g., from a pump discharge back to the pump suction).

(c) A safety pressure relief valve is a type of valve used to relieve the pressure in a system or vessel, caused by a process upset, instrument or equipment failure, or fire. Its purpose is to protect people and equipment from a potential explosion or leak. The flow is one-directional. In case of overpressure, the fluid is discharged to a safe location outside the pressurized system.

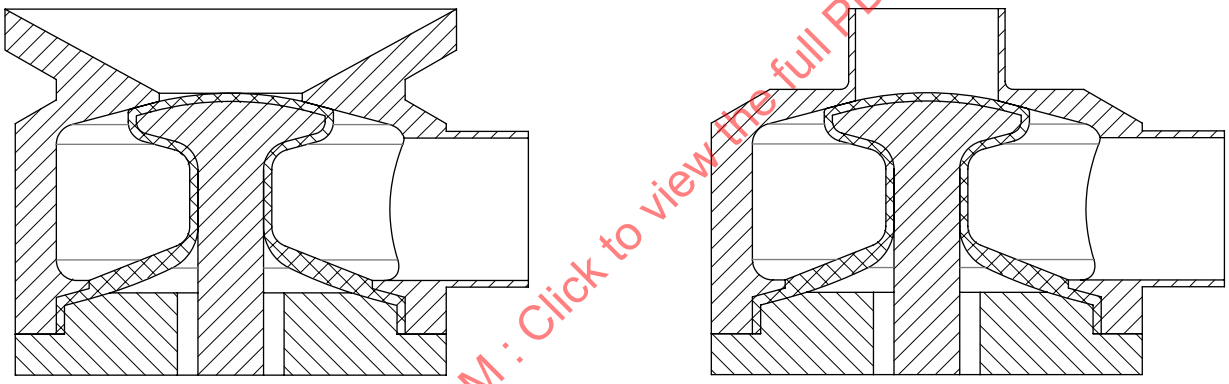
Figure MC-2.3.1.2-1
Weir Valves



(a) Weir Diaphragm Valve

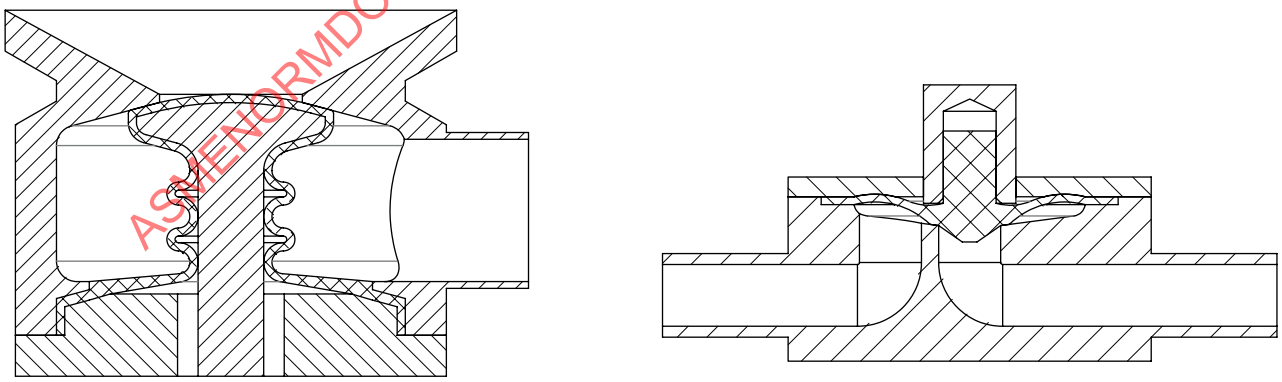
(b) Weir Diaphragm Tank Bottom Valve

Figure MC-2.3.1.2-2
Radial Valves



(a) Radial Diaphragm Tank Bottom Valve

(b) Radial Diaphragm Valve



(c) Bellows Radial Diaphragm Tank Bottom Valve

(d) In-Line Radial Diaphragm Valve

Figure MC-2.3.1.2-3
Weirless Diaphragm Valve

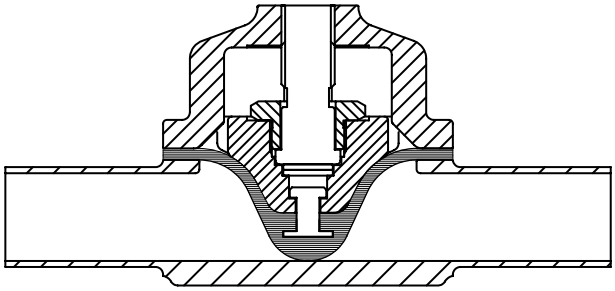
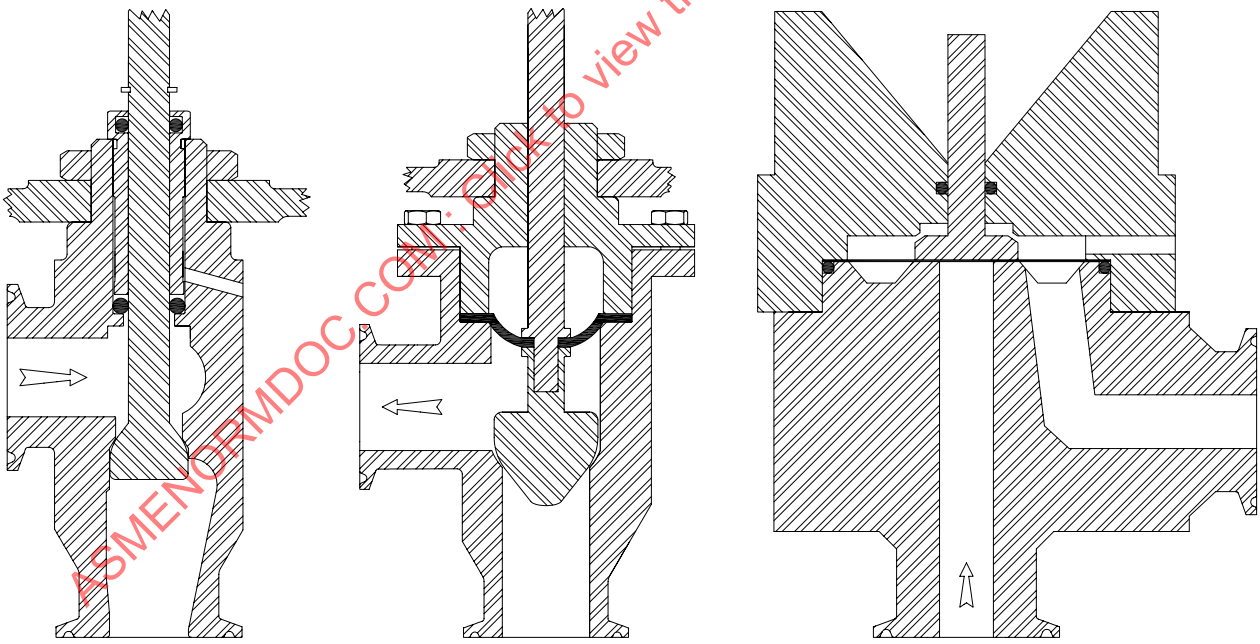


Figure MC-2.3.1.2-4
Linear Control Valves



(a) Linear Control Valve With O-Ring Seal

(b) Linear Control Valve With Elastomer Diaphragm Seal

(c) Linear Control Valve With Metallic Diaphragm Seal

Figure MC-2.3.1.2-5
Regulator Valve

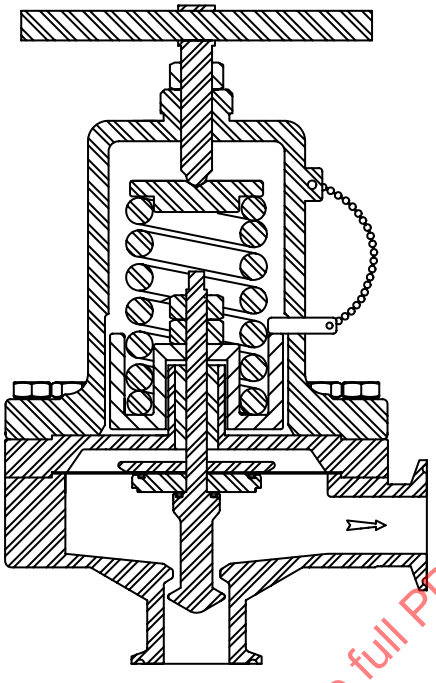
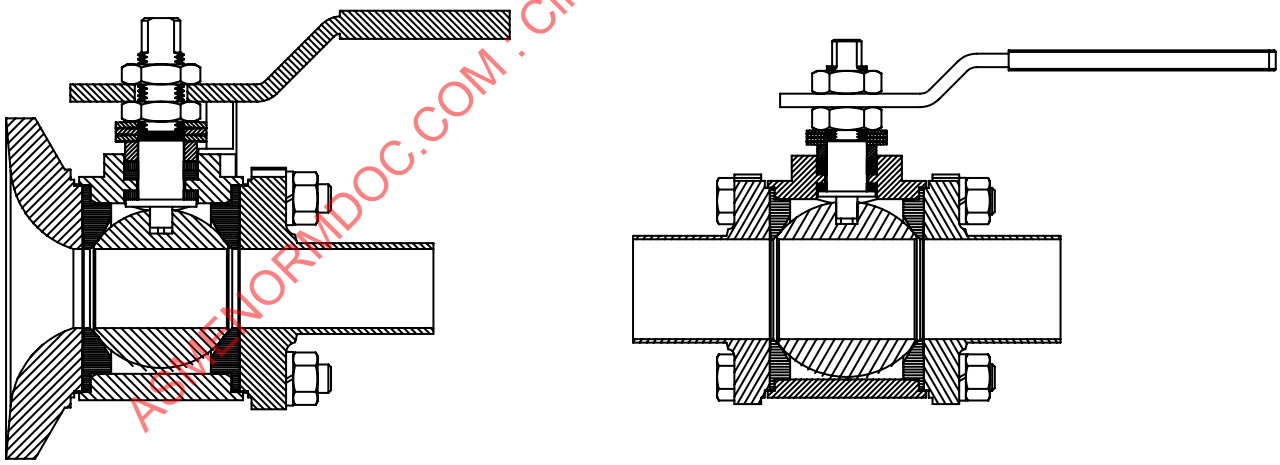


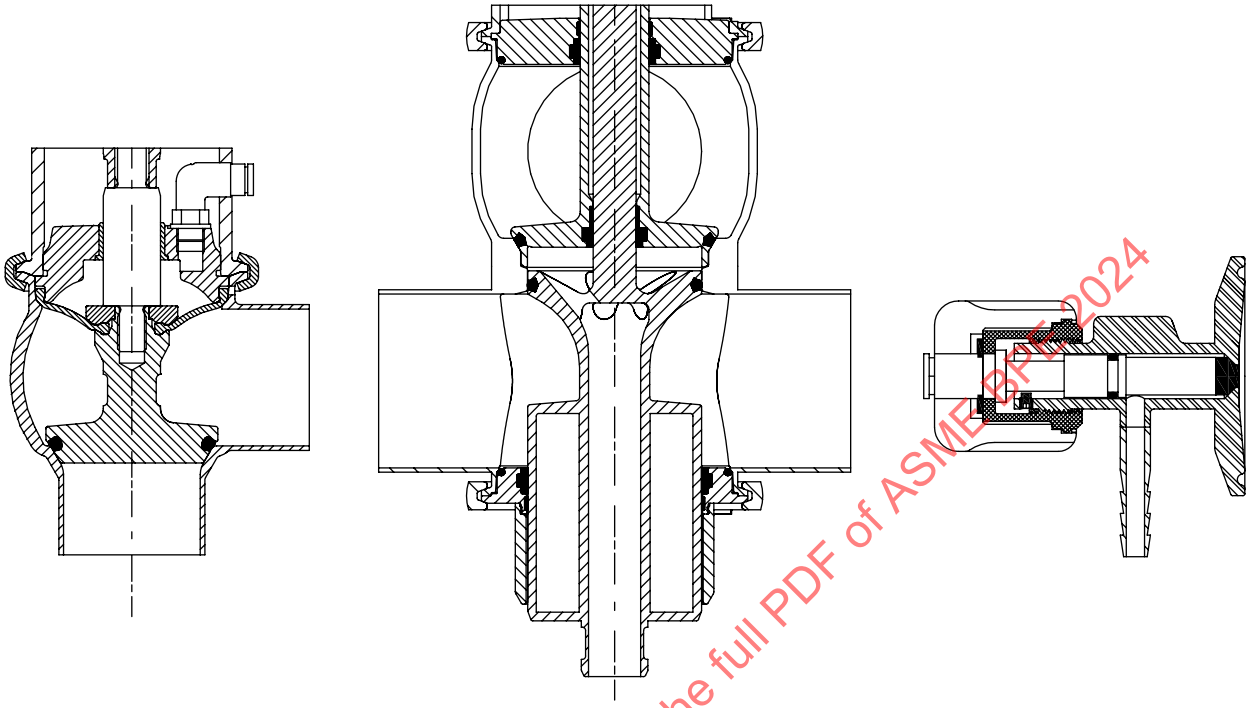
Figure MC-2.3.1.3-1
Ball Valves



(a) Ball Tank Bottom Valve

(b) Ball Valve

Figure MC-2.3.1.4-1
Rising Stem Single, Double-Seat Mix-Proof, and Needle Valves



(a) Rising Stem Single Valve

(b) Double-Seat Mix-Proof Valve

(c) Needle Valve

Figure MC-2.3.1.5-1
Butterfly Valve

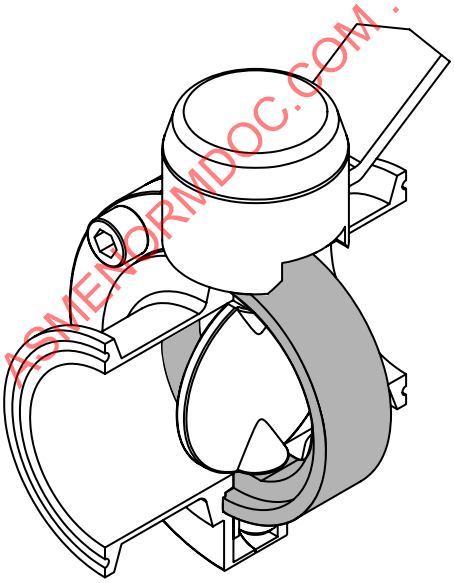


Figure MC-2.3.1.7-1
Back Pressure Control Valve

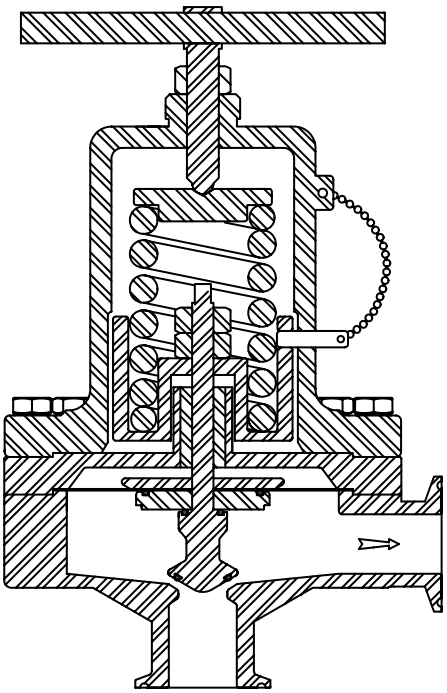
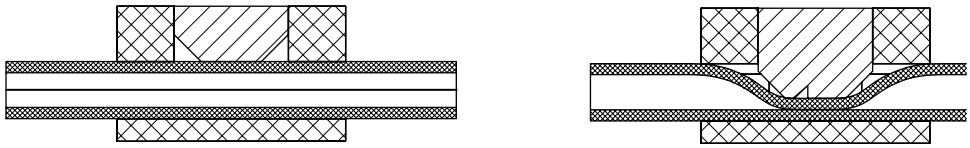


Figure MC-2.3.1.8-1
Pinch Valve

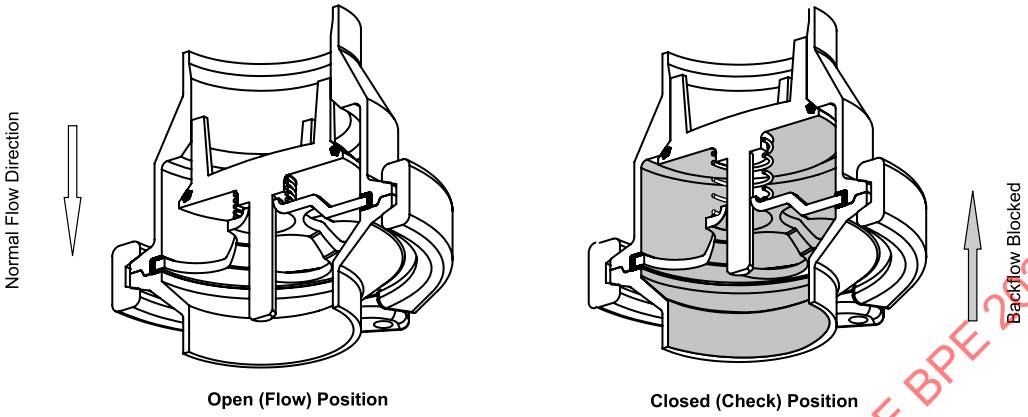


(a) Pinch Valve Open

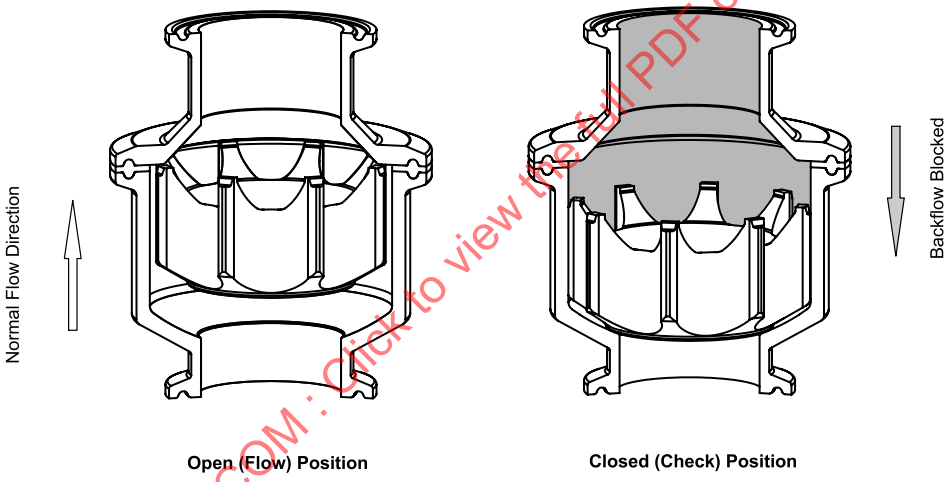
(b) Pinch Valve Closed

(24)

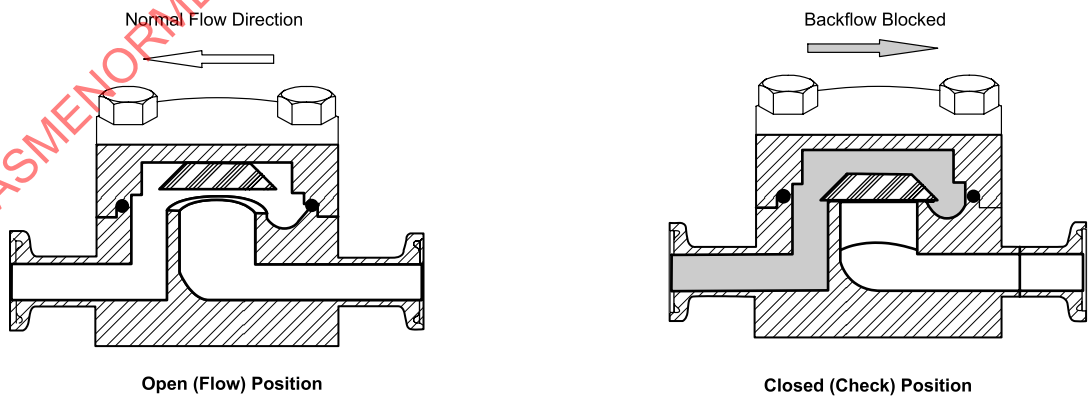
Figure MC-2.3.1.9-1
Check Valves



(a) Spring-Type Check Valve [Note (1)]



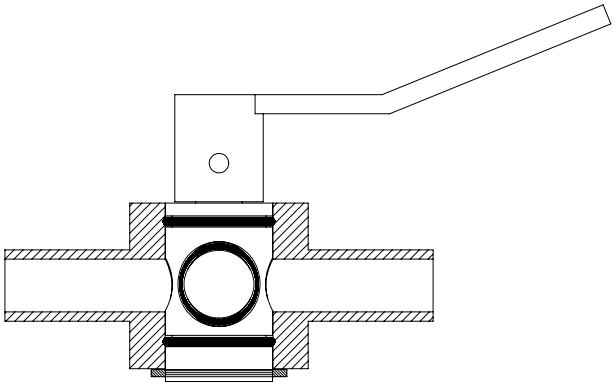
(b) Poppet-Type Check Valve (Vertical Configuration) [Note (1)]



(c) Poppet-Type Check Valve (Horizontal Configuration) [Note (1)]

NOTE: (1) Gray color represents backflow blocked.

Figure MC-2.3.1.10-1
Plug Valve



MC-2.3.1.10 Plug Valves. The plug-body valve or plug-seal valve functions as a dynamic seal against the rotating plug (see Figure MC-2.3.1.10-1).

MC-2.3.2 Mechanical Seals

MC-2.3.2.1 General. An end face mechanical seal is a device that controls leakage of fluids along rotating shafts. Sealing is accomplished by a stationary face bearing against the face of a rotating ring mounted to the shaft. The sealing faces are perpendicular to the shaft axis. Axial mechanical force and fluid pressure maintain the contact between the wearing seal faces.

MC-2.3.2.2 Single Mechanical Seals

(a) Single mechanical seals are seal arrangements in which there is only one mechanical seal per seal chamber.

(b) Single mechanical seals offer simplicity and an observable leakage path to the atmosphere.

(c) Single mechanical seals weep fluid across the face in the direction from high pressure to low pressure.

(d) Single Mechanical Seals for Pumps

(1) The process fluid provides lubrication and cooling for the faces. A single seal operating in dry or vacuum conditions will result in seal failure.

(2) Not all process fluids will provide adequate lubrication and cooling. In this case an alternative seal design or flush plan shall be considered.

(3) A typical single seal for pumps is illustrated in Figure MC-2.3.2.2-1.

(e) Single Mechanical Seals for Top-Mounted Agitators

(1) Single mechanical seals for top-mounted agitators operate in the head space of the vessel typically exposed to the gas phase of the process fluid.

(2) Top-mounted agitator single seals may contain a debris well to catch wear material from dry contacting faces.

(3) A typical single-seal design for top-mounted agitators is illustrated in Figure MC-2.3.2.2-2.

MC-2.3.2.3 Dual Mechanical Seals

(a) Dual Mechanical Seals–Pressurized

(1) Dual mechanical seals–pressurized consist of an inboard mechanical seal and an outboard mechanical seal. Pressurized barrier fluid is injected between these two seals. The inboard mechanical seal has process contact, and the outboard mechanical seal has atmospheric contact.

(2) Pressurized barrier fluid means the barrier fluid pressure is higher than the process pressure acting on the inboard mechanical seal.

(3) Dual mechanical seals–pressurized offer absolute separation of process and atmosphere.

(4) The pressurized barrier fluid will weep into the process and will weep into the atmosphere.

(5) The owner/user shall arrange for a pressurized barrier fluid to be introduced between the inboard seal and the outboard seal to ensure a positive barrier exists between the process and the atmosphere. A liquid barrier fluid such as water also cools and lubricates the seal. A gas barrier fluid such as air provides a barrier between the atmosphere and process only and does not provide cooling or lubrication to the seal faces.

(6) Barrier fluid shall be at an appropriate flow, pressure, and temperature and should be based on the recommendation of the equipment manufacturer.

(7) A typical dual mechanical seal–pressurized is illustrated in Figure MC-2.3.2.3-1 for pumps and in Figure MC-2.3.2.3-2 for top-entry agitators.

(b) Dual Mechanical Seals–Unpressurized

(1) Dual mechanical seals–unpressurized consist of an inboard mechanical seal and an outboard mechanical seal. Buffer fluid is injected between these two seals. The inboard mechanical seal has process contact, and the outboard mechanical seal has atmospheric contact.

(2) Unpressurized buffer fluid means the buffer fluid pressure is lower than the process pressure acting on the inboard mechanical seal. The highest pressure in the sealing system is the process pressure on the inboard side of the inboard seal. The lowest pressure of the system is the atmosphere pressure on the outboard seal.

(3) Dual mechanical seals–unpressurized offer absolute separation of the atmosphere from the process but do not provide absolute separation of the process from the atmosphere.

(4) Process fluid will weep into the unpressurized buffer fluid, and the buffer fluid will in turn weep into the atmosphere along with dilute process fluid.

(5) The owner/user shall arrange for an unpressurized buffer fluid to be introduced between the inboard seal and the outboard seal to ensure a buffer between the process and the atmosphere. The process fluid will penetrate between the inboard seal faces. The buffer fluid with traces of process fluid will penetrate the outboard seal faces.

Figure MC-2.3.2.2-1
Single Mechanical Seal

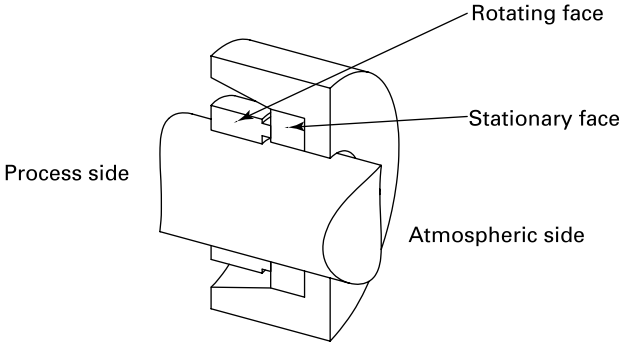


Figure MC-2.3.2.3-2
Dual Mechanical Seal–Pressurized for Top-Entry Agitator

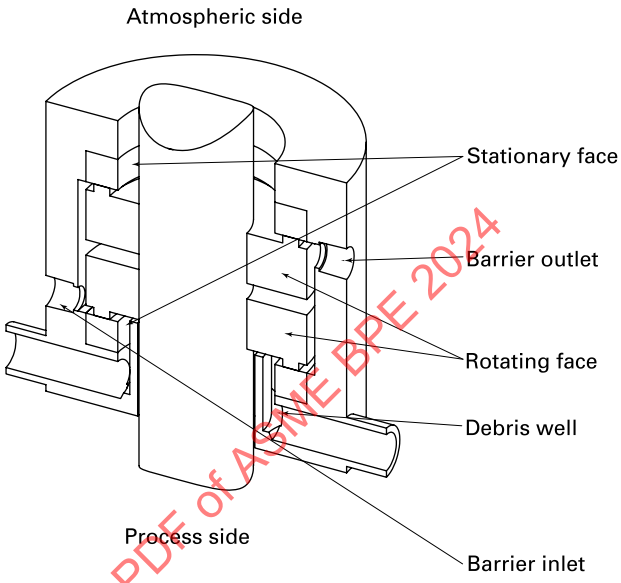


Figure MC-2.3.2.2-2
Single Seal for Top-Entry Agitator

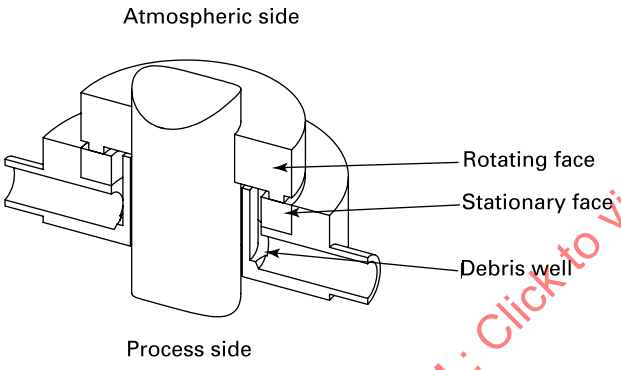


Figure MC-2.3.2.3-1
Dual Mechanical Seal–Pressurized for Pumps

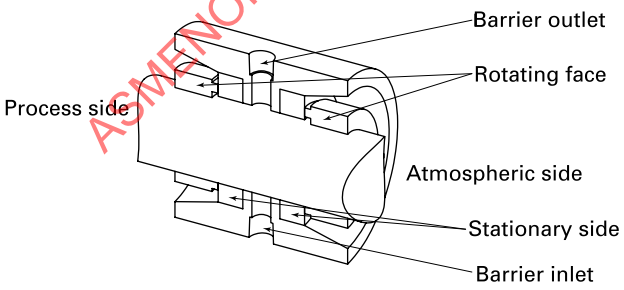
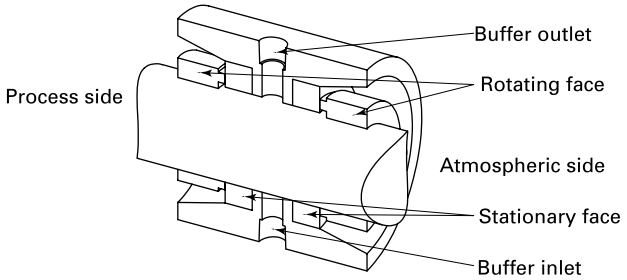


Figure MC-2.3.2.3-3
Dual Mechanical Seal–Unpressurized for Pumps



(6) Buffer fluid shall be at an appropriate flow, pressure, and temperature and should be based on the recommendation of the equipment manufacturer.

(7) A typical dual mechanical seal–unpressurized is illustrated in Figure MC-2.3.2.3-3.

(24) **MC-2.3.2.4 Seal Support System Plans.** Seal supplort system plans describe how the end face mechanical seal is lubricated and cooled. The plan numbers were developed by the American Petroleum Institute (API 682), were subsequently approved by the American National Standards Institute (ASME B73 series), and are common nomenclature for seal support systems. If properly implemented to the requirements of this Standard, all of the following plans are acceptable for use in the bioprocessing industry. The numbering system used below is also recognized and used by the Fluid Sealing Association (FSA) and the European Sealing Association (ESA).

(a) Plan 01. Flush provided by internal circulation from a higher-pressure region of the pump to the lower-pressure seal chamber. The flush cools and lubricates the seal faces. See Figure MC-2.3.2.4-1.

(b) Plan 02. Dead-ended seal chamber with no circulation (i.e., no flush or additional measures to cool or lubricate the seal faces). The ambient conditions of the seal chamber are satisfactory for the process fluid to remain a coolant and lubricant for the seal faces. See Figure MC-2.3.2.4-2.

(c) Plan 03. Dead-ended seal chamber with circulation between the seal chamber and the pump created by the design of the sealing chamber. The flow of process fluid cools and lubricates the seal faces and may prevent the accumulation of solids in the seal chamber. See Figure MC-2.3.2.4-3.

(d) Plan 11. Circulation from pump discharge to the seal chamber. This plan often uses an orifice, but the flush line itself may be considered an orifice. A high-pressure discharge of the process fluid flows to the low-pressure seal chamber. The flow of process fluid cools and lubricates the seal faces. See Figure MC-2.3.2.4-4.

(e) Plan 32. Flush from an external source. A fluid that is compatible with the process is injected into the seal chamber to cool and lubricate the seal. Plan 32 flush fluid will go into the process. See Figure MC-2.3.2.4-5.

(f) Plan 52. This plan is for dual seals–unpressurized only. The buffer fluid circulates through a reservoir at a pressure less than that of the process side of the inboard seal. This plan offers protection from product entering the atmosphere, and buffer fluid and atmosphere from entering the process side. If the process is exposed to vacuum conditions, buffer fluid may enter the process side. Adequate circulation shall be provided to cool the seal. See Figures MC-2.3.2.4-6 and MC-2.3.2.4-7.

(g) Plan 53. This plan is for dual seals–pressurized only. Barrier fluid circulates through a reservoir where it is cooled and returned to the seal cavity at a pressure greater than the process side of the inboard seal. Circulation shall be provided by a pumping mechanism located in the dual-seal design or externally. Adequate flow shall be provided to cool the seal. This plan offers protection from cross-contamination between the atmosphere and process fluid under normal operating conditions. The barrier fluid shall be compatible with the process fluid. See Figures MC-2.3.2.4-8 and MC-2.3.2.4-9.

(h) Plan 54. This plan is for dual seals–pressurized only. Pressurized barrier fluid flows through the dual-seal cavity from an external source. The source of flow and pressure is not defined by this plan. The barrier fluid pressure between the inboard and outboard seals shall be higher than the process pressure acting on the inboard seal. The barrier fluid shall be compatible with the process fluid. See Figures MC-2.3.2.4-10 and MC-2.3.2.4-11.

(i) Plan 55. This plan is for dual seals–unpressurized only. Unpressurized buffer fluid flows through the dual-seal cavity from an external source. The source of flow is not defined by this plan. The buffer fluid pressure between the inboard and outboard seals shall be lower than the process pressure acting on the inboard seal. This plan offers protection from cross-contamination between the process fluid and atmosphere under normal operating conditions. See Figures MC-2.3.2.4-12 through MC-2.3.2.4-14. Figure MC-2.3.2.4-13 shows an example of Plan 55 where flow and pressure are taken from the pump discharge and injected between the dual seals. The seal cavity is vented to a low-pressure point.

(j) Plan 74. This plan is only for dual gas mechanical seals–pressurized. The barrier fluid pressure between the inboard and outboard seals shall be higher than the process pressure acting on the inboard seal. The barrier fluid shall be compatible with the process fluid. See Figures MC-2.3.2.4-15 and MC-2.3.2.4-16.

Figure MC-2.3.2.4-1
Plan 01

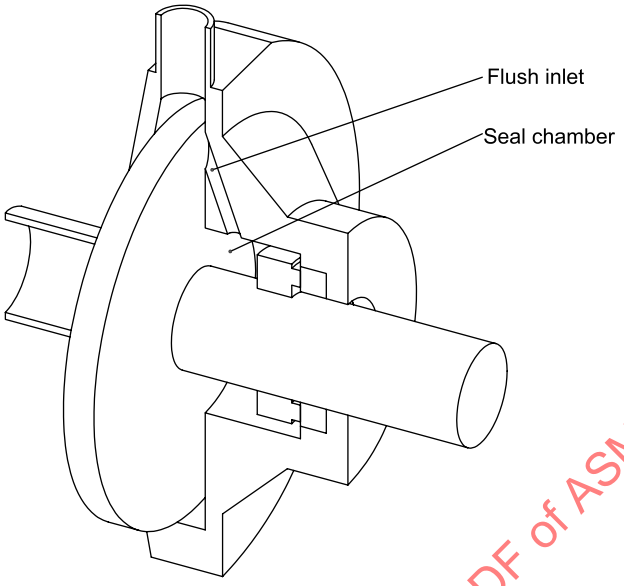


Figure MC-2.3.2.4-2
Plan 02

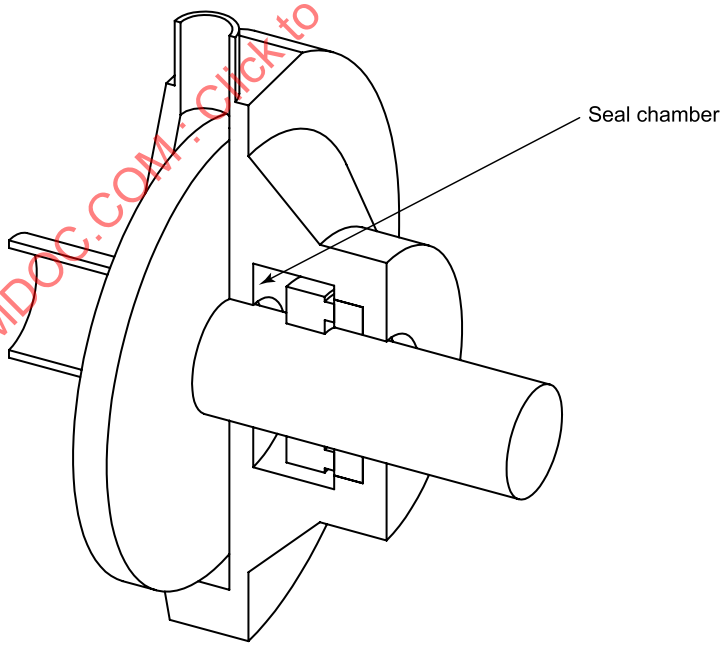


Figure MC-2.3.2.4-3
Plan 03

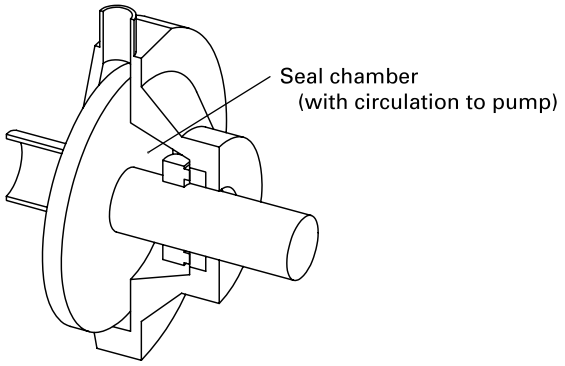


Figure MC-2.3.2.4-5
Plan 32

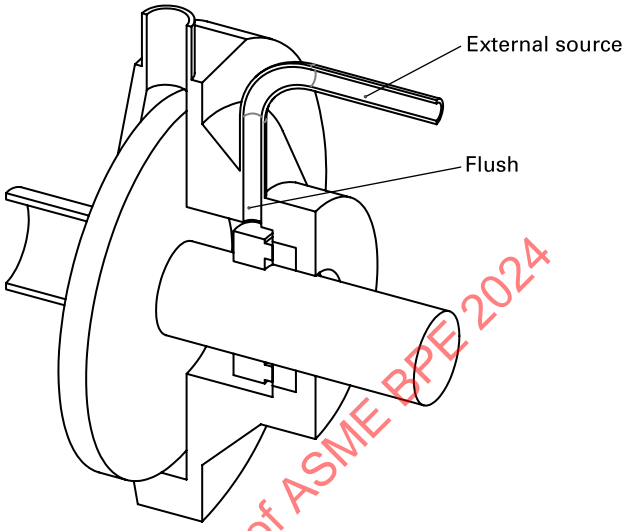


Figure MC-2.3.2.4-4
Plan 11

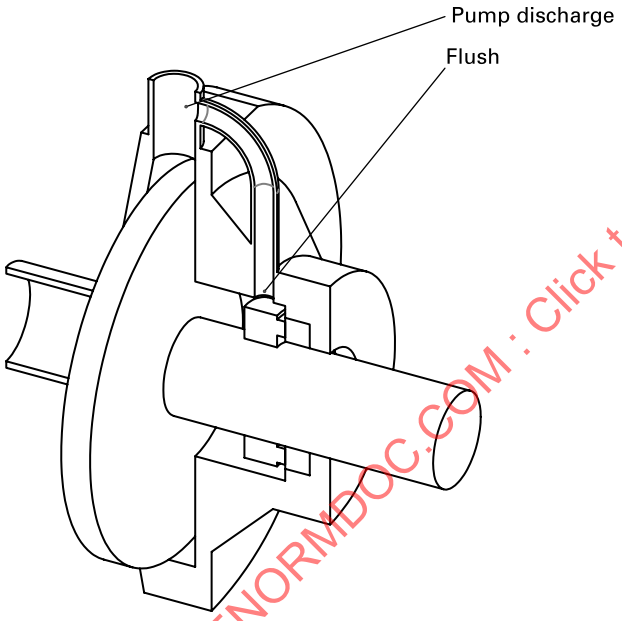


Figure MC-2.3.2.4-6
Plan 52 for Pump

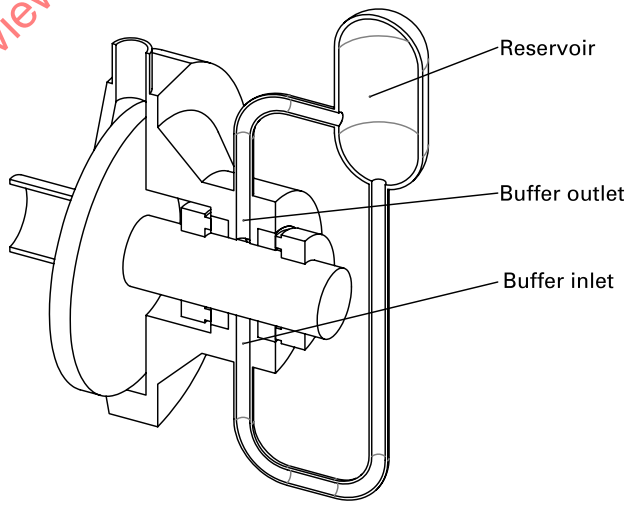


Figure MC-2.3.2.4-7
Plan 52 for Top-Entry Agitator

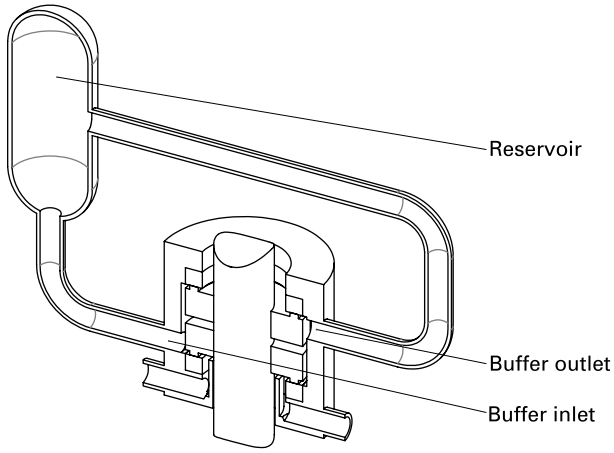


Figure MC-2.3.2.4-9
Plan 53 for Top-Entry Agitator

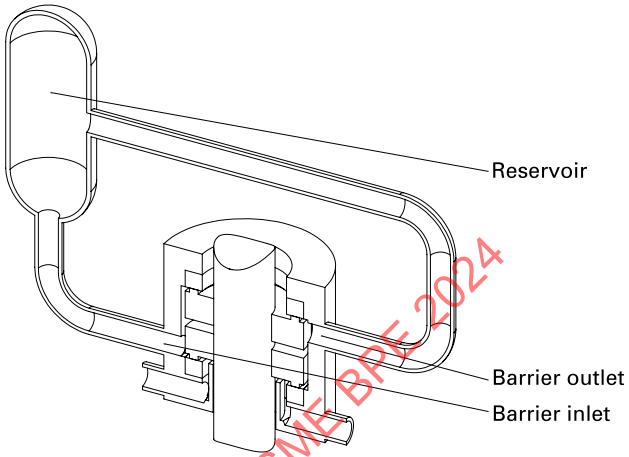


Figure MC-2.3.2.4-8
Plan 53 for Pump

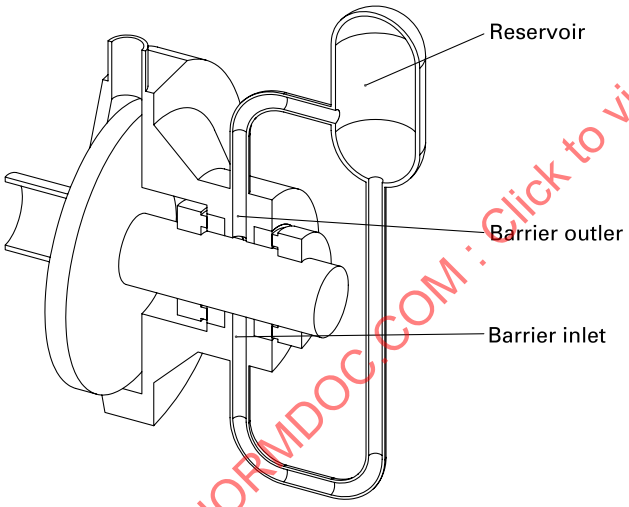


Figure MC-2.3.2.4-10
Plan 54 for Pump

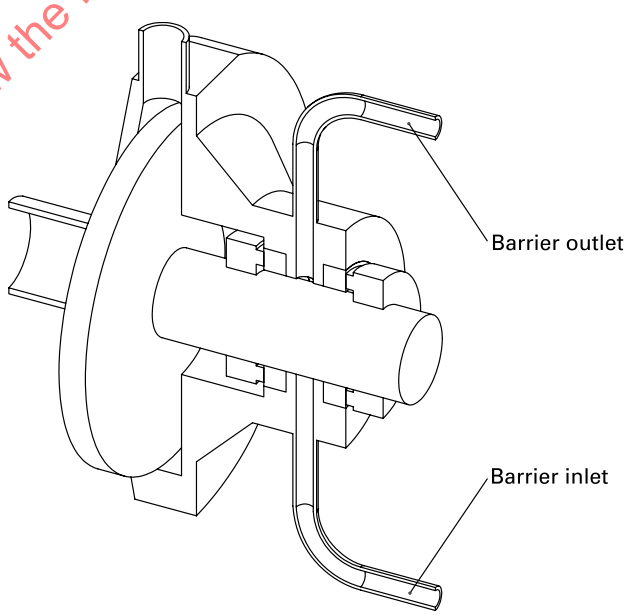


Figure MC-2.3.2.4-11
Plan 54 for Top-Entry Agitator

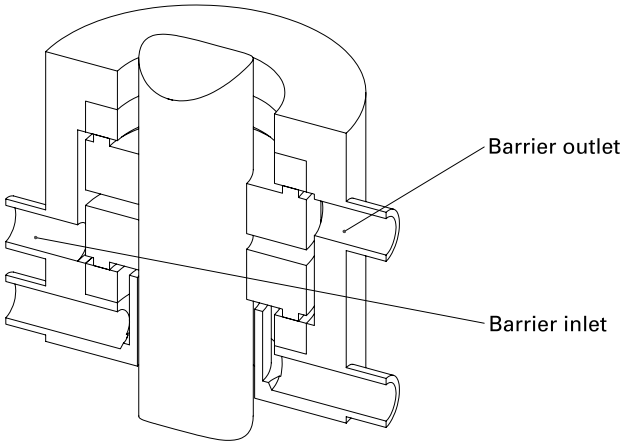


Figure MC-2.3.2.4-12
Plan 55 for Pump

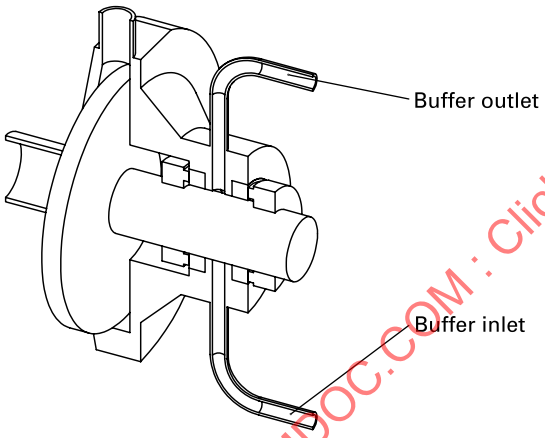


Figure MC-2.3.2.4-13
Plan 55 With Buffer Fluid From Pump Discharge

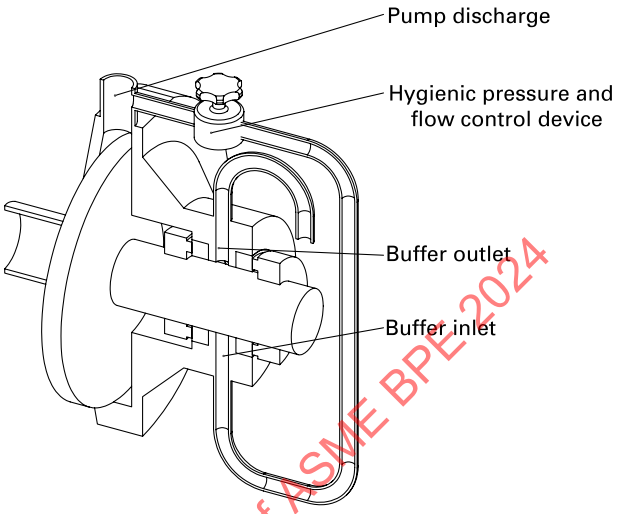


Figure MC-2.3.2.4-14
Plan 55 for Top-Entry Agitator

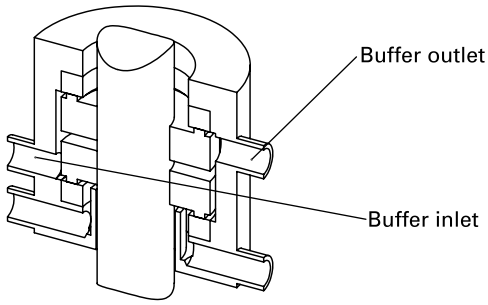


Figure MC-2.3.2.4-15
Plan 74 for Pump

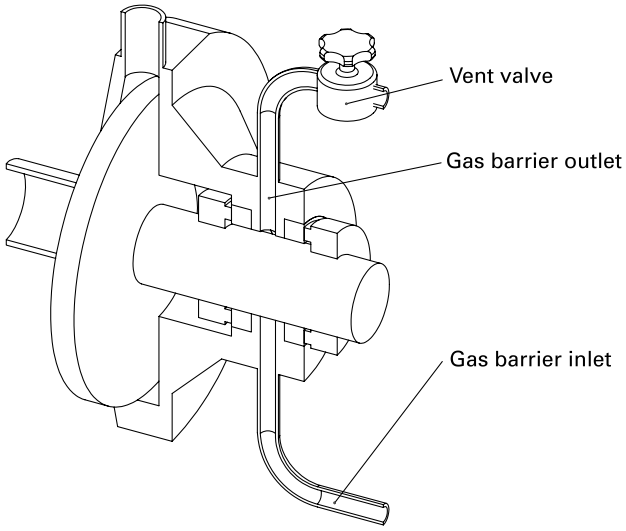
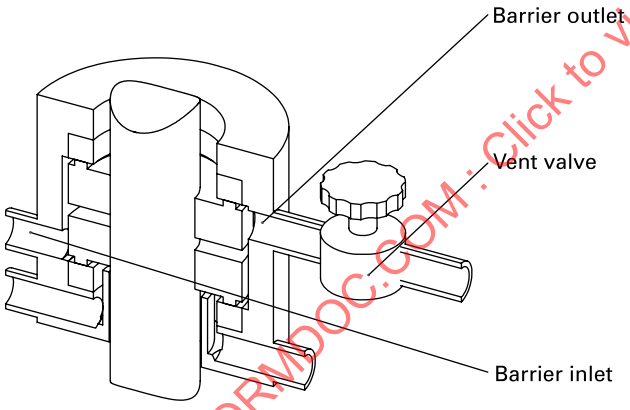


Figure MC-2.3.2.4-16
Plan 74 for Top-Entry Agitator



MC-2.3.3 Other Dynamic Seals

MC-2.3.3.1 Reciprocating Seals. Reciprocating seals have axial movement between the inner and outer elements, as in a plunger or a piston and a cylinder. The seal, usually an O-ring, slides along the sealing surface.

MC-2.3.3.2 Oscillating Seals. Oscillating seals have angular movement around an arc, as in a valve handle. The seal, usually an O-ring, slides between the inner and outer elements and has limited or no longitudinal movement.

MC-3 SEALING COMPONENTS GENERAL DESIGN REQUIREMENTS (GENERAL PROVISIONS)

MC-3.1 Process Conditions

The equipment supplier/manufacturer shall provide documentation stating the recommended operational limits of the sealing components and maintain appropriate data (e.g., test results, calculations) supporting these limits.

The equipment supplier/manufacturer should provide available information relevant to common applications (e.g., sterilization, cleaning, and passivation). Form S-1, Application Data Sheet, may be used by the owner/user to communicate pertinent information for the supplier/manufacturer to assess compatibility with the specific owner/user process.

The equipment supplier/manufacturer should provide available information regarding the component's life cycle performance and the methodology used in its determination (e.g., test protocol). Nonmandatory Appendix K provides standard process test conditions for seal performance evaluation that may be used for this purpose.

MC-3.1.1 Thermal Cycling. Sealing components shall be designed to perform as intended when thermally cycled between the rated upper and lower temperature limits. The equipment supplier/manufacturer should provide available information regarding allowable number of thermal cycles.

MC-3.2 System Requirements

Sealing components designed for CIP shall meet the requirements of SD-2.4.2.

Sealing components designed for SIP shall be able to withstand continuous exposure to saturated steam at a minimum temperature of 266°F [130°C; representing 24.5 psig (1.70 bar) under saturated steam conditions] for a duration of at least 100 hr.

Sealing components shall be accessible for maintenance.

MC-3.3 Seal Construction

MC-3.3.1 Materials

(a) Biocompatibility. Biocompatibility testing shall be performed per PM-3.1. The testing shall be valid for all similar seals represented by the unique combination of the materials and manufacturing processes used in the test article. Biocompatibility testing shall be repeated for significant changes in raw materials or manufacturing processes. Otherwise, biocompatibility testing is used on initial qualification of the material and process by the seal supplier/manufacturer.

(b) Process Compatibility. Seal materials shall be resistant to corrosion from process, cleaning, and sterilization fluids. Selection shall be based on all media that could

come in contact with the seal, including cleaning and sterilization media. Special consideration shall be made when the exposure is at elevated temperature. Material selection shall be governed by Part PM and reference Form S-1, Application Data Sheet. It is unlikely that any single seal material can withstand all conditions present in the facility. Material selection should be done in concert with the seal supplier/manufacturer to ensure that seal performance is maximized for each location within a process. However, material selection remains the responsibility of the owner/user.

(c) Permeation Resistance. Seal permeation shall be included in seal leakage criteria and is not addressed as an individual topic.

(d) Surface Finish

(1) Seals shall be free of molding imperfections or burrs within the system boundary and on sealing surfaces.

(2) Seals shall be free of foreign matter on surfaces within the system boundary and on sealing surfaces.

(3) Surfaces to be sealed shall meet specifications provided by the seal supplier/manufacturer based on performance and the requirements in Part SF.

(4) Molded seals and components shall have molding flash removed to prevent contact with the process stream.

(e) Particle Generation. Seal designs should minimize wear that generates particles that could enter the process stream.

(f) Lubrication. When required to facilitate installation, seals may be lubricated with an acceptable lubricant that is compatible with the seal material and process. The supplier/manufacturer shall disclose lubrication requirements. The selection of lubricants is the responsibility of the owner/user.

MC-3.3.2 Design

MC-3.3.2.1 General

(a) Crevices. A smooth, contoured, pocketless interior surface shall be created when seals are placed between the seal contact surfaces. All recessed seal contact surfaces shall avoid sharp corners and be easily cleanable with the seal removed. All seal and seal contact surfaces shall be designed to minimize cracks or crevices that might harbor system media.

(b) Dead Spaces. Dead spaces are defined here as a void in the process contact surface(s) portion of the structure not completely occupied by a seal and are usually required to allow for thermal expansion of the seal material. These should be avoided. All seal and seal contact surfaces shall be designed so that the system is drainable when seals are properly installed.

MC-3.3.2.2 Static Seals

(a) Static Seal General Design Requirements. MC-2.2 lists some standards describing the design of hygienic unions, O-rings, and other static seals. Figures MC-2.2.2-1 through MC-2.2.2-4 illustrate typical static hygienic and O-ring connections. Figure MC-2.2.2-5 illustrates unacceptable connections. In addition, the following general requirements apply to all hygienic static seals:

(1) Gaskets and O-ring seals shall seal and meet the cleanability and bioburden control requirements of the application. Fittings should be selected or designed to consider the gasket or O-ring geometry, materials of construction, and seal performance under operating conditions.

(2) Static seals should be self-aligning and self-positioning.

(b) Hygienic Unions. Most common hygienic union geometries used in bioprocessing are listed in MC-2.2.2. All hygienic unions shall conform to the general design requirements in this Part, the material requirements of Parts MM and PM, and the surface finish requirements of Part SF. Intrusion categories of hygienic seals are defined in MC-4.2 and illustrated in Figure MC-4.2-1.

(c) O-Ring Seals

(1) General O-Ring and Gland Design Criteria. An O-ring is a seal with a circular cross section (a toroid), designed to be seated in a groove and compressed during assembly. These are most often used in static seals. O-rings are used extensively in hygienic applications and can seal by applying compression (squeeze) on the radially and/or axially opposed faces. In addition to sealing performance during bioprocessing production, performance during other processes, typically CIP and bioburden control processes, shall be considered in the design of a hygienic O-ring seal. The following design criteria should be evaluated:

(-a) seal performance under all process conditions

(-b) proximity of the sealing point to the bulk fluid flow for CIP and bioburden control processes

(-c) consistent location of the sealing point and exposed surfaces under all relevant process conditions

(-d) ability to handle the effects of thermal expansion and chemical swell

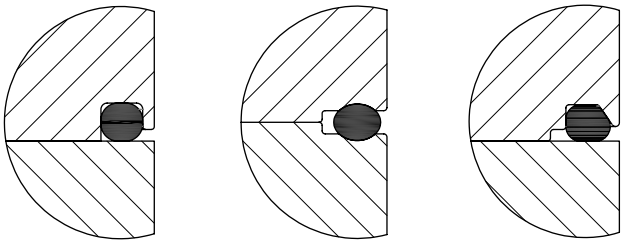
(-e) drainability

Often designs that target specific criteria sacrifice others. For example, installation of O-rings in tight grooves to improve cleanability often causes problems due to the thermal expansion of elastomers being significantly greater than the thermal expansion of stainless steel or other nonmetallic materials.

The owner/user should consult with the seal designer to optimize the design for an application. The owner/user should determine whether an O-ring seal provides adequate overall performance for a specific application.

Some examples of O-ring groove designs are shown in Figure MC-3.3.2.2-1.

Figure MC-3.3.2.2-1
Examples of Static O-Ring Grooves



(2) O-Ring/Gland Sizing (Fill). Proper gland design and appropriate O-ring selection are critical for proper sealing. O-ring selection includes the proper sizing and proper material selection for the process environment. An O-ring gland shall include sufficient room for thermal expansion and chemical swell to prevent seal material extrusion and damage. Seal designs that compress in multiple directions require extra caution.

(3) O-Ring Stretch (Elastomeric O-Rings). It is suggested that O-ring stretch during installation be limited. The designer should consider the maximum amount of allowable stretch to prevent O-ring breakage during part assembly. When located in position for use, the O-ring stretch should not exceed 5%. Similarly, the O-ring diameter should not be too large for a groove, which would cause the ring to buckle. Overstretching or oversizing an O-ring can lead to premature seal failure.

(4) O-Ring Compression (Squeeze). Proper O-ring compression is critical to proper sealing. At ambient temperature, O-ring compression is frequently in the range of 10% to 25%; however, this can vary greatly depending on materials, conditions, and applications (e.g., static vs. dynamic). O-ring compression over 30% should generally be avoided. Relative O-ring compression can increase during heating due to thermal expansion. Factors to consider for O-ring compression include chemical swell, temperature change, elastomer hardness, etc. Caution should be taken when substituting elastomeric seals for nonelastomeric seals or vice versa. A nonelastomeric seal may require a crush groove, and direct substitution of an elastomer into such a groove may result in premature seal failure.

(5) O-Ring Thermal Expansion. O-ring thermal expansion is dependent on the particular material and formulation. The O-ring supplier/manufacturer can provide information on the material's coefficient of thermal expansion (CTE) characteristics.

(6) Hygienic O-ring connections are available (see Figures MC-2.2.2-3 and MC-2.2.2-4) in threaded, flanged, or clamped styles. The O-ring connections shall be manufactured to a hygienic standard (e.g., DIN 11864 parts 1 to 3) or shall be accepted as a hygienic connection by a recognized independent organization [e.g., the European Hygienic Engineering and Design Group (EHEDG)]. O-ring connections shall conform to this paragraph and SD-3.1.1. The construction of the fitting shall be such that excessive deformation of the seal will not be caused as a result of overtightening the connection.

(7) O-Rings Fabricated From Molded or Extruded Section Using Vulcanized Molded Joints

(-a) O-Rings. Fully molded O-rings should be used, wherever possible.

(-b) Vulcanized Bonded Joints. When the fully molded seal diameters are not available, O-rings fabricated from molded section using molded vulcanized joints can be fitted as long as the following parameters are kept:

(-1) Materials. All bonded joint seal materials shall conform to MC-3.3.1 and any additional requirements specified by the owner/user. The vulcanized bonded joint should consist of either an unvulcanized portion of the seal material or a compatible material where this gives an improved joint. In both cases, the joining material shall meet the same requirements as the seal material.

(-2) Joint Integrity. The joint integrity shall meet the strength requirements of the application. A vulcanized O-ring should contain only one joint. Where tooling availability limits seal diameter, extra joints can be included with approval of the owner/user.

(-3) Excessive Material and Tool Marks. All excessive joint material shall be removed. The surface finish and any residual material, tool marks, or reductions in cross-sectional tolerances should not be at a level that compromises seal performance and cleanability.

(-c) Adhesive-Bonded Joints. Adhesive-bonded joints should be avoided and used only with approval by the owner/user.

(d) Other Static Seals

(1) Flat Gaskets. All flat gaskets shall conform to the general design requirements in this Part, the material requirements of Part PM, and the surface finish requirements of Parts SD and SF.

(2) Inflatable Seals. Inflatable seals shall conform to the general design requirements of this Standard.

MC-3.3.2.3 Valves

(a) General

(1) Process flow valves should be drainable and prevent pooling when installed in their proper drain orientation.

(2) When possible, welding valves into the process line is the preferred method of installation to minimize the use of seals.

(3) All process contact surfaces of components designed for CIP/SIP shall be accessible by CIP fluids and SIP steam.

(4) Valve surfaces that may become process contact surfaces if a component (e.g., diaphragm) fails in service shall be readily accessible for examination, maintenance, and cleaning.

(5) The metallic fluid-contact surfaces of the valve, including the body cavity, shall conform to the applicable requirements in Part SF.

(6) The internal geometry of cluster, block, and multiport valves should be designed to minimize the conditions that contribute to a dead leg and enable draining when installed per design.

(7) The internal volume of the valve should be kept to a minimum while meeting other requirements of the process design.

(8) Any crevices (e.g., between mating parts of a valve) should be minimized in areas in contact with the process.

(9) Any guiding of valve trim and operating mechanisms should be minimized in areas in contact with the process.

(10) Valves intended for CIP/SIP/sanitization shall be capable of opening as required during those processes.

(11) Valves not capable of CIP shall be able to be disassembled for cleaning/steaming.

(12) The valve design should enable immediate leakage detection between the process side and environment at any seal when possible. The area between a primary and secondary stem seal should be fitted with a leakage detection port to indicate primary seal leakage.

(13) Pneumatically controlled valves shall be designed to prevent air transfer from the actuator to the process.

(14) See Form S-1, Application Data Sheet, to communicate process conditions to the supplier/manufacturer.

(b) *Diaphragm Valves*

(1) Diaphragm valves use nonsliding seals and are the preferred valve for bioprocessing fluid applications.

(2) Two-way, weir-style diaphragm valve bodies shall be permanently marked on both sides of the body to indicate drain position. When submittal drawings are required for welded and machined multiple-port valves, the proper installation orientation shall be included. Other types of diaphragm valves should be installed to the manufacturer's recommendations.

(3) Point-of-use (POU) valves should be designed with the seal at or below the lowest point in the tube to enable draining.

(4) Diaphragms should be marked in accordance with Section 12.3 of MSS-SP-88.

(5) Weirless diaphragm valves use nonsliding seals. The installation angle is not critical due to the elimination of the weir in the body design; however, the valve should be installed to the manufacturer's recommendations.

(c) *Rising Stem Seal Valves.* Rising stem seal valves use sliding and nonsliding seals (see Figure MC-3.3.2.3-1). Suitable designs are available for fluid utility applications such as clean steam and CIP as well as for product. The owner/user should define the degree of suitability of the design for the application.

(1) Seals for rising stem valves are classified as follows:

(-a) *Primary Rising Stem Seals.* Primary rising stem seals serve as pressure barriers for process fluids. Such seals shall be exposed for cleaning and shall meet the pressure and temperature requirements of the specified materials as outlined in this Standard and the aseptic and bioburden control requirements specified by the owner/user. In addition, they shall meet all of the general requirements for seals outlined in this section. Primary sealing can be provided in different ways.

(-1) Nonsliding seals such as bellows and diaphragms eliminate contamination risk by preventing the product/process contact surface(s) portion of the stem from contacting the atmosphere. When the primary stem seal is a nonsliding seal, a secondary stem seal is not required.

(-2) Sliding seals such as lip-seals and O-rings can be used for the reciprocating stem between process fluid and atmosphere. Single sliding stem seals can be used for fluid utility applications such as clean steam and CIP. If sliding seals are to be used as the primary seal for product contact applications, there should be a secondary stem seal to facilitate cleaning and sanitization behind the primary sliding seal.

(-b) *Secondary Rising Stem Seals.* Secondary seals serve as the sealing between atmosphere and a stem disinfection chamber (e.g., steam barrier or disinfection means barrier). These seals shall be designed to serve as pressure barriers for sanitizing fluid. Such seals shall meet the pressure and temperature requirements of the specified material outlined in Part MC of this Standard. Secondary stem seals are typically sliding seals (e.g., O-rings or lip-seals).

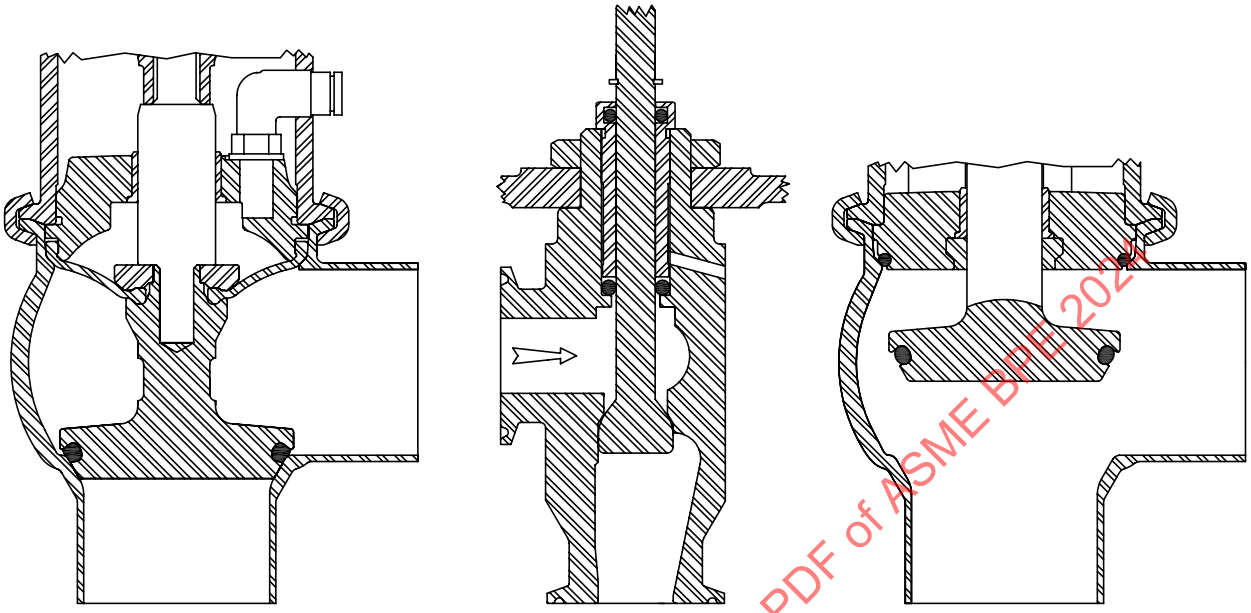
(2) Wherever elastomeric or polymeric seals are retained under static compression, adjoining metal surfaces shall be machined to a roughness specified by the seal manufacturer to ensure required performance, and shall meet the requirements of Part SF, if the surface can become exposed to the system fluid under the normal course of system operation.

(3) Primary stem O-ring seals should be fitted in grooves located as close to the valve body cavity as possible.

(4) When made from metal, static seals shall meet the surface finish requirements for the valve housing interior on the side facing the process fluid.

(d) *Regulator Valves.* When using regulator valves, a means of override is normally required to allow cleanability and drainability of the valve.

Figure MC-3.3.2.3-1
Seals for Rising Stem Valves



(a) Rising Stem Valve With Elastomeric Diaphragm

(b) Rising Stem Valve With O-Ring Seal

(c) Rising Stem Valve With Molded Seal

(e) Ball Valves. Ball valves (see Figure MC-2.3.1.3-1) are not recommended for product contact streams. The owner/user should determine whether a ball valve is acceptable for other process contact applications. Applications where ball valves are typically acceptable include liquid and gas utility and process support applications, such as clean steam. The valve bore I.D., including ball and body, shall match the I.D. of the connecting tubing to enable draining. Cavity fillers shall not be used.

(f) Butterfly Valves. Butterfly valves use sliding seals. Butterfly valves are commonly used for powder and vacuum applications. The valve should be installed per the manufacturer's recommendations to enable draining.

(g) Steam Traps (Thermostatic). A thermostatic steam trap shall be designed to minimize the risk of soil attachment to the process fluid surfaces. The bellows should have a low subcool to prevent the backup of condensate into the process equipment and clean steam system. Steam traps shall be installed with an uninsulated section upstream of the trap to facilitate proper steam trap function (see Figure SD-3.12-1).

(h) Back Pressure Control Valves. Back pressure control valves shall be designed to enable draining through the outlet or inlet port. Crevices created by a pierced diaphragm or soft seat plug shall be minimized.

(i) Pinch Valves. When using pinch valves, care shall be taken to prevent permanent deformation of the flexible tube or sleeve that restricts the flow or affects drainability.

(j) Check Valves. Check valves may use sliding and/or nonsliding seals. A check valve, clack valve, nonreturn valve, or one-way valve is a valve that allows fluid flow in one direction. Check valves using an exposed coil spring shall be of a design to prevent the coil spring from full compression creating an enclosure.

(k) Plug Valves. Rotating plug valves use sliding seals and are not preferred in product contact applications. Plug valves are suitable for liquid and gas utility applications such as clean steam and CIP. The plug valve uses a $^{1}/_{4}$-turn cylindrical plug with O-ring seals to provide straight-through flow. If the plug I.D. does not match the I.D. of the tubing, the valve may not be drainable.

MC-3.3.2.4 End Face Mechanical Seal General Design Requirements

(a) General

(1) Mechanical seal hardware used to mount the mechanical seal to equipment shall be consistent with nonpooling and drainability requirements of Part SD.

(2) Springs and drive mechanisms (e.g., pins) shall not be located in the process fluid.

(3) When applicable, the seal should be designed in accordance with this Standard for CIP and/or SIP.

(4) Surface requirements for the process side of the mechanical seal shall be consistent with the requirements of Part SF.

(5) Process-side hardware radii shall meet the requirements of SD-2.4.2.

(6) Secondary seals are used in static and dynamic positions. The dynamic position in a typical mechanical seal is where the secondary seal is in contact with the spring-loaded seal face. The dynamic secondary seal accommodates motion during operation and face movement as the primary faces wear. Secondary seal cavities shall be located and designed so that the process side is accessible to fluid flow and is drainable consistent with the requirements of Part SD.

(7) Secondary seal material should be selected to minimize compression set on all phases of operation, which may include CIP and/or SIP.

(8) Materials of construction shall meet Part PM for polymers or other nonmetallics and Part MM for metal components. The owner/user is responsible for selection of appropriate materials.

(9) Form S-1, Application Data Sheet, should be filled out with appropriate information to make a correct seal selection.

(10) Assembly lubrication should be specified by the owner/user. The owner/user should determine compatibility of the lubricant with the process. The equipment supplier/manufacturer should determine the compatibility of the lubricant with the seal components.

(b) Single Mechanical Seal

(1) Single mechanical seals are applied for their simplicity, observable leakage path to the atmosphere, and no requirement for a seal support system.

(2) Single mechanical seals protect the process boundary at the seal's secondary seals and at the seal's primary face.

(3) When operating in pressurized process fluid, single mechanical seals will weep process fluid to atmosphere. If a process upset occurs that creates a temporary vacuum in the equipment, the seal will weep atmosphere into the process fluid.

(4) Single liquid mechanical seals are applied when the process fluid has desirable lubricating characteristics to support the rubbing of the primary seal faces.

(-a) Fluids that have desirable lubricating characteristics do not include fluids that change state, are in gaseous phase, precipitate solids, and cause thin film bonding, congealing, solidification, or crystallization between the seal faces.

(-b) An example of a possible desirable lubricant is pure steam condensate at 100°F (38°C).

(5) Single dry contacting gas seals will operate in a gaseous phase environment.

(c) Dual Mechanical Seal–Pressurized

(1) Dual mechanical seals–pressurized are preferred to prevent process fluid from weeping to atmosphere and to prevent atmosphere from weeping into the process.

(2) Dual mechanical seals–pressurized protect the process boundary with a pressurized barrier fluid.

(3) Dual mechanical seals–pressurized are used when the process fluid does not have desirable lubricating characteristics.

(4) Dual mechanical seals–pressurized shall be designed for liquid or gas barrier fluid. Dual mechanical seals–pressurized cannot be designed for gas and liquid lubrication.

(5) Dual gas mechanical seals–pressurized can be contacting or noncontacting face design.

(6) A barrier fluid compatible with the process fluid and atmosphere shall be specified by the owner/user. The owner/user should consult with the equipment supplier/manufacturer to determine suitability of the barrier fluid for the dual mechanical seal–pressurized.

(7) Form S-1, Application Data Sheet, should be filled out with appropriate information to determine the appropriate pressure, flow rate, and temperature of the barrier fluid.

(d) Dual Mechanical Seal–Unpressurized

(1) Dual mechanical seals–unpressurized are preferred to prevent dilution of the process fluid by the buffer fluid weeping across the inboard faces. The buffer fluid will prevent atmosphere from entering the process fluid. The process fluid will weep into the buffer fluid that may weep to the atmosphere.

(2) Dual mechanical seals–unpressurized protect the process boundary with an unpressurized buffer fluid.

(3) Dual mechanical seals–unpressurized are used when the process fluid has desirable lubricating characteristics.

(4) Dual mechanical seals–unpressurized shall be designed for liquid or gas buffer fluid. Dual mechanical seals–unpressurized cannot be designed for gas and liquid lubrication.

(5) Dual gas mechanical seals–unpressurized can be contacting or noncontacting face design.

(6) A buffer fluid compatible with the process fluid and atmosphere should be specified by the owner/user. The owner/user should consult with the equipment supplier/manufacturer to determine suitability of the buffer fluid for the dual mechanical seal–unpressurized.

(7) Form S-1, Application Data Sheet, should be filled out with appropriate information to determine the appropriate pressure, flow rate, and temperature of the buffer fluid.

MC-3.4 Conformance Requirements for Sealing Elements

MC-3.4.1 General Requirements. A Certificate of Conformance shall be issued by the seal manufacturer to certify conformance to this Standard. At a minimum, seals exposed to process contact fluids and/or that have a high probability of exposure will conform to the United States Pharmacopeia (USP) directive with regard to USP <87> (or ISO 10993-5) and USP <88> Class VI (or ISO 10993-6, -10, and -11) on biological

reactivity (see Part PM for additional details). Examples of seals coming in direct contact with a process stream include gaskets, O-rings, diaphragms, pinch tubes, and valve stem seals.

MC-3.4.2 Certificate of Conformance. See PM-2.2.1.

MC-3.4.3 Test Requirements. Conformance testing is done on initial qualification of the hygienic union. Testing is intended to show design conformance and is not required on every seal. Testing shall be repeated for significant changes in raw materials or processes used to fabricate seals. The seal manufacturer shall provide a certificate of design conformance that the sealed union meets the intrusion requirements of MC-4.2. The intrusion value is defined as the measured quantity that provides the maximum radial distance from the fitting I.D. to the point of maximum intrusion under the manufacturer's specified conditions (e.g., torque, fitting design, clamp design). The point of maximum intrusion/recess shall be measured using a method that does not cause deformation of the components being measured.

MC-3.5 Seal Identification

Marking on the seal package should include all items listed in MC-3.4.2.

Manufacturer's name and lot number shall be marked on either the seal itself or the seal package containing the seal. The lot number should enable the manufacturer to identify the raw material and processing conditions used to fabricate the article. Manufacturers are encouraged to mark the seal itself to avoid potential loss of traceability and to aid in positive identification of seals after removal from a process stream. When marking diaphragms, any marking shall be done on those portions of the diaphragm that are not exposed beyond the sealing portion of the housing.

MC-4 SEAL PERFORMANCE REQUIREMENTS

(24) MC-4.1 General Requirements

Seals form an integral part of process systems and maintain static and/or dynamic system boundaries while being exposed to chemical, thermal, and mechanical (hydraulic and pneumatic) conditions in both cyclic and continuous modes of operation. On exposure to operating conditions, the seal shall not swell, shed, crack, erode, or otherwise deteriorate to an extent that it impacts the product or process during its expected lifetime. The seal shall not add to nor remove from the process or product to which it is exposed beyond an acceptable level (see PM-3). Following exposure to the process conditions, the seal shall be capable of being inspected, serviced, and/or replaced. Specific seal performance criteria should be established by the owner/user. Form S-1, Application Data Sheet, may be used to communicate expected process conditions.

Any given seal is not designed to perform in all possible operating conditions.

Parameters for evaluating the performance of a seal include leak rate, sealing location, dimensional stability, material stability (including shedding), and serviceability. The requirements for each of the parameters depend on the seal type and application. To predict how a seal will perform in service it shall be evaluated (e.g., testing, past performance). Standardized performance test conditions and methods permit a consistent approach to gathering data used to evaluate seal performance. When evaluating performance test data, the owner/user should consider if the test parameters are relevant to the conditions expected in the application. Performance data should be considered when determining the appropriate service interval for the desired application.

See Nonmandatory Appendix AA for seal application material selection guidance.

MC-4.2 Static Seal Performance (24)

Static seals shall meet the general performance requirements of MC-4.1.

On initial installation in a metallic hygienic union or in a polymeric hygienic union, a hygienic static seal shall provide a substantially flush interface with the hygienic clamp ferrules. Hygienic seals shall meet and be designated by one of the following intrusion categories when tested by the seal manufacturers:

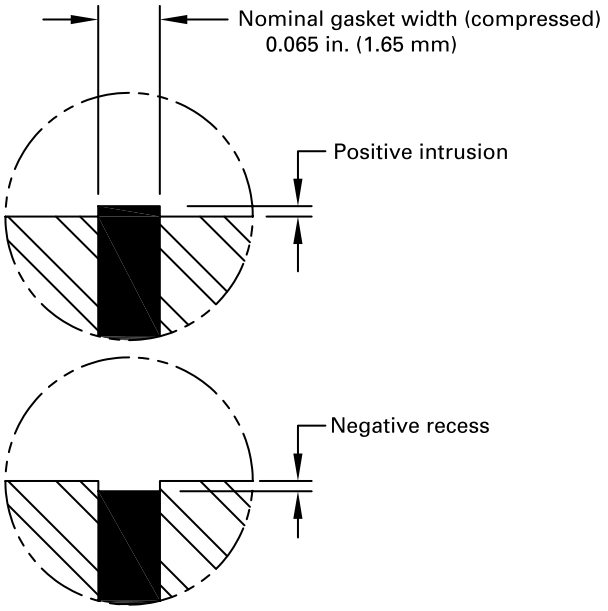
(a) Intrusion Category I. Seals having a maximum intrusion/recess of 0.025 in. (0.6 mm).

(b) Intrusion Category II. Seals having a maximum intrusion/recess of 0.008 in. (0.2 mm).

The purpose of a flush interface is to minimize the entrapment of material in a dead space that can lead to microbial growth and contamination (see Figure MC-4.2-1). Excessive intrusion into the process stream may lead to erosion of elastomeric seals, thereby contaminating the process stream. The amount of intrusion depends on the dimensional control of the seal, the hygienic clamp ferrule dimensions [see Table DT-7.1-1 or Table DT-7.1-2 and Figure MC-2.2.2-1, illustrations (a) through (c)], the amount of torque applied to the flange, the material properties of the seal, the application of steam, and the surface of the seal (wet or dry) during installation.

Testing parameters used to identify the desired performance should be based on the intended operating conditions. Nonmandatory Appendix K identifies standard process test conditions (SPTC) and a method for performing testing to gather data used to evaluate the appropriate level (e.g., 10, 100, or 500) of the seal for the given service life. Performance data are collected at 10-, 100-, and/or 500-cycle intervals. The 10-cycle interval is intended to provide data for short durations

Figure MC-4.2-1
Typical Hygienic Clamp Union: Allowable Gasket Intrusion



(e.g., single-use or inspect-between-use applications). The 100- and 500-cycle intervals are intended to provide data on the service life of the seals (e.g., multiple-use applications) that are not routinely inspected.

MC-4.3 Dynamic Seal Performance

MC-4.3.1 Valve Seal Performance. Valve seal performance is acceptable when the seal maintains the system boundaries and design flow characteristics for which it was intended (e.g., static and/or dynamic). A valve seal shall operate through the desired range of motion against differential pressure. It shall meet the requirements stated in MC-3.3.2.3. A valve seal shall meet these performance conditions following exposure to operating conditions in both cyclic and continuous modes of operation.

Performance data shall be collected at intervals that reflect the use mode (e.g., discrete/open/closed or modulating), operation (e.g., continuous or cyclic), and intended service life (e.g., continuous hours of exposure or number of cycles) of the valve seal.

Testing parameters shall be based on the operating conditions of the intended application. Nonmandatory Appendix K identifies standard process test conditions and a method for conducting performance tests of seals in simulated process conditions. For valve seal testing, the method identified in Nonmandatory Appendix K requires modification to reflect a specific use mode and intended operation of a valve seal. Form S-1, Application Data Sheet, identifies a number of operational conditions (e.g., chemistry, temperature, pressure) to consider when developing nonstandard performance tests.

MC-4.3.1.1 New Valve Seal Performance. The valve manufacturer shall test each valve assembly as part of the production process or shall validate the design and manufacturing process. One-hundred percent leak testing is not required for validated manufacturing processes.

When EN 12266-1 is specified below, use leakage rate A when evaluating seat leakage performance. For control valves, other leakage rates may be used with approval by the owner/user.

(a) For diaphragm valves, the following requirements shall apply:

(1) seat leakage rates per MSS-SP-88, EN 12266-1, or ANSI/FCI Standard 70-2, Class VI

(2) shell leakage rates per MSS-SP-88 category C or EN 12266-1

(b) For ball valves, the requirements of MSS-SP-72, MSS-SP-110, or EN 12266-1 shall apply.

(c) For rising stem, mix-proof, and needle valves, the requirements of EN 12266-1 shall apply. For seat tightness, Test P12 of EN 12266-1, use the globe valve test method.

(d) For butterfly valves, the requirements of MSS-SP-67 or EN 12266-1 shall apply.

(e) For pinch valves, the requirements of EN 12266-1 shall apply. For seat tightness, Test P12 of EN 12266-1, use the diaphragm valve test method.

(f) For plug valves, the requirements of EN 12266-1 shall apply.

MC-4.3.2 Mechanical Seal Performance. Mechanical seal performance may be characterized by leakage rate, service life, cleanability, particle shedding, suitability for application, and heat generation. Acceptable values for each of these characteristics may vary widely, so it is strongly advised that the mechanical seal's various characteristics and the ramifications of each to the service are understood.

Nonmandatory Appendix K, K-2.1 provides important information about mechanical seal performance. It provides exceptions to normal seal performance that are commonly found in the industry. Familiarity with these items will help the reader understand the impact that design, installation, and operation can have on mechanical seal performance. Also included in Nonmandatory Appendix K, K-2.1 are outlines for various methods of testing seal integrity.

MC-4.3.2.1 New Mechanical Seal Performance. There are four key points between procurement and operation of a new mechanical seal where the seal might be evaluated for performance. The four key points are manufacturing, installation, assembly, and use.

(a) Point of Manufacture. Mechanical seal manufacturers have performance requirements for new seals. The manufacturer's tests should be accepted. If special

performance requirements are necessary, those special requirements shall be specified.

If the mechanical seal manufacturer alters the design, material, or manufacturing technique of a mechanical seal in service, it is the responsibility of the mechanical seal manufacturer to inform all relevant parties that changes have occurred. Specific information may be requested from the seal manufacturer to support the premise that seal performance has not been altered.

(b) Point of Seal Installation. The mechanical seal will be installed in a piece of equipment. An original equipment manufacturer (OEM) will typically have its own test to verify the performance of the mechanical seal. The test of the OEM should be accepted. A review of the OEM test procedure may be requested. The OEM should consult with its seal supplier/manufacturer for seal performance issues and questions.

Contractors may install a new seal in a piece of equipment. The seal performance test may be reviewed with the installation contractor.

If unique conditions exist where special performance requirements are necessary, it is the customer's responsibility to specify the additional requirements. An acceptable performance test may be developed.

If the OEM alters the design, material, or manufacturing technique of a mechanical seal in service, or is informed by the seal manufacturer that the design, material, or manufacturing technique has been altered, it is the responsibility of the OEM to inform all relevant parties that changes have occurred.

(c) Point of Systems Assembly. The equipment that contains the seal is installed in a system. The system's supplier/manufacturer will have standard test procedures for testing the system integrity. The test procedures of the system's supplier/manufacturer should be accepted. A review of the test procedure may be requested. The system assembler should consult with the OEM/supplier for seal performance issues and questions.

If the system assembler alters the design, material, or manufacturing technique of a mechanical seal in service, or is informed by the OEM that the design, material, or manufacturing technique has been altered, it is the responsibility of the system assembler to inform all relevant parties that changes have occurred.

(d) Point of Use. It is the owner/user's responsibility to determine if the mechanical seals meet performance requirements.

MC-4.3.2.2 Installed Seals. Original point-of-use performance requirements shall be used to determine if the seal is suitable for continued use. Refurbished seals shall be held to the original point-of-use performance requirements. It is the owner/user's responsibility to monitor equipment for failure.

MC-5 HOSE ASSEMBLIES (24)

MC-5.1 General

Hose assemblies are defined here as a length of a flexible, polymeric element with at least one end connection securely affixed and capable of containing fluids under specified conditions (e.g., pressure and temperature).

MC-5.2 Hose Construction

MC-5.2.1 Flexible Elements. Elements may be constructed from a single, homogeneous material or multiple layers. Multilayer elements may consist of an inner contact layer surrounded by one or more additional reinforcement layers and an outer cover. Reinforcement layers may include fabric braiding, metal wire braiding, and various elastomeric materials. The liner design shall allow for drainability and cleanability as required by the end-user.

MC-5.2.2 Mechanically Affixed and Reusable End Connections. Metallic and nonmetallic end connections are attached to the flexible element by mechanical compression. The design shall ensure a seal is maintained at the end of the barb [see Figure SD-3.2.1-1, illustration (d)]. Band-style hose clamps are not recommended [see Figure SD-3.2.1-1, illustration (c)]. The fitting should be designed to minimize entrapment of liquid in the hose assembly. Dimensions and tolerances of the process connection shall be consistent with Table DT-7.1-1 or Table DT-7.1-2.

MC-5.2.3 Flare-Through End Connections. Flare-through end connections are connections in which the inner contact layer of the flexible element extends through the fitting and is formed into the end connector. Flare-through end connections may have integral gaskets or provisions for standard gaskets.

MC-5.2.4 Molded-in-Place End Connections. Molded-in-place end connections are secured to the flexible element by a thermal or chemical bond. Molded-in-place end connections using nonrigid materials may require additional stiffening reinforcement to achieve an adequate process connection seal. Molded-in-place end connections may include an integral gasket.

MC-5.2.5 Hose Materials. Hose assembly materials shall conform to applicable sections of SD-2.4.1.2 and PM-2.1.

(a) Biocompatibility. The biocompatibility and proper material selection shall be the responsibility of the end-user. Biocompatibility testing of candidate hose assemblies for qualification requires USP <87> (or ISO 10993-5) and USP <88> Class VI (or ISO 10993-6, -10, and -11) tests on all polymeric process contact materials. End-users may request similar testing on noncontact layers that may come in contact with the process fluid

if the inner liner fails. Hose assembly suppliers shall provide, on customer request, documentation of the biocompatibility testing on final manufactured hose assembly materials. Failure of either test indicates unacceptable biocompatibility of the candidate hose assembly.

(b) Surface Finish. Surface finish of metallic end fittings shall conform to the requirements of Part SF.

(c) Particle Generation. Hose assembly designs should minimize wear that generates particles that could enter the process.

(d) Extractables. Hose assembly materials shall conform to the requirements of PM-3.2.

MC-5.3 Hose Assembly Performance

The equipment supplier should be informed of all the conditions under which the hose assembly may be expected to operate. This should include the methods, frequency, and length of cleaning and sterilization procedures. In addition to the service temperature and pressure, any parameters that may affect the hose assembly performance should be provided. The equipment supplier should inform the end-user of the life cycle expectancy and the methods that will ensure that the hose assembly operates within its design specification (e.g., routine maintenance).

MC-5.3.1 Service Temperatures and Pressures. Hose assemblies shall be capable of withstanding thermal and pressure cycling between the rated upper and lower temperature and pressure limits.

MC-5.3.2 Nonroutine Events. The complete procedure for nonroutine events such as passivation, derouging, and postconstruction cleaning should be supplied by the end-user. The supplier should inform the end-user whether the hose assembly will perform as specified during these events. The end-user should perform a risk assessment to determine if a new hose assembly is required after nonroutine events.

MC-5.3.3 Cleaning Systems

(a) Clean-in-Place (CIP). Hose assemblies shall be designed in accordance with SD-3.1. The hose assembly shall be installed to enable drainability (see SD-3.2).

(b) Clean-out-of-Place (COP). External surfaces of hose assemblies subject to COP shall be compatible with cleaning agents and be nonabsorbent. Hose assemblies shall be designed to allow effective removal of cleaning agents from external surfaces.

MC-5.3.4 Sterilizing Systems. Hose assembly requirements shall be based on the sterilization method used. All process contact surfaces should be designed to minimize crevices. When crevices cannot be avoided, sterilization testing shall be performed to validate sterility within the system boundaries. All hose assemblies and hose assembly process contact surfaces shall be designed to accommodate expansion and contraction during sterilization and cooldown stages.

MC-5.4 Hose Assembly Installation

Hose assemblies shall be installed per SD-3.2 and used in accordance with the supplier's guidelines (e.g., bend radius). Change in hose assembly length due to pressure and temperature cycling and the potential effect on drainability should be considered by the end-user.

MC-5.5 Conformance Requirements for Hose Assemblies

MC-5.5.1 Certificate of Conformance. A Certificate of Conformance shall be issued by the hose assembly supplier containing the following information:

(a) manufacturer's name
(b) part number
(c) unique identifier of the hose assembly
(d) material of construction of process contact items
(e) compliance to USP <87> (or ISO 10993-5) and USP <88> Class VI (or ISO 10993-6, -10, and -11)
(f) packaging and storage recommendations (this may be in another document)

The supplier's name and unique identifier shall be marked on either the hose assembly itself or the package containing the hose assembly. The unique identifier shall enable the supplier to identify the raw material and processing conditions used to fabricate the article. Suppliers shall mark the hose assembly itself to avoid potential loss of traceability and to aid in positive identification of hose assemblies.

MC-5.5.2 Test Requirements. Conformance testing is done on initial qualification of the hose assembly. Testing is intended to show design conformance and is not required on every hose assembly. Testing shall be repeated for significant changes in raw materials or processes used to fabricate hose assemblies.

CHAPTER 6
FABRICATION, ASSEMBLY, AND ERECTION FOR MULTIUSE

PART MJ
MATERIALS JOINING FOR MULTIUSE

MJ-1 PURPOSE AND SCOPE

The purpose of this Part is to provide requirements for the joining of metallic and polymeric materials. This includes joining methods, welding procedure and performance qualifications, examination, inspection, testing, and acceptance criteria.

MJ-2 MATERIALS

MJ-2.1 Base Metals

MJ-2.1.1 Stainless Steels

(a) Austenitic Stainless Steels. Only the austenitic stainless steel grades listed in Table MM-2.1-1 or Table MM-2.1-3 may be used for welded components, except as permitted in MM-5.2.1.1(a).

Weld ends that are to be autogenously welded (without filler metal or consumable inserts) shall meet the requirements of MM-5.2.1.1(a).

However, a process component or tube of one of the above alloys with a sulfur content either below the lower limit or above the upper limit for sulfur in MM-5.2.1.1 may be used in a welded connection, provided all of the following conditions are met:

(1) Use of the process component or tube is agreed to by the owner/user.

(2) All welds on the component or tube are internally inspected and meet the requirements of MJ-8.4.

(b) Superaustenitic Stainless Steels. Only the superaustenitic stainless steel grades listed in Table MM-2.1-1 or Table MM-2.1-3 may be used for welded components, except as permitted in MM-5.1.

The superaustenitic stainless steels are prone to the precipitation of undesirable secondary intermetallic phases such as sigma and chi. The cautions of MM-5.2.1.2 shall be considered when welding superaustenitic stainless steels.

(c) Duplex Stainless Steels. Only the duplex stainless steel grades listed in Table MM-2.1-1 or Table MM-2.1-3 may be used for welded components, except as permitted in MM-5.1. The cautions of MM-5.2.1.3 shall be considered when welding duplex stainless steels.

MJ-2.1.2 Nickel Alloys. Only the nickel alloys listed in Table MM-2.1-2 or Table MM-2.1-3 may be used for welded components, except as permitted in MM-5.1.

MJ-2.1.3 Copper Alloys. Only the copper alloys listed in Table MM-2.1-4 may be used for brazed systems.

MJ-2.1.4 Other Metals. Other metals (e.g., titanium, tantalum, palladium, or gold, as used in instrumentation) may be joined, when specified by the owner/user.

MJ-2.2 Filler Metals

MJ-2.2.1 Stainless Steels. When filler metals are used, the matching filler metals listed in Tables MM-5.3-1, MM-5.3-2, MM-5.3-3, and MM-5.3-5 shall be used, except that higher alloy filler metals may be used when specified by the owner/user.

Austenitic stainless steel grades may be welded with or without filler metals. See MM-5.3 and MM-5.3.1 for further instructions.

Superaustenitic stainless steels may be welded with or without filler metals or consumable inserts. When welded autogenously (without filler metal or consumable inserts), postweld heat treatment in accordance with MM-5.4 is required. See MM-5.2.1.2, MM-5.3, and MM-5.3.2 for further instructions.

Duplex stainless steels may be welded with or without filler metals or consumable inserts. When welded autogenously, postweld heat treatment in accordance with MM-5.4 is required. Welding of duplex stainless steels generally results in an increase in the amount of ferrite in the microstructure, and, as a result, appropriate welding procedures should be selected. The balance of austenite and ferrite in the weld metal shall be maintained so that there is no less than 30% of the lesser phase. See

MM-5.2.1.3, MM-5.3, and MM-5.3.2 for further instructions.

MJ-2.2.2 Nickel Alloys. When filler metals are used, the matching filler metals listed in Table MM-5.3-4 shall be used, except that higher alloy filler metals may be used when specified by the owner/user.

Nickel alloys may be welded with or without filler metals. Postweld solution heat treatment is not required. See MM-5.3 for further instructions.

MJ-2.2.3 Copper Alloys. Brazing joint filler metals shall conform to Table MM-5.3.4-1. Copper-to-copper joints shall be brazed using copper-phosphorus or copper-phosphorus-silver brazing filler metal (BCuP series) without flux.

MJ-2.3 Nonmetallics

Joining of polymeric materials shall be performed in accordance with MJ-9. Joining of other nonmetallic materials shall be in accordance with procedures and processes recommended by the material manufacturer, and approved by the owner/user, using materials or compounds that are inert to the intended service.

MJ-3 JOINT DESIGN AND PREPARATION

MJ-3.1 General (24)

All joints shall have complete fusion on process contact surfaces. All weld joints shall have the process contact surfaces properly purged or protected for the prevention of discoloration or contamination. External attachments (e.g., lift lugs, dimple jackets, or ladder clips) shall have any discoloration of the process contact surface removed.

Welds attaching any connection that passes through the wall of a tank or vessel, or a branch connection on a pipe or tube system, in which one or both sides of the weld joint is a process contact surface, shall either be joined with a full penetration groove weld with a reinforcing fillet weld [similar to Figure SD-3.4.2-2, illustration (a)], or have at least one vent hole provided if double fillet welded only [similar to Figure SD-3.4.2-2, illustration (b)]. A vent hole is required on all lap, tee, corner, or edge (parallel) joints that have one weld as a process contact surface and are not attached by full penetration welds. The vent hole shall provide a path for process fluid or test media flow if the inner weld containment fails. Vent holes are not required when all welds are on process contact surfaces [e.g., Figure SD-3.4.3-2, illustration (c) detail or similar]. The vent hole shall be no larger than NPS ¼ in. (6 mm) and may be tapped for a preliminary compressed air and soapsuds test for tightness of inside welds. These vent holes may be plugged when the vessel is in service. The plugging material used shall not be capable of sustaining pressure between the lapped surfaces.

When vent holes are installed in a component with a published rating, e.g., ASME B16.5 slip-on flanges (see Figure MJ-3.1-1), the published pressure rating may no longer be valid. The pressure rating of the component shall be evaluated considering the addition of the vent hole. The marking on the component shall be changed to reflect that it is no longer in conformance with the original standard.

Socket welding is not permitted in process stream systems or where CIP or SIP requirements are defined.

MJ-3.2 Pressure Vessels and Tanks

Intermittent welds shall not be used on process contact surfaces on vessels and tanks. Head and shell welds leaving an unwelded process contact joint shall not be used.

See Figures MJ-3.2-1 and MJ-3.2-2 for examples of unacceptable and acceptable head-to-shell weld joints.

MJ-3.2.1 Pressure Vessels. Weld joint designs shall be those permitted by ASME BPVC, Section VIII and shall conform to MJ-3.1.

MJ-3.2.2 Tanks. Weld joint designs shall be those permitted by the code or standard of construction for the tank and shall conform to MJ-3.1.

MJ-3.3 Piping

Weld joint designs shall be those permitted by ASME B31.3 and shall conform to MJ-3.1.

MJ-3.4 Tubing and Fittings (24)

Weld joint designs for hygienic tubing and fittings shall be square butt joints. The tubing and fittings shall have ends prepared by machining or facing to provide a square end that meets the requirements of Table DT-3-1, Table DT-3-2, or Table DT-7.2-1. The butt weld joints shall be properly cleaned within ½ in. (13 mm) of the joint area on the inside and outside surfaces prior to welding. Welding on tubing shall be done using automatic (or machine) welding techniques (such as orbital tube welding or lathe welding), except where size or space will not permit. In that case, manual welding can be performed, but it shall be agreed to by the owner/user and contractor.

MJ-3.5 Tube-Attachment Welds

(a) Tube-attachment welds are those that

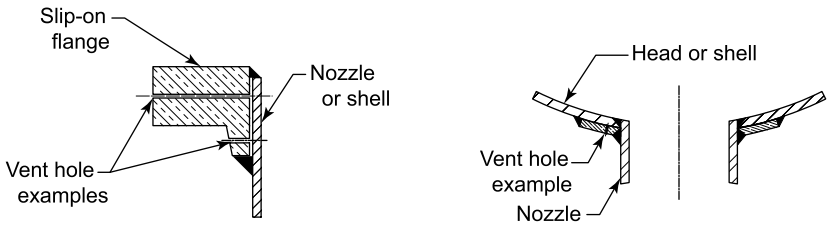
(1) make branch connections other than those used to fabricate the fittings described in Part DT

(2) attach tubes to other product forms

(3) attach nozzles to transfer panels

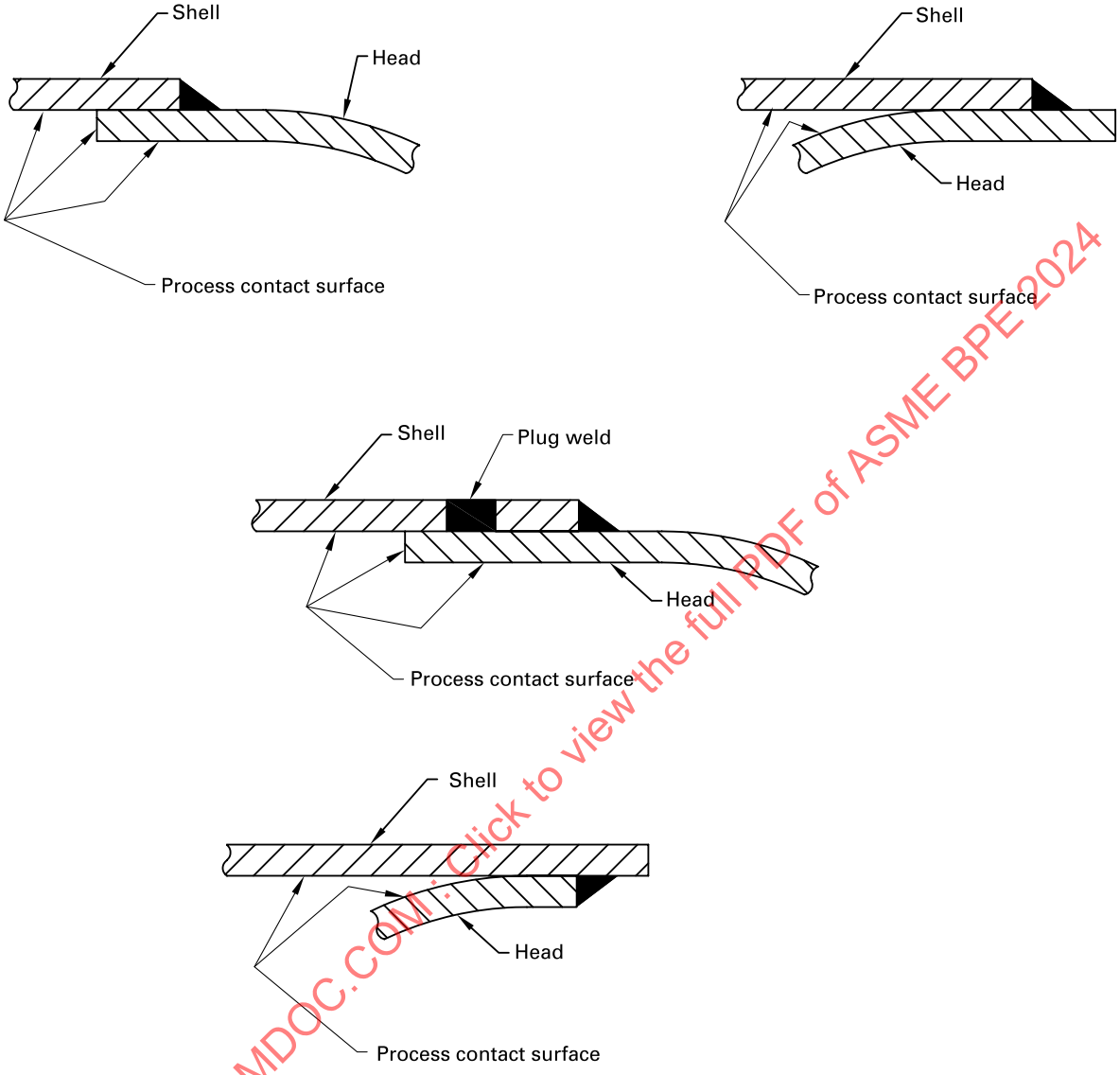
(4) attach a tube to any part of a hygienic system

Figure MJ-3.1-1
Vent Hole Examples



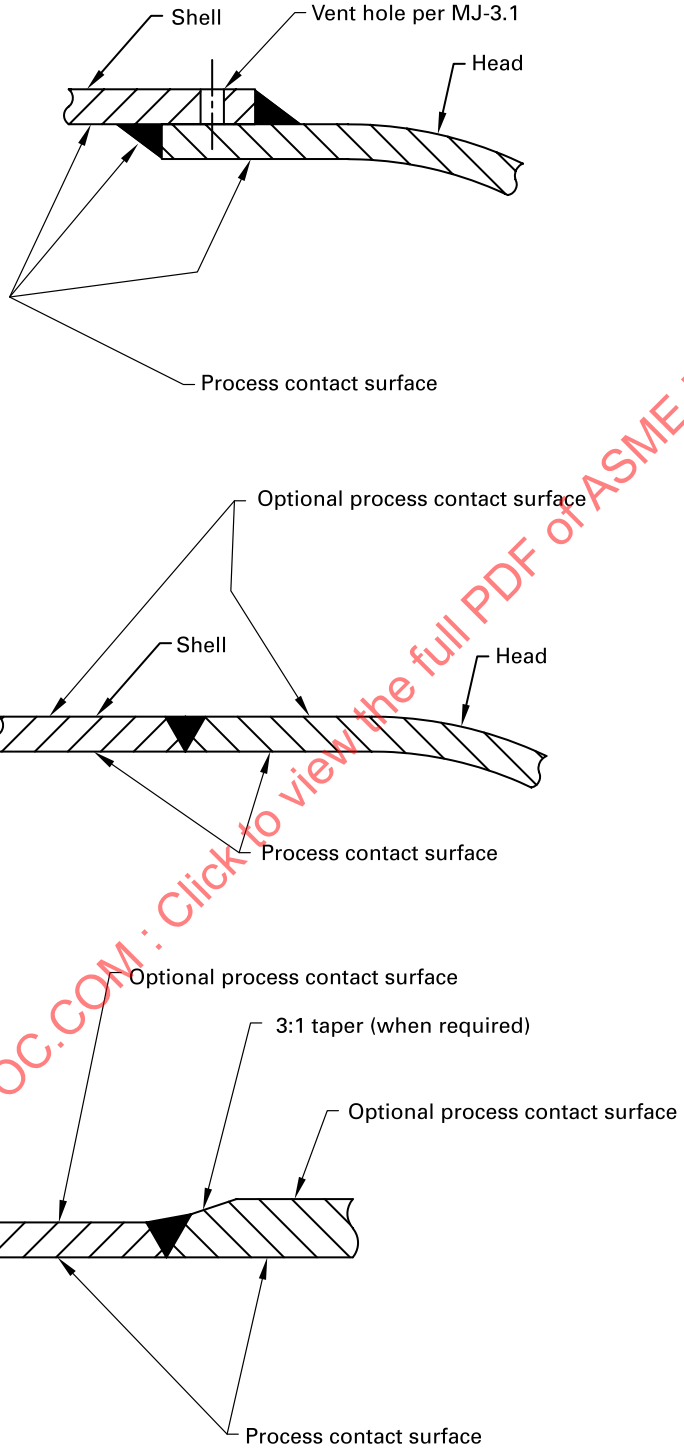
(24)

Figure MJ-3.2-1
Unacceptable Pressure Vessel and Tank Head-to-Shell Joint Configurations



GENERAL NOTE: This figure does not provide design criteria for weld joints. It only depicts examples of unacceptable weld configurations.

Figure MJ-3.2-2
Acceptable Pressure Vessel and Tank Head-to-Shell Joint Configurations



GENERAL NOTES:
(a) This figure does not provide design criteria for weld joints. It only depicts examples of acceptable weld configurations.
(b) The joint is only acceptable if it conforms to the design criteria of the governing code or standard.

(b) Tube-attachment welds not governed by this section include

(1) those governed by MJ-8.4

(2) tube-to-tubesheet welds that are governed by ASME BPVC, Section VIII, in addition to the visual examination requirements of Part SF and MJ-8.2

These welds may be performed manually, by machine, or by an automatic welding process. Joint designs shall conform to MJ-3.1. The weld joints for complete penetration welds shall be prepared by means compatible with hygienic service. The weld joints shall be properly cleaned within $\frac{1}{2}$ in. (13 mm) on the inside and outside surfaces, where accessible, prior to welding. Fillet welds, groove welds, or a combination of both may be used.

MJ-3.6 Brazed Joints

Joint design shall conform to the latest edition of NFPA 99.

MJ-4 JOINING PROCESSES AND PROCEDURES

MJ-4.1 Introduction

All welds, including tack welds, shall be made in accordance with a welding procedure qualified in accordance with MJ-5. All welders and welding operators, including those who make tack welds, shall be qualified per MJ-6.

MJ-4.2 Welds Finished After Welding

For pressure vessels, tanks, and piping and tubing systems where the process contact surface of the weld is to be finished after welding, the welding processes used shall be limited to the arc or high-energy beam (electron beam and laser beam) processes as defined in AWS A3.0. The owner/user and contractor shall agree that the welding process selected will provide the desired results.

MJ-4.3 Welds Used in the As-Welded Condition

For pressure vessels, tanks, and piping and tubing systems where the process contact surface of the weld is to be used as is, welding processes shall be limited to the inert-gas arc processes (such as gas tungsten-arc welding and plasma arc welding) or the high energy beam processes (such as electron beam or laser beam welding), as defined in AWS A3.0. Every effort shall be made to use an automatic or machine welding process. Autogenous welds, welds with filler wire, or welds with consumable inserts are acceptable provided they meet the requirements for all applicable codes. The owner/user and contractor shall agree that the welding process selected will provide the desired results.

MJ-4.4 Brazing

Joining of copper and copper alloy materials by brazing shall be in accordance with NFPA 99. All brazing procedures shall be qualified per MJ-5. All brazers shall be qualified per MJ-6.

MJ-5 PROCEDURE QUALIFICATIONS

MJ-5.1 Pressure Vessels and Tanks

Welding procedures for pressure vessels and tanks shall be qualified in accordance with ASME BPVC, Section VIII.

MJ-5.2 Piping

Welding procedures for piping systems shall be qualified in accordance with ASME B31.3.

MJ-5.3 Tubing

Welding procedures for hygienic tubing systems shall be qualified in accordance with ASME B31.3, with the following additions:

(a) A change in the type or nominal composition of the backing (purge) gas shall require requalification.

(b) If filler metal is used, a change from one AWS classification of filler metal to another, or to a proprietary filler metal, shall require requalification.

This includes qualification of procedures for welding of components to Part DT but does not apply to longitudinal welds on tubes made in accordance with a recognized standard.

MJ-5.4 Duplex Stainless Steels (24)

In addition to the welding procedure specification test requirements of ASME BPVC, Section IX, the weld metal and heat-affected zones from qualification test coupons of duplex stainless steels shall meet the applicable requirements of either ASTM A923 or ASTM A1084.

MJ-5.5 Brazing

Brazing procedures for piping systems shall be qualified in accordance with NFPA 99.

MJ-6 PERFORMANCE QUALIFICATIONS

MJ-6.1 Pressure Vessels and Tanks

Welder and welding operator performance qualifications for pressure vessels and tanks shall be in accordance with ASME BPVC, Section VIII.

MJ-6.2 Piping

Welder and welding operator performance qualifications for piping systems shall be in accordance with ASME B31.3. When the piping is to be used for hygienic

systems, the essential variables for welding operators in MJ-6.3 shall also apply.

MJ-6.3 Tubing

Welder and welding operator performance qualifications for hygienic tubing systems shall be in accordance with ASME B31.3. This includes qualification of welders and welding operators who fabricate components in accordance with Part DT but not those who manufacture tubes in accordance with a recognized standard.

For the qualification of welding operators, the following essential variables also apply:

(a) welding of a joint using an edge preparation other than a square groove.

(b) the addition or deletion of solid backing.

(c) a change in the fit-up gap from that qualified.

(d) a change in pipe/tube diameter. See Table MJ-6.3-1.

(e) the addition or deletion of filler metal.

(f) the addition or deletion of consumable inserts.

(g) a change in the thickness of the deposited weld metal. See Table MJ-6.3-2.

(h) the addition or deletion of backing gas (purge gas).

(i) a change in the current type or polarity.

(j) a change in the weld head type from open head to closed head or vice versa.

(k) a change from single-pass to multipass welding or vice versa, when using filler wire.

In addition, either the original ASME BPVC, Section IX qualification coupon or another tube-to-tube weld coupon made by that same welding operator shall be visually examined and shall meet all the requirements of Table MJ-8.4-1.

Any change in the variables listed in (a) through (k) requires welding of a new test coupon, for which only visual examination in accordance with Table MJ-8.4-1 is required. Conformance to the variables in this paragraph shall be documented.

MJ-6.4 Brazing

Brazer performance qualifications, for piping systems, shall be in accordance with NFPA 99 and shall be made under an internal purge and exhibit full joint penetration.

MJ-7 EXAMINATION, INSPECTION, AND TESTING

Owner/user, inspection contractor, and/or engineer shall agree to the types of examinations, inspections, and testing unless otherwise specified in the applicable code.

MJ-7.1 Examination Procedures

MJ-7.1.1 Pressure Vessels and Tanks. Examination procedures for pressure vessels and tanks shall be in accordance with ASME BPVC, Section VIII.

Table MJ-6.3-1
Metallic Tube/Pipe Diameter Limits for Orbital GTAW Performance Qualification

Outside Diameter of Test Coupon		Outside Diameter Qualified			
		Minimum		Maximum	
in.	mm	in.	mm	in.	mm
≤1/2	≤13	None	None	1/2	13
>1/2 to 3 1/2	>13 to 89	>1/2	>13	3 1/2	89
>3 1/2	>89	>3 1/2	>89	Unlimited	Unlimited

Table MJ-6.3-2
Metallic Weld Thickness Limits for Orbital GTAW Performance Qualification

Thickness of Test Coupon, T_w		Deposited Weld Thickness Qualified		
		Minimum		
in.	mm	in.	mm	Maximum
<1/16	<1.5	T_w	T_w	$2T_w$
1/16 ≤ t ≤ 3/8	1.5 ≤ t ≤ 10	1/16	1.5	$2T_w$
>3/8	>10	3/16	5	Unlimited

MJ-7.1.2 Piping. Examination procedures for piping systems shall be in accordance with ASME B31.3.

MJ-7.1.3 Tubing. Examination procedures for tubing systems shall be in accordance with ASME B31.3.

MJ-7.1.4 Tube Attachments. Examination procedures for tubing systems shall be performed in accordance with ASME B31.3.

MJ-7.1.5 Brazing. Examination procedures for brazed systems shall be in accordance with NFPA 99.

MJ-7.2 Personnel Requirements

MJ-7.2.1 Pressure Vessels and Tanks. Personnel performing examinations of pressure vessels and tanks designed to ASME BPVC, Section VIII shall meet the requirements of the appropriate section of that Code.

All inspectors shall be qualified in accordance with GR-4.1.

All Quality Inspector's Delegates shall meet the requirements of GR-4.2.

MJ-7.2.2 Piping. All examiners, inspectors, and Quality Inspector's Delegates shall be qualified in accordance with GR-4.

MJ-7.2.3 Tubing. All examiners, inspectors, and Quality Inspector's Delegates shall be qualified in accordance with GR-4.

MJ-7.2.4 Tube Attachments. All examiners, inspectors, and Quality Inspector's Delegates shall be qualified in accordance with GR-4.

MJ-7.2.5 Copper Tubing/Piping. All examiners, inspectors, and Quality Inspector's Delegates shall be qualified in accordance with GR-4.

MJ-7.2.6 Examination Personnel Eye Examination Requirements. Personnel performing examinations shall have eye examinations as described in GR-4.2.3(d).

MJ-7.3 Examination, Inspection, and Testing Requirements

MJ-7.3.1 Pressure Vessels and Tanks

(a) Examination. Examinations shall be performed in accordance with the provisions of ASME BPVC, Section VIII. In addition, all welds having a process contact surface shall be visually examined by the fabricator.

(b) Inspection. In addition to the inspection required by ASME BPVC, Section VIII, the owner/user or inspection contractor shall perform inspection(s) necessary to ensure conformance to this Standard as well as any additional requirements of the owner/user's specification.

(c) Testing. In addition to the testing required by ASME BPVC, Section VIII, the owner/user or inspection contractor shall perform testing necessary to ensure conformance to this Standard as well as any additional requirements of the owner/user's specification.

MJ-7.3.2 Piping

(a) Examination. Examinations shall be performed in accordance with the provisions of the specified fluid service in ASME B31.3.

(b) Inspection. The owner/user, inspection contractor, and/or engineer shall agree to the minimum percentage of process contact welds to be selected for borescopic or direct visual inspection, and they shall inform the installation contractor. The inspection contractor shall submit an inspection plan to ensure that welds meet the acceptance criteria of this Part. This plan shall include borescopic or direct visual inspection of the process contact surfaces on at least 20% of the welds in each system installed. A representative sample of each welder's and/or welding operator's work (as applicable) shall be included.

The examination required for conformance to ASME B31.3 may be included in the minimum inspection percentage, provided those examinations were direct visual or borescopic and of the process contact surface.

(c) Testing. Leak testing of piping systems shall be performed in accordance with the specified fluid service requirements in ASME B31.3.

MJ-7.3.3 Tubing

(a) Examination. Examinations shall be performed in accordance with the provisions of the specified fluid service in ASME B31.3. The external surfaces of all welds shall be visually examined.

If ASME B31.3, High Purity Fluid Service (Chapter X), is specified, radiographic, ultrasonic, or in-process examination is not required unless specified by the owner/user.

(b) Inspection. The owner/user, inspection contractor, and/or engineer shall agree to the minimum percentage of process contact welds to be selected for borescopic or direct visual inspection, and they shall inform the installation contractor. The inspection contractor shall submit an inspection plan to ensure that welds meet the acceptance criteria of this Part. This plan shall include borescopic or direct visual inspection of the process contact surfaces on at least 20% of the welds in each system installed. A representative sample of each welder's and/or welding operator's (as applicable) work shall be included. There shall also be a plan for inspecting a representative sample of each welder's and/or welding operator's (as applicable) first shift of production. A procedure shall be submitted for inspecting blind welds. The random selection of accessible welds to be inspected shall be up to the owner/user's inspector's discretion.

The examination required for conformance to ASME B31.3 may be included in the minimum inspection percentage, provided those examinations were direct visual or borescopic and of the process contact surface.

(c) Testing. Leak testing of tubing systems shall be performed in accordance with the specified fluid service requirements in ASME B31.3.

MJ-7.3.4 Tube Attachments

(a) Examination. Examinations shall be performed in accordance with the provisions of the specified fluid service in ASME B31.3. The external surfaces of all welds shall be visually examined.

(b) Inspection. Visual inspection shall be performed on all process contact surfaces affected by the attachment welding.

(c) Testing. Testing shall be performed in conjunction with the system test.

MJ-7.3.5 Brazing

(a) Examination. Examinations shall be performed in accordance with NFPA 99.

(b) Inspection. The owner/user, inspection contractor, and/or engineer shall agree to the minimum percentage of brazed joints to be selected for direct visual inspection, and they shall inform the installation contractor. The inspection contractor shall submit an inspection plan to ensure that joints meet the acceptance criteria of this Part. A representative sample of each brazer's work shall be included.

(c) Testing. Leak testing of copper systems shall be performed in accordance with the specified fluid service requirements in ASME B31.3.

MJ-7.4 Records

See GR-5.

MJ-8 ACCEPTANCE CRITERIA

MJ-8.1 General

Welding for a sterile environment requires that the weld shall not result in a surface that will contribute to microbiological growth and contamination of the process fluid. The weld shall not have any discontinuities such as cracks, voids, porosity, or joint misalignment that will promote contamination of the process fluid. All welding procedures shall be qualified to MJ-5.

MJ-8.2 Pressure Vessel and Tank Welds

Weld acceptance criteria for pressure vessels and tanks shall be in accordance with ASME BPVC, Section VIII, with the additional requirements of Table MJ-8.2-1.

MJ-8.3 Piping Welds

Weld acceptance criteria for piping shall be in accordance with the specified fluid service of ASME B31.3. See SD-3.1.1 for cautionary information if using pipe instead of tube for hygienic systems.

Welding of metallic pipe and piping components typically will produce weld beads or heat-affected zones with greater levels of discoloration compared with welds made on tube and tubing components. The additional requirements of Table MJ-8.3-1 shall apply.

MJ-8.4 Tubing Welds

Weld acceptance criteria (including borescopic acceptance criteria) for tubing and components shall be in accordance with Table MJ-8.4-1 (see also Figures MJ-8.4-1 through MJ-8.4-4). This includes welds on components but not longitudinal welds on tubes manufactured in accordance with a recognized standard. Welds performed in the fabrication of extruded branch outlets (such as tees) and reducers are exempt from the misalignment criteria.

Preproduction sample welds, when required, shall be submitted by the contractor to the owner/user to establish weld quality. The owner/user, contractor, and inspection contractor shall agree to the number and type of sample welds.

During construction, sample welds shall be made on a regular basis to verify that the equipment is operating properly and that the purging setup is adequate to prevent discoloration beyond the level agreed on by the owner/user and contractor. The owner/user and contractor shall agree to the frequency of sample welds. It is strongly recommended that these sample welds be made at the beginning of each work shift, whenever the purge source bottle is changed, and when the automatic or machine welding equipment is changed (such as when the orbital tube weld head is changed).

The sample welds described in the preceding paragraphs, and any associated welding machine printed records (e.g., welding parameter printouts directly from the welding machine or downloaded from a welding machine), if any, may be disposed of after written acceptance of the coupons by the owner, the owner's representative, or the inspector.

MJ-8.4.1 Sample Welds. Sample welds for tubing shall meet all the acceptance criteria of Table MJ-8.4-1. An internal bead width of 1.0 to 2.5 times the nominal wall thickness is required.

MJ-8.4.2 Rewelding. Rewelding (reflow) may be attempted one time only for the following defects:

(a) incomplete penetration (lack of penetration)

(b) incomplete fusion (lack of fusion)

(c) unconsumed tack welds that can be inspected on the process contact side

(d) convexity and concavity

All rewelds shall either totally consume the original weld or overlap the original weld with no base metal between the welds.

MJ-8.5 Tube-Attachment Welds

The acceptance criteria for tube-attachment welds shall be in accordance with Table MJ-8.5-1 (see also Figure MJ-8.5-1).

MJ-8.5.1 Sample Welds. Sample welds are not required for tube-attachment welds or seal welds.

MJ-8.5.2 Rewelding. Rewelding is allowed, except for welds that are process contact surfaces, for which the rewelding restrictions of MJ-8.4.2 apply.

MJ-8.6 Brazed Joints

Brazed joint acceptance criteria shall be in accordance with NFPA 99.

MJ-9 JOINING OF POLYMERIC MATERIALS

MJ-9.1 General

Polymeric materials are described in Part PM. All joining techniques may not be available for all polymeric materials, nor are all methods acceptable for all processes. The selection of materials of construction and joining techniques is based on application requirements.

Table MJ-8.2-1
Visual Examination Acceptance Criteria for Welds on Metallic Pressure Vessels and Tanks

Discontinuities	Welds on Process Contact Surfaces			Welds on Non–Process Contact Surfaces	
	Welds Left in the As-Welded Condition	Prior to Postweld Finishing	After Postweld Finishing	Welds Left in the As-Welded Condition	After Postweld Finishing
Cracks	None	None	None	None	None
Lack of fusion	None	None	None	None	None
Incomplete penetration	None on process contact side; otherwise, see Note (1)	None on process contact side; otherwise, see Note (1)	None on process contact side; otherwise, see Note (1)	[Notes (1) and (2)]	[Notes (1) and (2)]
Porosity	None open to the surface; otherwise, see Note (1)	[Note (1)]	Table SF-2.2-1 for acceptance criteria for pits/porosity	None open to the surface; otherwise, see Note (1)	None open to the surface; otherwise, see Note (1)
Inclusions [metallic (e.g., tungsten) or nonmetallic]	None open to the surface; otherwise, see Note (1)	[Note (1)]	None open to the surface; otherwise, see Note (1)	None open to the surface; otherwise, see Note (1)	None open to the surface; otherwise, see Note (1)
Undercut	None	[Note (1)]	None	[Note (1)]	[Note (1)]
Groove weld concavity	[Note (1)]	[Note (1)]	Maximum of 10% of the nominal wall thickness of thinner member	[Note (1)]	[Note (1)]
Fillet weld convexity	$1/16$ in. (1.5 mm) max.	Per applicable design and fabrication code	$1/32$ in. (0.8 mm) max.	[Note (1)]	[Note (1)]
Discoloration (heat-affected zone and weld bead)	Discoloration of light straw to light blue color is permitted (see Figures MJ-8.4-2 and MJ-8.4-3). Acceptable discoloration levels beyond that shall be established between the owner/user and contractor. Any discoloration present must be tightly adhering to the surface such that normal operations will not remove it. In any case, the discoloration shall have no evidence of rust, free iron, or sugaring [Note (3)].	N/A	Discoloration of light straw to light blue color is permitted (see Figures MJ-8.4-2 and MJ-8.4-3). Acceptable discoloration levels beyond that shall be established between the owner/user and contractor. Any discoloration present must be tightly adhering to the surface such that normal operations will not remove it. In any case, the discoloration shall have no evidence of rust, free iron, or sugaring [Note (3)].	Per customer specification	Per customer specification
Oxide island	Oxide islands are permitted as long as they are adherent to the surface. Reflective color of oxide island is not cause for rejection. Alloy types are identified in Tables MM-2.1-1 through MM-2.1-3.	N/A	None allowed	Oxide islands permitted	Oxide islands permitted
Reinforcement	[Note (1)]	[Note (1)]	$1/32$ in. (0.8 mm) max.	[Note (1)]	[Note (1)]
Tack welds	[Note (1)]	N/A	N/A	[Note (1)]	N/A
Arc strikes	None	N/A	None	None	None

Table MJ-8.2-1
Visual Examination Acceptance Criteria for Welds on Metallic Pressure Vessels and Tanks (Cont'd)

Discontinuities	Welds on Process Contact Surfaces			Welds on Non–Process Contact Surfaces	
	Welds Left in the As-Welded Condition	Prior to Postweld Finishing	After Postweld Finishing	Welds Left in the As-Welded Condition	After Postweld Finishing
Overlap	None	None	None	None	None
Weld bead width	N/A	N/A	N/A	N/A	N/A
Minimum fillet weld size	[Note (1)]	[Note (1)]	[Note (1)]	[Note (1)]	[Note (1)]
Misalignment (mismatch)	[Note (1)]	[Note (1)]	[Note (1)]	[Note (1)]	[Note (1)]

NOTES:
(1) The limits of ASME BPVC, Section VIII shall apply.
(2) Does not apply to insulation sheathing and similar welds.
(3) Welds on pressure vessels or tanks that have been in service may require unique criteria.

Table MJ-8.3-1
Visual Examination Acceptance Criteria for Welds on Metallic Pipe

Discontinuities	Welds on Process Contact Surfaces			Welds on Non–Process Contact Surfaces	
	Welds Left in the As-Welded Condition	Prior to Postweld Finishing	After Postweld Finishing	Welds Left in the As-Welded Condition	After Postweld Finishing
Cracks	None	None	None	None	None
Lack of fusion	None	None	None	None	None
Incomplete penetration	None	None on process contact side; otherwise, see Note (1)	None on process contact side; otherwise, see Note (1)	[Notes (1) and (2)]	[Notes (1) and (2)]
Porosity	None open to the surface; otherwise, see Note (1)	[Note (1)]	See Table SF-2.2-1 for acceptance criteria for pits/porosity	None open to the surface; otherwise, see Note (1)	None open to the surface; otherwise, see Note (1)
Inclusions [metallic (e.g., tungsten) or nonmetallic]	None open to the surface; otherwise, see Note (1)	[Note (1)]	None open to the surface; otherwise, see Note (1)	None open to the surface; otherwise, see Note (1)	None open to the surface; otherwise, see Note (1)
Undercut	None	[Note (1)]	None	[Note (1)]	[Note (1)]
Concavity	[Note (1)]	[Note (1)]	[Note (1)]	[Note (1)]	[Note (1)]
Fillet weld convexity	$1/16$ in. (1.5 mm) max.	[Note (1)]	$1/32$ in. (0.8 mm) max.	[Note (1)]	[Note (1)]
Discoloration (heat-affected zone and weld bead)	Discoloration of light straw to light blue color is permitted. Acceptable discoloration levels beyond that shall be established between the owner/user and contractor. The color photos in Figure MJ-8.4-3, PFI Standard ES-50, or AWS D18.2 may be used as a guide. Any discoloration present must be tightly adhering to the surface such that normal operations will not remove it. In any case, the discoloration shall have no evidence of rust, free iron, or sugaring [Note (3)].	N/A [Note (3)]	Discoloration of light straw to light blue color is permitted. Acceptable discoloration levels beyond that shall be established between the owner/user and contractor. The color photos in Figure MJ-8.4-3, PFI Standard ES-50, or AWS D18.2 may be used as a guide. Any discoloration present must be tightly adhering to the surface such that normal operations will not remove it. In any case, the discoloration shall have no evidence of rust, free iron, or sugaring [Note (3)].	Per customer specification	Per customer specification
Oxide island	Oxide islands are permitted as long as they are adherent to the surface. Reflective color of oxide island is not cause for rejection. Alloy types are identified in Tables MM-2.1-1 through MM-2.1-3.	N/A	None allowed	Oxide islands permitted	Oxide islands permitted
Reinforcement	[Note (1)]	[Note (1)]	$1/32$ in. (0.8 mm) max.	[Note (1)]	[Note (1)]

Table MJ-8.3-1
Visual Examination Acceptance Criteria for Welds on Metallic Pipe (Cont'd)

Discontinuities	Welds on Process Contact Surfaces			Welds on Non–Process Contact Surfaces	
	Welds Left in the As-Welded Condition	Prior to Postweld Finishing	After Postweld Finishing	Welds Left in the As-Welded Condition	After Postweld Finishing
Tack welds	Must be fully consumed by final weld bead	Must be fully consumed by final weld bead	Must be fully consumed by final weld bead	Per customer specification	Per customer specification
Arc strikes	None	None	None	None	None
Overlap	None	None	None	None	None
Weld bead width	N/A	N/A	N/A	N/A	N/A
Minimum fillet weld size	[Note (1)]	[Note (1)]	[Note (1)]	[Note (1)]	[Note (1)]
Misalignment (mismatch)	[Notes (1) and (4)]	[Notes (1) and (4)]	[Notes (1) and (4)]	[Notes (1) and (4)]	[Notes (1) and (4)]

NOTES:
(1) The limits of ASME B31.3 shall apply.
(2) Does not apply to insulation sheathing and similar welds.
(3) Special surface preparation may be needed to meet the criteria. Welds on piping that has been in service may require unique criteria.
(4) It is recognized that the I.D. misalignment is more relevant to hygienic design than O.D. misalignment. However, not all connections facilitate ready measurement of I.D. misalignment. For situations where conformance to O.D. misalignment criteria results in an I.D. misalignment that could affect drainability or cleanability, see Nonmandatory Appendix C for further details.

Table MJ-8.4-1
Visual Examination Acceptance Criteria for Groove Welds on Metallic Tube-to-Tube Butt Joints

Discontinuities	Welds on Process Contact Surfaces	Welds on Non–Process Contact Surfaces
Cracks	None	None
Lack of fusion	None	None
Incomplete penetration	None [see Figure MJ-8.4-1, illustration (g)]	None [see Figure MJ-8.4-1, illustration (g)]
Porosity	None open to the surface; otherwise, see Note (1). If postweld finishing is performed, see Table SF-2.2-1 for acceptance criteria for pits/porosity.	None open to the surface; otherwise, see Note (1)
Inclusions [metallic (e.g., tungsten) or nonmetallic]	None open to the surface; otherwise, see Note (1)	[Note (1)]
Undercut	None	[Note (1)]
Concavity	10% T_w max. [see Figure MJ-8.4-1, illustration (d)]. However, O.D. and I.D. concavity shall be such that the wall thickness is not reduced below the minimum thickness required in DT-3 [Note (2)].	10% T_w max. [see Figure MJ-8.4-1, illustration (c)] over entire circumference with up to 15% T_w permitted over a maximum of 25% of the circumference [Note (2)]
Convexity	10% T_w max. [see Figure MJ-8.4-1, illustration (f)] [Note (2)]	0.015 in. (0.38 mm) max. [see Figure MJ-8.4-1, illustration (e)] [Note (2)]
Discoloration (heat-affected zone and weld bead)	Discoloration of light straw to light blue color is permitted (see Figures MJ-8.4-2 and MJ-8.4-3). Any discoloration present must be tightly adhering to the surface such that normal operations will not remove it. In any case, the discoloration shall have no evidence of rust, free iron, or sugaring [Note (3)].	Discoloration level shall be agreed on between the owner/user and contractor. Postweld conditioning may be allowed to meet discoloration requirements at the discretion of the owner/user [Note (3)].
Reinforcement	See convexity	See convexity
Tack welds	Must be fully consumed by final weld bead [Note (4)]	Same as process contact side
Arc strikes	None	[Note (5)]
Overlap	None	None
Weld bead width	No limit provided that complete joint penetration is achieved	If process contact surface cannot be examined (such as I.D. of a tube beyond the reach of remote vision equipment), then the non-process contact surface weld bead shall be straight and uniform around the entire weld circumference [see Figure MJ-8.4-4, illustration (a)]. The minimum weld bead width shall not be less than 50% of the maximum weld bead width [see Figure MJ-8.4-4, illustration (b)]. The maximum weld bead meander shall be 25% of the weld bead width, measured as a deviation from the weld centerline, as defined in Figure MJ-8.4-4, illustration (c).
Minimum throat	N/A	N/A
Misalignment (mismatch) [Notes (6), (7), and (8)]	N/A [Note (6)]	15% T_w max. [see Figure MJ-8.4-1, illustration (b)], except that 4-in. tube may have a maximum of 0.015 in. (0.38 mm) misalignment on the O.D. and 6-in. tube may have a maximum of 0.030 in. (0.76 mm) misalignment on the O.D. Figure MJ-8.4-1, illustration (b) does not apply to 4-in. and 6-in. tube [Notes (2) and (6)].
Oxide island	Oxide islands are permitted as long as they are adherent to the surface. Reflective color of oxide island is not cause for rejection. Alloy types are identified in Tables MM-2.1-1, MM-2.1-2, and MM-2.1-3.	Oxide islands permitted

GENERAL NOTE: Includes all product forms (e.g., tube, fittings, castings, forgings, and bar) whose final dimensions meet Part DT requirements.

NOTES:
(1) The limits of ASME B31.3 shall apply.
(2) T_w is the nominal wall thickness of the thinner of the two members being joined. Weld metal shall blend smoothly into base metal.
(3) Welds on tubing that has been in service may require unique criteria.

Table MJ-8.4-1
Visual Examination Acceptance Criteria for Groove Welds on Metallic Tube-to-Tube Butt Joints (Cont'd)

NOTES: (Cont'd)

(4) Any weld that shows unconsumed tack welds on the non–process contact surface shall be examined on the process contact surface; otherwise it is rejected. If the weld cannot be examined on the process contact surface, rewelding per MJ-8.4.2 is not allowed. Rewelding per MJ-8.4.2 is allowed if the weld can be examined on the process contact surface after rewelding.

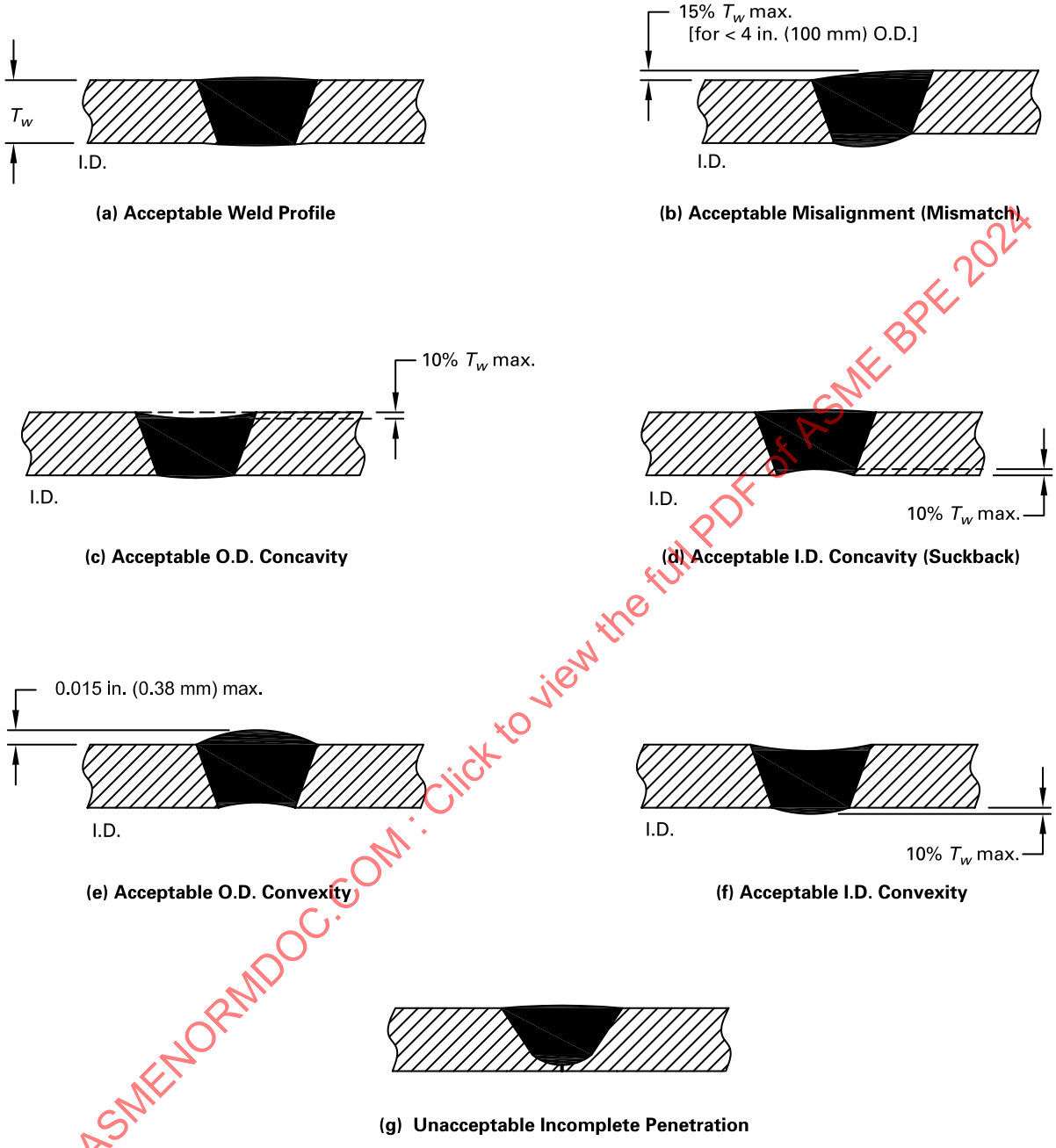
(5) Arc strikes on the non–process contact surface may be removed by mechanical polishing as long as the minimum design wall thickness is not compromised.

(6) Note that misalignment is controlled on the O.D. and is based on allowable O.D. dimensions and tolerances of fittings and tubing. The owner/user is cautioned that this can result in greater I.D. misalignment because this also takes into consideration the wall thickness dimensions and tolerances of fittings and tubing. However, there are no specified I.D. misalignment acceptance criteria.

(7) It is recognized that the I.D. misalignment is more relevant to hygienic design than O.D. misalignment. However, not all connections facilitate ready measurement of I.D. misalignment. For situations where conformance to O.D. misalignment criteria results in an I.D. misalignment that could affect drainability or cleanability, see Nonmandatory Appendix C for further details.

(8) Misalignment criteria do not apply in the fabrication of extruded branch outlets (such as tees) and reducers.

Figure MJ-8.4-1
Acceptable and Unacceptable Weld Profiles for Groove Welds on Metallic Tube-to-Tube Butt Joints



(a) Acceptable Weld Profile

(b) Acceptable Misalignment (Mismatch)

(c) Acceptable O.D. Concavity

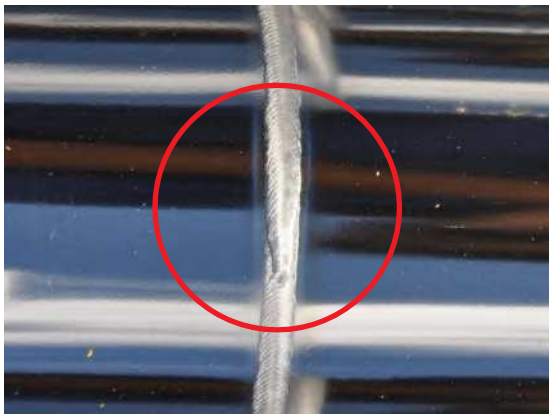
(d) Acceptable I.D. Concavity (Suckback)

(e) Acceptable O.D. Convexity

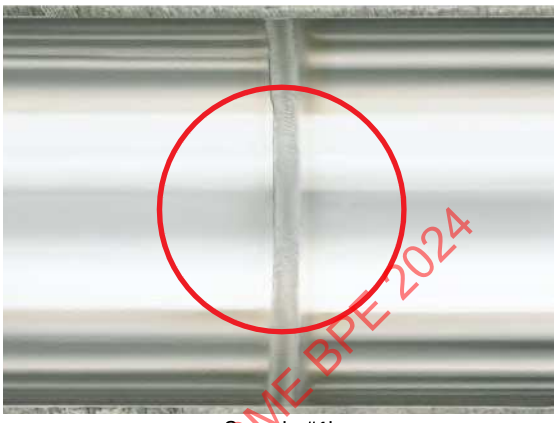
(f) Acceptable I.D. Convexity

(g) Unacceptable Incomplete Penetration

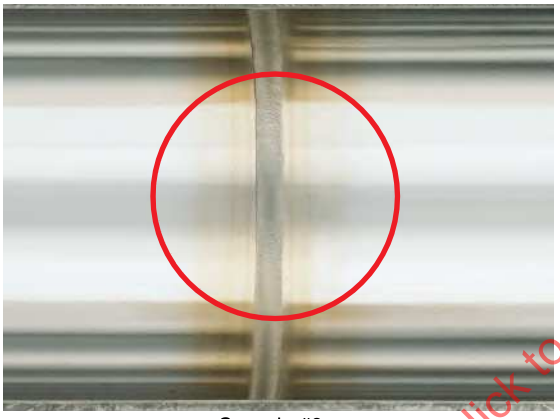
Figure MJ-8.4-2
Discoloration Acceptance Criteria for Welds and Heat-Affected Zones on Electropolished UNS S31603 Tubing



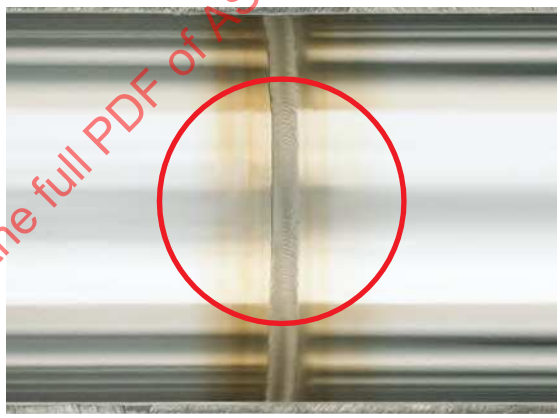
Sample #1a



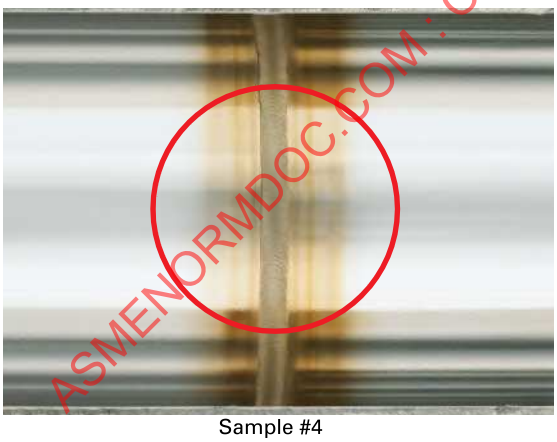
Sample #1b



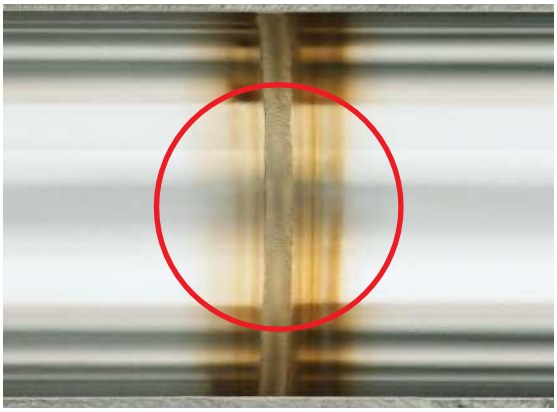
Sample #2



Sample #3



Sample #4



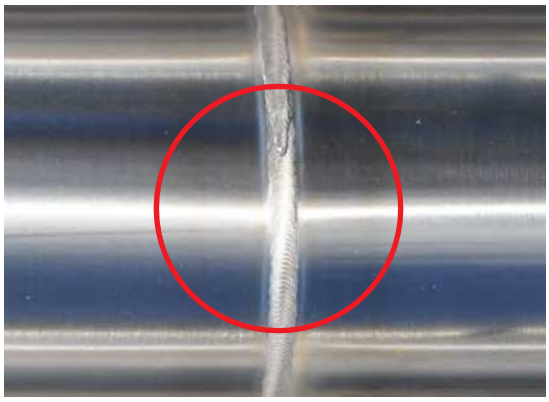
Sample #5

The weld beads shown in the above photographs are the weld beads on the I.D. of the tubing. The area for comparison in each photograph is the area inside the red circle. Welds and heat-affected zones on electropolished UNS S31603 tubing with discoloration levels no worse than Samples #1 through #4 in the as-welded condition are acceptable. Discoloration levels more severe than that shown in Sample #4 are unacceptable. Sample #5 shows unacceptable discoloration levels for comparison. The user is cautioned that the colors observed during direct visual examination or borescope examination will be different viewing directly down (90 deg) at the surface compared with viewing at a lower angle along the edges.

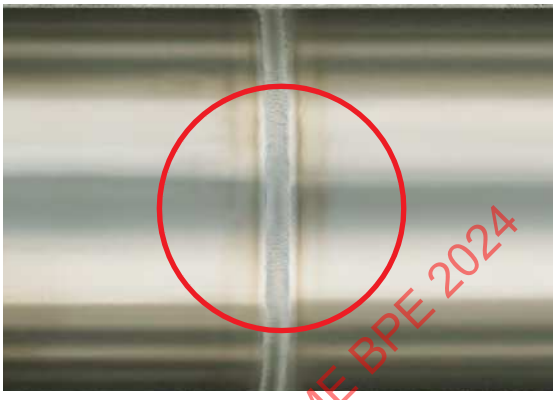
GENERAL NOTE: The user is cautioned that electronic versions or photocopies of these acceptance criteria shall not be used for evaluation of sample or production welds since subtle differences in color can influence weld acceptability. Nonmandatory Appendix N explains the technique by which these acceptance criteria were determined.

This figure is also available as a stand-alone document from ASME as ASME BPE-EP.

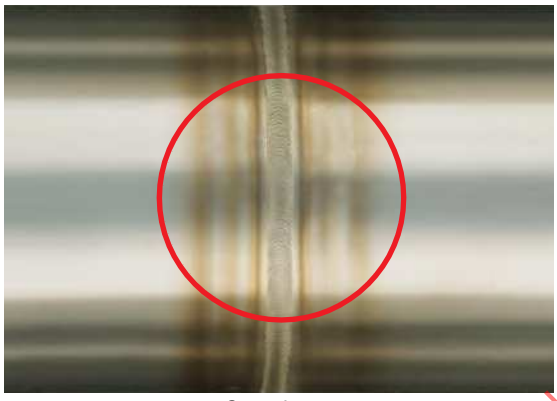
Figure MJ-8.4-3
Discoloration Acceptance Criteria for Welds and Heat-Affected Zones on Mechanically Polished UNS S31603 Tubing



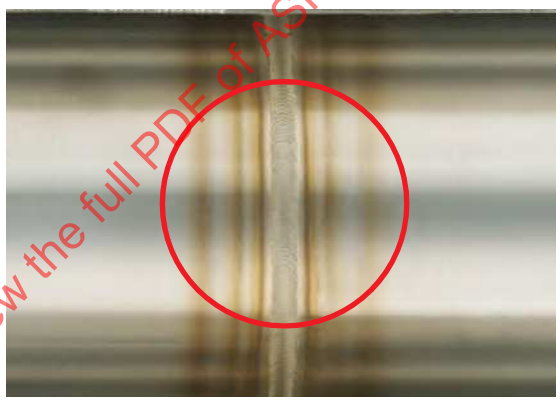
Sample #1a



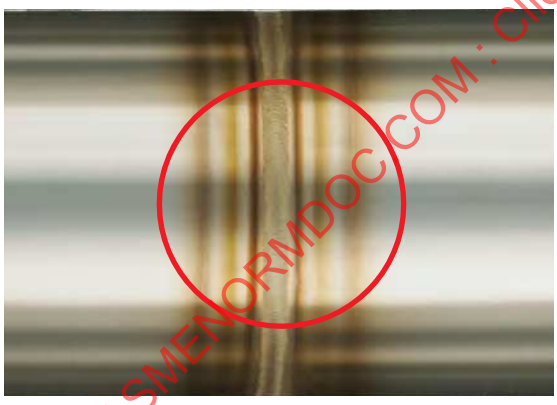
Sample #1b



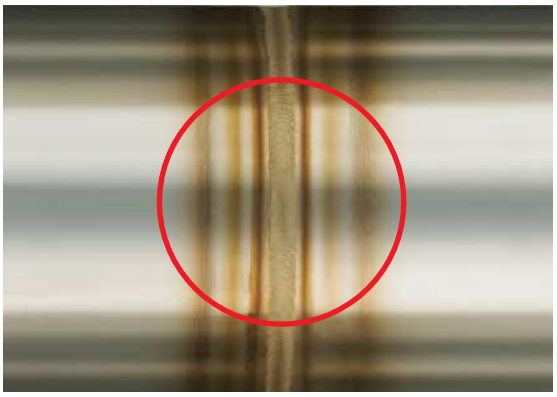
Sample #2



Sample #3



Sample #4



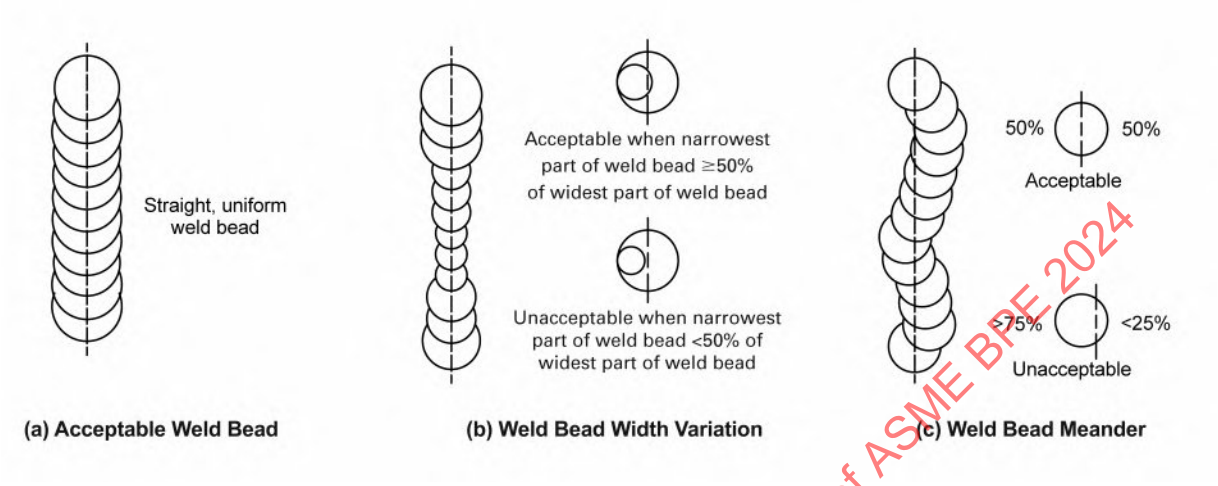
Sample #5

The weld beads shown in the above photographs are the weld beads on the I.D. of the tubing. The area for comparison in each photograph is the area inside the red circle. Welds and heat-affected zones on mechanically polished UNS S31603 tubing with discoloration levels no worse than Samples #1 through #3 in the as-welded condition are acceptable. Discoloration levels more severe than that shown in Sample #3 are unacceptable. Samples #4 and #5 show unacceptable discoloration levels for comparison. The user is cautioned that the colors observed during direct visual examination or borescope examination will be different viewing directly down (90 deg) at the surface compared with viewing at a lower angle along the edges.

GENERAL NOTE: The user is cautioned that electronic versions or photocopies of these acceptance criteria shall not be used for evaluation of sample or production welds since subtle differences in color can influence weld acceptability. Nonmandatory Appendix N explains the technique by which these acceptance criteria were determined.

This figure is also available as a stand-alone document from ASME as ASME BPE-MP.

Figure MJ-8.4-4
Acceptable and Unacceptable Metallic Weld Bead Width and Meander on Non–Process Contact Surfaces of Groove Welds on Tube-to-Tube Butt Joints (24)



GENERAL NOTE: Applies only to non-process contact surfaces and only if weld on process contact surface cannot be examined (blind weld).

Table MJ-8.5-1
Visual Examination Acceptance Criteria for Metallic Tube-Attachment Welds

Discontinuities	Groove Welds [Note (1)]		Fillet Welds	
	Welds on Process Contact Surfaces	Welds on Non-Process Contact Surfaces	Welds on Process Contact Surfaces	Welds on Non-Process Contact Surfaces
Cracks	None	None	None	None
Lack of fusion	None	None	None	None
Incomplete penetration	None	None	N/A	N/A [Note (2)]
Porosity	None open to the surface; otherwise, see Note (3). If postweld finishing is performed, see Table SF-2.2-1 for acceptance criteria for pits/porosity.	None open to the surface; otherwise, see Note (3)	None open to the surface; otherwise, see Note (3). If postweld finishing is performed, see Table SF-2.2-1 for acceptance criteria for pits/porosity.	None open to the surface; otherwise, see Note (3)
Inclusions [metallic (e.g., tungsten) or nonmetallic]	None open to the surface	None open to the surface	None open to the surface	None open to the surface
Undercut	None	[Note (3)]	None [Note (4)]. [For autogenous fillet welds see Figure MJ-8.5-1, illustration (c)]	[Notes (3) and (5)]. [For autogenous fillet welds see Figure MJ-8.5-1, illustration (c)]
Concavity	10% T_w max. [see Figure MJ-8.4-1, illustrations (c) and (d)]. However, O.D. and I.D. concavity shall be such that the wall thickness is not reduced below the minimum thickness required in DT-3 [Note (6)].	10% T_w [see Figure MJ-8.4-1, illustrations (c) and (d)] over entire circumference with up to 15% T_w permitted over a maximum of 25% of the circumference [Note (6)]	N/A [see Figure MJ-8.5-1, illustrations (a) and (c)] [Note (4)]	N/A [see Figure MJ-8.5-1, illustrations (a) and (c)] [Note (5)]
Convexity	10% T_w max.	0.015 in. (0.38 mm) max. [Note (3)]	10% T_w max. [see Figure MJ-8.5-1, illustration (b)] [Note (6)]	N/A
Discoloration (heat-affected zone and weld bead)	Discoloration of light straw to light blue color is permitted (see Figures MJ-8.4-2 and MJ-8.4-3). Any discoloration present must be tightly adhering to the surface such that normal operations will not remove it. In any case, the discoloration shall have no evidence of rust, free iron, or sugaring [Note (7)].	Discoloration level shall be agreed on between the owner/user and contractor. Postweld conditioning may be allowed to meet discoloration requirements at the discretion of the owner/user [Note (7)].	Discoloration of light straw to light blue color is permitted (see Figures MJ-8.4-2 and MJ-8.4-3). Any discoloration present must be tightly adhering to the surface such that normal operations will not remove it. In any case, the discoloration shall have no evidence of rust, free iron, or sugaring [Note (7)].	Discoloration level shall be agreed on between the owner/user and contractor. Postweld conditioning may be allowed to meet discoloration requirements at the discretion of the owner/user [Note (7)].

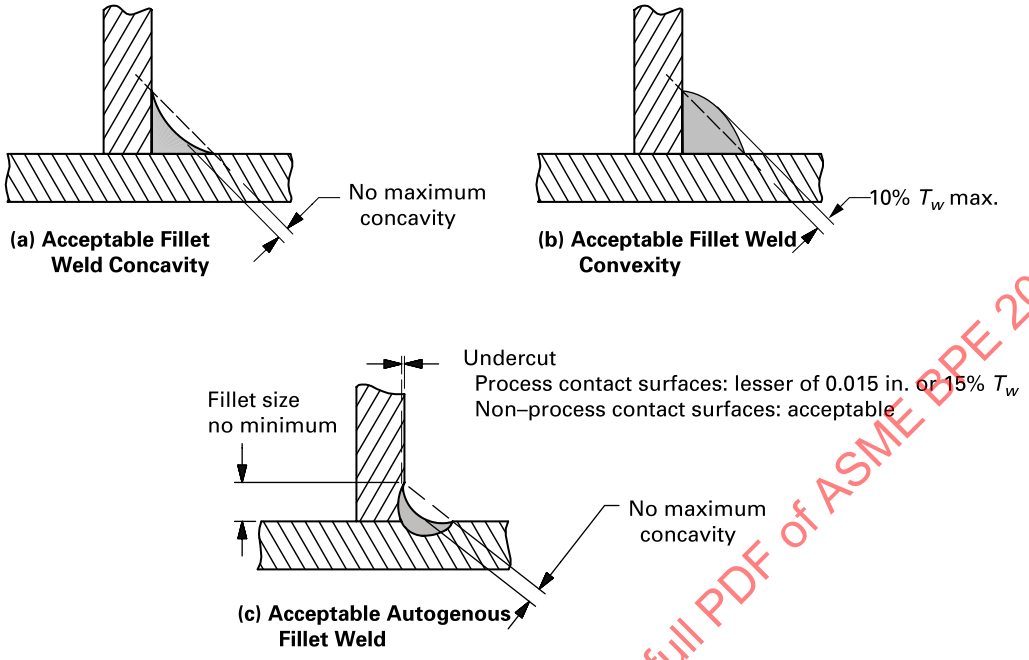
Table MJ-8.5-1
Visual Examination Acceptance Criteria for Metallic Tube-Attachment Welds (Cont'd)

Discontinuities	Groove Welds [Note (1)]		Fillet Welds	
	Welds on Process Contact Surfaces	Welds on Non-Process Contact Surfaces	Welds on Process Contact Surfaces	Welds on Non-Process Contact Surfaces
Oxide island	Oxide islands are permitted as long as they are adherent to the surface. Reflective color of oxide island is not cause for rejection. Alloy types are identified in Tables MM-2.1-1, MM-2.1-2, and MM-2.1-3.	Oxide islands permitted	Oxide islands are permitted as long as they are adherent to the surface. Reflective color of oxide island is not cause for rejection. Alloy types are identified in Tables MM-2.1-1, MM-2.1-2, and MM-2.1-3.	Oxide islands permitted
Reinforcement	See convexity	See convexity	N/A	N/A
Tack welds	Must be fully consumed by final weld bead [Note (8)]	Must be fully consumed by final weld bead [Note (9)]	Must be fully consumed by final weld bead [Note (8)]	Must be fully consumed by final weld bead [Note (9)]
Arc strikes	None	[Note (10)]	None	[Note (10)]
Overlap	None	None	None	None
Weld bead width	N/A	N/A	N/A	N/A
Minimum fillet weld size	N/A	N/A	Per client specification [Note (4)]. [For autogenous fillet welds see Figure MJ-8.5-1, illustration (c)]	Per client specification [Note (5)]. [For autogenous fillet welds see Figure MJ-8.5-1, illustration (c)]
Misalignment (mismatch)	N/A as long as other conditions are met	N/A as long as other conditions are met	N/A	N/A

GENERAL NOTE: Tube attachment welds include groove welds and fillet welds in various joint configurations, such as proximity stems on jumpers on transfer panels, transfer panel nozzles, and locator pins on sprayballs.

NOTES:
(1) Any weld where penetration is required into the joint.
(2) Penetration to the process contact surfaces is neither required nor prohibited. Welds that penetrate through to the process contact surface may exhibit intermittent penetration. Weld penetration through to the process contact surface shall meet all other process contact surface requirements of this Table.
(3) The limits of ASME B31.3 shall apply.
(4) For welds designated by the owner/user as autogenous fillet welds (seal welds), there is no minimum fillet weld size or throat. Concavity requirements are not applicable. Undercut in process contact surfaces shall not exceed the lesser of 0.015 in. or 15% T_w and shall have a smooth transition between weld and base metal.
(5) For welds designated by the owner/user as autogenous fillet welds (seal welds), there is no minimum fillet weld size or throat. Concavity and undercut requirements are not applicable.
(6) T_w is the nominal thickness of the thinner of the two members being joined. Weld metal shall blend smoothly into base metal.
(7) Welds on tube attachments that have been in service may require unique criteria.
(8) Rewelding per MJ-8.5.2 is allowed.
(9) Any weld showing unconsumed tack weld(s) on the non-process contact surface can be rewelded per MJ-8.5.2 if the process contact surface can be reexamined. Otherwise, it is rejected.
(10) Arc strikes on the non-process contact surface may be removed by mechanical polishing as long as the minimum design wall thickness is not compromised.

Figure MJ-8.5-1
Acceptable Weld Profiles for Metallic Tube-Attachment Fillet Welds



MJ-9.2 Weld Joint Design and Preparation

The weld surfaces to be joined shall be properly aligned. This may include planing or facing of the components. The weld surfaces shall be protected against adverse environmental influences, including excessive moisture, extreme temperature conditions, excessive drafts, and contamination sources (e.g., dirt, dust, oil, foreign material shavings).

MJ-9.2.1 Tubing and Piping. Joint designs for tubing, piping, and fittings shall be square butt joints. Joining surfaces shall have ends prepared by molding, cutting, machining, or facing to provide a square end that meets requirements for the applicable welding procedure specification (WPS).

MJ-9.3 Joining Processes and Procedures

Tube and pipe systems composed of polymeric materials are joined by a variety of heat fusion welding methods, including beadless fusion, noncontact infrared (IR) fusion, contact butt fusion, and socket fusion. Fusion does not require solvents or glue to join material, and nothing is added or changed chemically between the two components being joined. Other joining methods may be used when agreed on by the owner/user. Joining of polymeric materials shall be performed in accordance with a documented WPS that is qualified in accordance with MJ-9.4. The owner/user, contractor, and manufacturer shall agree that the welding process selected will provide the desired results.

MJ-9.3.1 Beadless Welding. Beadless welding (a material-dependent process) shall be used where drainability is required (see Figure MJ-9.7.1-1 and SD-2.4.3).

MJ-9.3.1.1 Records. Weld equipment should monitor and record critical weld parameters such as heat, cool time, and temperature. If the equipment does not have monitoring or recording capabilities, weld data shall be recorded in welding protocols or on data carriers.

MJ-9.3.2 Noncontact IR and Contact Butt Fusion Welding. Noncontact infrared and contact butt fusion are not suitable joining processes for systems requiring drainability. Either may be acceptable for single-use applications. Refer to the WPS or manufacturer's written procedures.

MJ-9.3.3 Socket Fusion Welding. Socket fusion is not suitable for systems requiring drainability. Socket fusion may be acceptable for single-use applications where approved by the owner/user for the intended service. Refer to the WPS or manufacturer's written procedures.

MJ-9.4 Procedure Qualifications

Welding procedures shall be qualified in accordance with AWS B2.4. A WPS shall be provided for each polymeric material and process being used. Environmental condition recommendations shall be included in the WPS.

MJ-9.5 Performance Qualifications

Welder and welding operator performance qualifications shall be in accordance with AWS B2.4. The quality of polymeric weld joints depends on the qualification of the welders and welding operators, the suitability of the equipment used, environmental influences, and adherence to the applicable WPS. Welders and welding operators shall be trained and possess a valid qualification certificate from the manufacturer for the process and material being welded.

MJ-9.6 Examination, Inspection, and Testing

Examination, inspection, and testing criteria and methods are dictated by material type and joining method. The owner/user, inspection contractor, and/or engineer shall agree to the types of examinations, inspections, and testing unless otherwise specified in the applicable code.

MJ-9.6.1 Examination Procedures. Written visual examination procedures shall be used.

MJ-9.6.2 Personnel Requirements

MJ-9.6.2.1 Personnel Qualifications. All examiners, inspectors, and Quality Inspector's Delegates shall be qualified in accordance with GR-4 and shall be trained and possess a valid qualification certificate from the manufacturer for the process and material being welded.

MJ-9.6.2.2 Examination Personnel Eye Examination Requirements. Personnel performing examinations shall have eye examinations as described in GR-4.2.3(d).

MJ-9.6.3 Examination, Inspection, and Testing Requirements

MJ-9.6.3.1 Examination. Examinations shall be performed in accordance with the provisions of the specified fluid service in ASME B31.3.

The external surfaces of all welds shall be visually examined. If ASME B31.3, High Purity Fluid Service (Chapter X), is specified, radiographic, ultrasonic, or in-process examination is not required unless specified by the owner/user.

Preproduction sample welds, when required, shall be submitted by the contractor to the owner/user to establish weld quality. The owner/user, contractor, and inspection contractor shall agree to the number and type of sample welds. During construction, sample welds shall be made on a regular basis to verify that the equipment is operating properly and that the setup is adequate to prevent discoloration beyond the level agreed on by the owner/user and contractor. The owner/user and contractor shall agree to the frequency of sample welds. It is strongly recommended that these sample welds be made at the beginning of each work shift and when changing the welder and/or welding operator (as applicable) and welding equipment.

The sample welds described in the preceding paragraphs, and any associated welding machine printed records (e.g., welding parameter printouts directly from the welding machine or downloaded from a welding machine), if any, may be disposed of after written acceptance of the coupons by the owner, the owner's representative, or the inspector.

MJ-9.6.3.2 Inspection. The owner/user, inspection contractor, and/or engineer shall agree to the minimum percentage of process contact welds to be selected for borescopic or direct visual inspection, and they shall inform the installation contractor. The inspection contractor shall submit an inspection plan to ensure that welds meet the acceptance criteria of this Part. This plan shall include borescopic or direct visual inspection of the process contact surfaces or visual inspection with light illumination of the weld cross sections on at least 20% of the welds in each system installed. A representative sample of each welder's and/or welding operator's (as applicable) work shall be included. There shall also be a plan for inspecting a representative sample of each welder's and/or welding operator's (as applicable) first shift of production. A procedure shall be submitted for inspecting blind welds. The random selection of accessible welds to be inspected shall be up to the owner/user's inspector's discretion.

The examination required for conformance to ASME B31.3 may be included in the minimum inspection percentage, provided those examinations were direct visual or borescopic and of the process contact surface.

MJ-9.6.3.3 Testing. Hydrostatic leak testing shall be performed in accordance with the specified fluid service requirements in ASME B31.3. Hydrostatic leak testing shall never exceed the manufacturer's rating of the system installed.

The use of pneumatic testing is not recommended on these systems.

MJ-9.6.4 Records. See GR-5.

MJ-9.7 Weld Acceptance Criteria

Common visual acceptance criteria include complete bonding of joining surface, straight and aligned joints, and exclusion of dirt and foreign substances in the weld zone.

MJ-9.7.1 Acceptance Criteria for Beadless Welds. Weld acceptance criteria for beadless welds shall be in accordance with Table MJ-9.7.1-1 (see also Figure MJ-9.7.1-1).

MJ-9.7.2 Acceptance Criteria for Nonbeadless Welds. Acceptance criteria for nonbeadless welds in piping shall be in accordance with AWS G1.10M or DVS 2202-1.

Table MJ-9.7.1-1
Visual Examination Acceptance Criteria for Polymeric Pipe Beadless Welds

Discontinuities	Acceptance Criteria
Cracks and crevices	None [see Figure MJ-9.7.1-1, illustration (b)]
Pits and pores	None [see Figure MJ-9.7.1-1, illustration (c)]
Voids (microbubbles) [Note (1)]	Single void diameter 10% T_w max. or total of all void diameters in a given cross-sectional examination 10% T_w max. [see Figure MJ-9.7.1-1, illustration (d)]
Fit-up and mismatch [Note (2)]	10% T_w max. [see Figure MJ-9.7.1-1, illustration (e)]
Inclusions [Note (3)]	Visible inclusion(s) or speck(s) unacceptable [see Figure MJ-9.7.1-1, illustration (f)]
Discoloration	Weld zone may be permitted to have light straw color. Dark color on the surface or at the weld interface is unacceptable [see Figure MJ-9.7.1-1, illustration (g)]
Concavity	10% T_w max. for I.D. concavity [see Figure MJ-9.7.1-1, illustration (h)]

NOTES:
(1) Voids or microbubbles in the weld zone are the result of molten material shrinking as it cools, leaving small voids, usually in the center of the weld, due to volume displacement. They are not uncommon in beadless welding, and their presence alone is not reason for rejection.
(2) Components shall be aligned to prevent holdup that would contaminate the process fluid. It is not recommended to join components of different wall thicknesses.
(3) Slight discoloration in the weld zone is not uncommon in beadless welding.

MJ-9.7.3 Acceptance Criteria for Sample Welds. Sample welds shall meet all the acceptance criteria of MJ-9.7.1.

MJ-9.7.4 Rewelding. Rewelding is not allowed.

MJ-9.8 Documentation Requirements

The following documentation shall be presented to the owner/user or their designee, as a minimum:

(a) Welding Documentation. Welding procedure specifications (WPSs) used, their procedure qualification records (PQRs), and welder performance qualifications (WPQs)/performance qualification test records (PQTRs) and/or welding operator performance qualifications (WOPQs).

(b) Weld Maps. When required by the owner/user, weld maps of bioprocessing components, weld inspection logs of bioprocessing components (including type and date of inspection), and welder and/or welding operator identification of each weld shall be provided either on the weld map or on the inspection log.

Fusion equipment that electronically stores welding histories and serializes welds should be used. Welding history shall be turned over, in printed or electronic format, to the owner/user on completion of work and as part of the installation qualification (IQ) process.

(c) Materials. All molded fittings, molded valves, and extruded piping shall be intrinsically identified to provide, as a minimum, material of construction, lot number, and date of production to ensure traceability. Certificates of Conformance shall be provided for molded/extruded components not individually labeled.

(d) Testing Records. Other records (e.g., pressure test, surface finish) shall be provided as required by the owner/user.

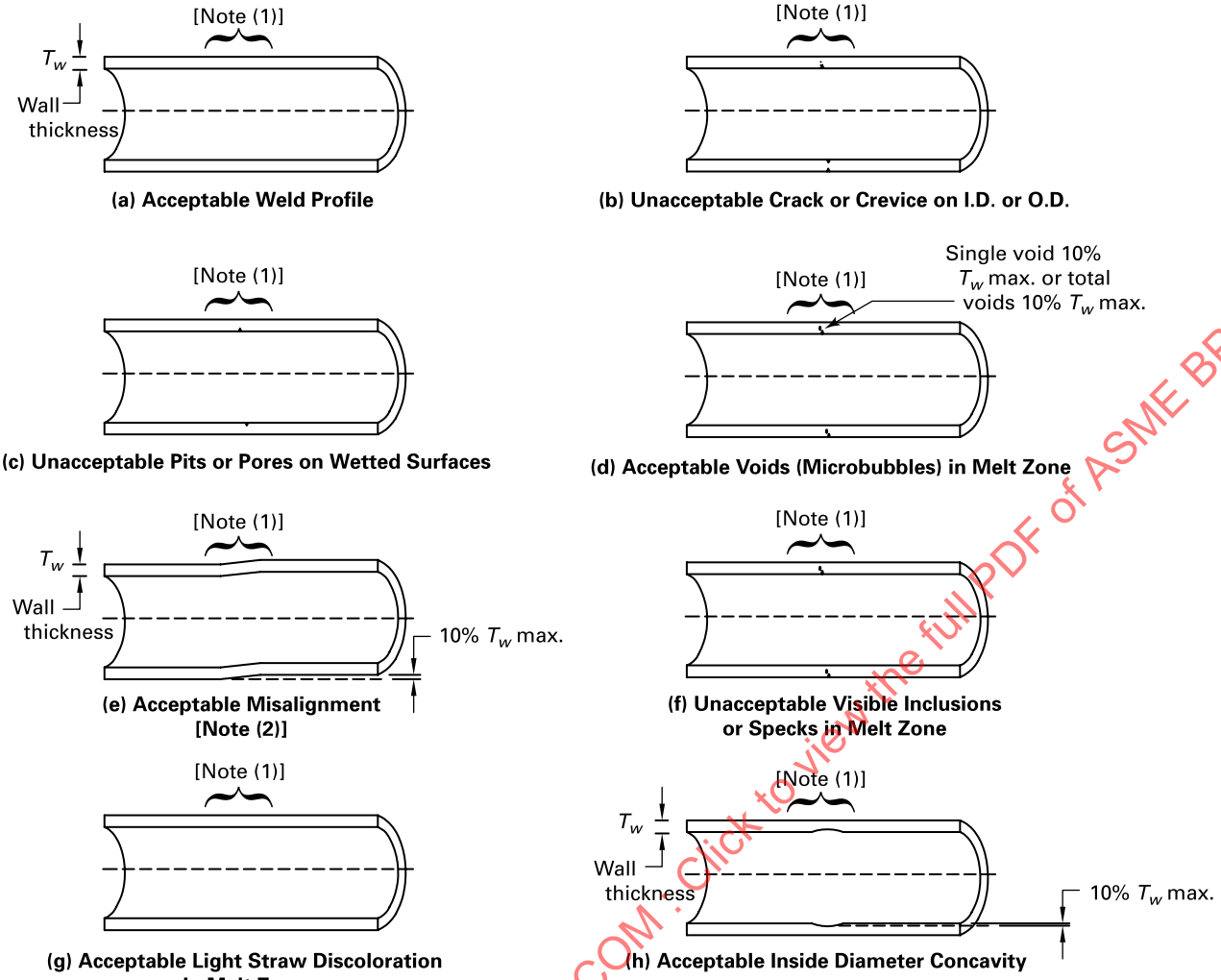
MJ-10 DOCUMENTATION REQUIREMENTS

The requirements for metallic materials and weld documentation are listed in GR-5. For polymeric materials, see MJ-9.8.

MJ-11 PASSIVATION

See SF-2.6.

Figure MJ-9.7.1-1
Acceptable and Unacceptable Weld Profiles for Polymeric Beadless Welds



NOTES:
(1) Weld examination area: melt zone (area that was supported during fusion).
(2) Note that misalignment is controlled on the O.D. and is based on allowable O.D. dimensions and tolerances of fittings and piping. The owner/user is cautioned that this can result in greater I.D. misalignment because this also takes into consideration the wall thickness dimensions and tolerances of fittings and piping. However, there are no specified I.D. misalignment acceptance criteria.

PART SF
PROCESS CONTACT SURFACE FINISHES FOR MULTIUSE

SF-1 PURPOSE AND SCOPE

The purpose of this Part is to provide process contact surface finish acceptance criteria for metallic and polymeric materials.

SF-2 METALLIC APPLICATIONS

SF-2.1 Applicable Systems

This Part shall be applicable to all systems designated by the owner/user or representative thereof.

Process contact surface requirements shall apply to all accessible and inaccessible areas of the systems that directly or indirectly come in contact with the designated product.

These systems shall include, but are not limited to, one or more of the following:

(a) USP water-for-injection (WFI)
(b) USP purified water
(c) USP pure steam
(d) other product/process contact surface systems

SF-2.2 Acceptance Criteria

Acceptance criteria for common austenitic stainless steels as per Table MM-2.1-1 are listed in Tables SF-2.2-1 and SF-2.2-2. Acceptance criteria for other alloys as described in Part MM may differ and should be specified by the owner/user. Visual comparison charts or samples may be used to define acceptable and unacceptable process contact surfaces.

SF-2.3 Examination Techniques Employed in the Classification of Process Contact Surface Finishes

SF-2.3.1 General. Process contact surface finish examinations shall be made by one or more of the following methods:

(a) visual examination
(1) direct visual examination
(2) remote visual examination (e.g., videoscopes, borescopes)
(b) liquid penetrant testing
(c) surface roughness measurement device (profilometer)

All examiners, inspectors, and Quality Inspector's Delegates shall be qualified in accordance with GR-4. Written procedures are required for all examinations and inspections being performed. Qualification of the written examination procedure is not required.

Acceptance criteria for metallic process contact surface finishes are shown in Table SF-2.2-1.

Acceptance criteria for electropolished metallic process contact surface finishes shall meet requirements shown in Table SF-2.2-2 in addition to those shown in Table SF-2.2-1.

SF-2.3.2 Direct Visual Examination. Direct visual examinations should be performed with a light source having a color temperature between 5,000 K and 6,500 K. Illumination should be at least 500 lux at the surface to be examined. Personnel performing direct visual examinations shall meet the eye examination requirements of GR-4.2.3(d). The size, shape, and contour of many process components (piping, vessels, valves, etc.) may limit the accessibility of direct visual examinations; however, direct visual examinations should be conducted with the eye at a distance of not more than 24 in. (600 mm) from the surface at an angle of not less than 30 deg.

SF-2.3.3 Remote Visual Examination. In some cases where areas subject to examination are inaccessible for direct visual examination, remote visual examination may be used. Such examination systems shall have a resolution capability at least equivalent to that obtainable by direct visual examination. Remote visual examination systems using cameras need particular attention paid to the following specific features:

(a) The observed colors may differ significantly from the actual colors due to the combined electronic data handling of camera, monitor, and software.
(b) Magnification level of viewed areas or objects should be verified. See ASTM A1015, para. 7, Calibration, for reference.
(c) Illumination typically is self-adjusted by the camera by changing readout time. Illumination requirements for direct visual examinations do not apply.

Table SF-2.2-1
Acceptance Criteria for Metallic Process Contact Surface Finishes

Anomaly or Indication	Acceptance Criteria
Pits/porosity	If diameter <0.020 in. (0.51 mm) and bottom is shiny [Notes (1) and (2)]. Pits ≥0.003 in. (0.08 mm) diameter are relevant whereas pits <0.003 in. (0.08 mm) diameter are irrelevant and acceptable.
Cluster of pits/porosity	No more than 4 relevant pits per 0.5 in. (12.7 mm) × 0.5 in. (12.7 mm) inspection window. The cumulative total diameter of all relevant pits shall not exceed 0.040 in. (1.02 mm).
Dents	None accepted [Note (3)]
Finishing marks	If R_a max. is met
Welds	Welds used in the as-welded condition shall meet the requirements of MJ-8. Welds finished after welding shall be flush with the base metal, and concavity and convexity shall meet the requirements of MJ-8. Such finishing shall meet the R_a requirements of Table SF-2.4.1-1.
Nicks	None accepted
Scratches	For tubing, if cumulative length is <12.0 in. (305 mm) per 20 ft (6.1 m) tube length or prorated and if depth is <0.003 in. (0.08 mm) For fittings, valves, and other process components, if cumulative length is <0.25 in. (6.4 mm), depth <0.003 in. (0.08 mm), and R_a max. is met For vessels, if length <0.50 in. (13 mm) at 0.003 in. (0.08 mm) depth and if <3 per inspection window [Note (4)]
Surface cracks	None accepted
Surface inclusions	If R_a max. is met
Surface residuals	None accepted, visual inspection
Surface roughness (R_a)	See Table SF-2.4.1-1
Weld slag	For tubing, up to 3 per 20 ft (6.1 m) length or prorated, if <75% of the width of the weld bead For fittings, valves, vessels, and other process components, none accepted (as welded shall meet the requirements of MJ-8 and Table MJ-8.4-1)
Blistering	None accepted

GENERAL NOTE: This table covers surface finishes that are mechanically polished or any other finishing method that meets the R_a max.

NOTES:
(1) Black bottom pit of any depth is not acceptable.
(2) Pits in superaustenitic and nickel alloys may exceed this value. Acceptance criteria for pit size should be established by the owner/user. All other pit criteria remain the same.
(3) For vessels, dents in the area covered by and resulting from welding dimple heat transfer jackets are acceptable.
(4) An inspection window is defined as an area 4 in. × 4 in. (100 mm × 100 mm).

Table SF-2.2-2
Additional Acceptance Criteria for Electropolished Metallic Process Contact Surface Finishes

Anomaly or Indication	Acceptance Criteria
Cloudiness	Acceptable if R_a max. is met
End grain effect	Acceptable if R_a max. is met
Fixture marks	Acceptable if electropolished
Haze	Acceptable if R_a max. is met
Interrupted electropolish	Acceptable if R_a max. is met
Orange peel	Acceptable if R_a max. is met
Stringer indication	Acceptable if R_a max. is met
Weld whitening	Acceptable if R_a max. is met
Variance in luster	Acceptable if R_a max. is met

SF-2.4 Surface Condition

The process contact surfaces of metallic materials listed in Tables MM-2.1-1 through MM-2.1-3 shall be cleaned prior to being placed into service. The process contact surfaces of stainless steels listed in Tables MM-2.1-1 and MM-2.1-3 should be passivated after cleaning. See Nonmandatory Appendix E for cleaning and passivating guidelines. Passivation of electropolished surfaces is not required unless the process contact surface has been altered (e.g., welded or mechanically polished) or exposed to external contamination after electropolishing. Specific passivation requirements shall be defined in the engineering design documents or specifications and shall be in accordance with SF-2.6.

SF-2.4.1 Surface Finishing. Process contact surfaces shall be finished using mechanical polishing, cold working, machining, or electropolishing in conformance with applicable sections of this Part.

Table SF-2.4.1-1
R_a Readings for Metallic Process Contact Surfaces

Surface Designation	Mechanically Polished [Note (1)]	
	R_a Max.	
	µin.	µm
SF0	No finish requirement	No finish requirement
SF1	20	0.51
SF2	25	0.64
SF3	30	0.76
	Electropolished	
	R_a Max.	
	µin.	µm
SF4	15	0.38
SF5	20	0.51
SF6	25	0.64

GENERAL NOTES:
(a) All R_a readings are to be in accordance with ASME B46.1.
(b) All R_a readings are taken across the lay, wherever possible.
(c) No single R_a reading shall exceed the R_a max. value in this table.
(d) Other R_a readings are available, not to exceed values in this table.

NOTE: (1) Or any other finishing method that meets the R_a max.

Electropolished surfaces may have variances in luster that are acceptable, if the surface roughness values meet the requirements in Table SF-2.4.1-1. Mechanical buffing as a final polishing finish is unacceptable. All surfaces shall be clean. Cleanliness applies to finished components/equipment as produced and packaged by the manufacturer. Subsequent shipping, storage, handling, and installation may affect the cleanliness.

(24) SF-2.5 Electropolishing Procedure Qualification

Electropolishing service providers performing electropolishing processes on components, equipment, or systems shall implement and maintain a quality management system.

Electropolishing of process contact surfaces shall be conducted in accordance with a written procedure that produces a surface that meets the acceptance criteria of Nonmandatory Appendix H, Table H-4.3-1.

ASME Certificate Holders' procedures shall be qualified in accordance with Nonmandatory Appendix H.

Flash electropolishing is not permitted.

(24) SF-2.6 Passivation Procedure

Passivation for this Part shall be limited to newly installed or newly modified sections of systems and components. Flushing for removal of construction debris or particulates shall be performed in accordance with SD-2. Passivation shall be performed in accordance with an approved quality assurance/control program. The passivation method(s) including procedures for chemical cleaning and degreasing, passivation, and final rinse(s) shall be qualified in accordance with a written procedure and documentation package. This procedure shall specify the acceptable ranges of the passivation essential variables. Nonmandatory Appendix E has been provided as a guide to passivation practices and evaluation of passivated surfaces. Spot passivation is permitted. The pickling process shall not be accepted as a substitute for passivation. There is no universally accepted nondestructive test for the presence of a passive layer.

For passivated process contact surfaces, the acceptance criteria in Table SF-2.6-1 apply in addition to Tables SF-2.2-1 and SF-2.2-2, as applicable. Tests to ensure the presence of a passive layer should be specified by the owner/user.

SF-2.7 Normative References (24)

The following standards contain provisions that, through reference, specify terms, definitions, and parameters for the determination of surface texture (roughness, waviness, and primary profile) by profiling methods.

ASME B46.1. Surface Texture (Surface Roughness, Waviness, and Lay). The American Society of Mechanical Engineers.

ISO 3274. Geometrical Product Specifications (GPS) — Surface texture: Profile method — Nominal characteristics of contact (stylus) instruments. International Organization for Standardization.

ISO 4287. Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters. International Organization for Standardization.

ISO 4288. Geometrical Product Specifications (GPS) — Surface texture: Profile method — Rules and procedures for the assessment of surface texture. International Organization for Standardization.

ISO 11562. Geometrical Product Specifications (GPS) — Surface texture: Profile method — Metrological characteristics of phase correct filters. International Organization for Standardization.

SF-2.8 Rouge and Stainless Steel (24)

Rouge is a naturally occurring phenomenon in existing stainless steel high-purity process systems (including water or pure steam). The degree to which it forms depends on

(a) the stainless steel material used for each component within the system

(b) how the system was fabricated (e.g., welding, surface finish, passivation treatment)

Table SF-2.6-1
Acceptance Criteria for Metallic Passivated Process Contact Surface Finishes

Anomaly or Indication	Acceptance Criteria
Surface particles	No particles observed under visual inspection, without magnification, and using adequate room lighting
Stains	None accepted (weld discoloration to conform to appropriate table of MJ-8)
Visible construction debris	None accepted
Visible oils or organic compounds	None accepted

GENERAL NOTES:
(a) Surface condition shall meet Tables SF-2.2-1 and SF-2.2-2, as applicable.
(b) Additional tests/acceptance criteria may be selected from Nonmandatory Appendix E, Table E-5-1.

(c) what process conditions the system is exposed to (e.g., water purity, process chemicals, temperatures, pressures, mechanical stresses, flow velocities, and concentration of dissolved gases, such as oxygen or carbon dioxide)

(d) how the system is maintained

The presence of rouge in a system needs to be evaluated against its potential to affect the product, process, and long-term operation of the system. Nonmandatory Appendix D provides the methods to measure rouge in a system both in the process solution and on the actual process contact surface. It also suggests various fabrication and operation practices to minimize rouge formation and methods/techniques for its remediation. See the definition of rouge in GR-11.

For more information, refer to the ISPE Water and Steam Systems Baseline® Pharmaceutical Engineering Guide.

SF-3 POLYMERIC APPLICATIONS

SF-3.1 Applicable Systems

This section shall be applicable to all systems designated by the owner/user or representative thereof.

Process contact surface requirements shall apply to all accessible and inaccessible areas of the systems that directly or indirectly come in contact with the designated product.

These systems shall include process systems and clean utilities.

SF-3.2 Materials

The preferred materials of construction for these systems shall be as described in PM-2.

SF-3.3 Examination Techniques Employed in the Classification of Process Contact Surface Finishes

Process contact surface finish examinations shall be made by one or more of the following methods:

(a) visual examination

(1) direct visual examination (e.g., illumination through pipe/tube wall)

(2) remote visual examination (e.g., videoscopes, borescopes)

(b) surface roughness measurement device: profilometer or other surface measurement devices

Acceptance criteria of polymeric process contact surface finishes are shown in Table SF-3.3-1.

Visual examination shall be performed under adequate room lighting. Additional lighting shall be used when appropriate to illuminate blind or darkened areas and to clarify questionable areas.

The same techniques shall be used for both examinations and inspections.

SF-3.4 Surface Condition

The following surface finishes of polymeric materials are available:

(a) piping/tubing and fittings
(1) as molded
(2) as extruded
(3) as machined
(4) as fabricated from molded, extruded, or machined components

(b) sheet, rod, and block
(1) as molded
(2) as extruded
(3) as machined after molding or extrusion

These are generally used terms and may not be applicable in all cases. The final criteria shall be determined by the R_a values shown in Table SF-3.4-1.

Table SF-3.3-1
Acceptance Criteria for Polymeric Process Contact Surface Finishes

Anomaly or Indication	Acceptance Criteria
Scratches	For rigid tubing/piping, if cumulative length is <12.0 in. (305 mm) per 20 ft (6.1 m) tube/pipe length or prorated and if depth <0.003 in. (0.08 mm) For other process components, surface finish should be specified by the owner/user
Surface cracks	None accepted
Surface inclusions	None accepted
Surface roughness, R_a	See Table SF-3.4-1

GENERAL NOTE: All process contact surface finishes shall be specified using the criteria described in SF-3.1.

Table SF-3.4-1
R_a Readings for Polymeric Process Contact Surfaces

Surface Designation	R_a max.	
	µin.	µm
SFP0	No finish requirement	No finish requirement
SFP1	15	0.38
SFP2	25	0.64
SFP3	30	0.76
SFP4	40	1.01
SFP5	50	1.27
SFP6	60	1.52

GENERAL NOTES:
(a) No single R_a reading shall exceed the R_a max. value in this table.
(b) Other R_a readings are available as specified by the supplier, not to exceed values in this table.

CHAPTER 7
DESIGN FOR SINGLE-USE

PART SU
SYSTEMS DESIGN FOR SINGLE-USE

SU-1 GENERAL

The purpose of this Part is to define the requirements that are applicable and unique to the use and manufacturing of single-use components and assemblies.

SU-2 GENERAL GUIDELINES

Single-use components and assemblies are intended for one-time use and may be referred to as disposables. Single-use components and assemblies are different from multiuse components and assemblies as they are not intended for SIP and CIP cycles. In this Part, "component" is defined as an individual unit, and "assembly" is defined as the combination of two or more individual components. This Part addresses the methods for identifying, inspecting, packaging, joining, biocompatibility, and sterilization applicable to single-use components and assemblies.

(24) SU-3 INTEGRITY

Integrity of single-use components and assemblies shall be maintained throughout the life cycle of the product (i.e., packaging, shipping, unboxing, storage, unpacking, setup, assembly, and use) as a joint responsibility between single-use suppliers and owner/users. Integrity in this context is the ability of the entire single-use system to maintain its intended barrier properties. A compromise in the integrity of single-use systems may result in loss of process material, microbial ingress, or impact to operator safety, and should be mitigated.

SU-3.1 Maintenance of Integrity

Maintenance of system integrity is paramount to both bioburden control and maintaining a sterile envelope. Qualification of design, validation of manufacturing processes, and, depending on the criticality of the process the single-use system is used for, appropriate levels of leak or integrity testing shall be implemented by the single-use system supplier to prove inherent integrity of the single-use system before shipment. Packaging and shipping validation according to relevant ASTM or ISTA standards (e.g., ASTM D4169 or ISTA 3 as referenced in Nonmandatory Appendix HH, Table HH-2) shall be conducted by the suppliers of single-use systems to ensure maintenance of integrity during transportation to the owner/user sites. At the owner/user site, visual inspection and leak tests should be conducted, commensurate with the level of risk for the intended use. Operator training and appropriate procedures shall be implemented to reduce the risk of compromising the integrity during installation and use.

Monitoring of integrity throughout the product life cycle, from manufacturing to disposal, should be performed to deliver reliability of performance.

SU-3.2 Integrity Versus Leak Testing and Correlation to Maximum Allowable Leakage Limit

When implementation of a leak test is required, physical test methods such as helium or pressure decay testing are nondestructive test methods that can be applied on single-use systems throughout their life cycle to allow further use. To ensure that such a test can fully cover the integrity of the single-use system, the test's detection limit shall be correlated to the maximum allowable leakage limit (MALL) (see GR-11 and Nonmandatory Appendix FF).

The manufacturer shall disclose if the physical test used is an integrity test or a leak test.

(a) If the physical test method can robustly detect a defect size at the MALL level and can confirm the barrier properties of the single-use system, it is an integrity test.

(b) If the test is less sensitive and cannot confirm the barrier properties of the single-use system, it is a leak test.

Direct correlation methods can be used in lieu of the indirect correlation method based on leak size.

SU-3.3 Common Leak and Integrity Test Methods

The decision to implement a leak or integrity test should be based on an overall risk mitigation strategy. Nonmandatory Appendix FF, Table FF-1-1 describes common physical nondestructive leak and integrity test

methods used for single-use systems. Nonmandatory Appendix FF, Table FF-1-2 describes common destructive leak and integrity test methods, including microbial challenge test methods, that can be used to determine the MALL for microbial integrity. The specifc test methods used during the life cycle shall be selected based on sensitivity, suitability, and practicality of the method.

SU-4 BIOCOMPATIBILITY

The biocompatibility of single-use components and assemblies shall be considered carefully due to the potential for large product contact areas and long contact times. Many of these components and assemblies are composed of multiple materials or multilayer structures, and the primary concern is how the process interacts with the contact surfaces. The design of the component and assembly shall not compromise the integrity, safety, or efficacy of the process fluid. The focus of evaluations should be on the material of construction of the process contact surface, but it is preferred to evaluate the complete component and assembly. At a minimum, the process contact surface shall conform to the following tests:

(a) biological reactivity, in vitro (cytotoxicity, i.e., USP <87>)

(b) biological reactivity, in vivo (i.e., USP <88>) or equivalent per recognized compendia

Additionally, the user should consider protein adsorption, preservative absorption, leaching of low-molecular-weight compounds, endotoxins, and the presence of animal-derived ingredients in single-use components and assemblies.

SU-5 EXTRACTABLES AND LEACHABLES

SU-5.1 General

Testing of process equipment/components made of polymeric materials for extractables and leachables should be done to identify chemical substances that could migrate into the process fluid, potentially affecting the process or altering the final product. Some examples of chemical substances identified in this testing include oligomers, monomers, curing (cross-linking) agents, catalysts, antioxidants, initiators, dyes, pigments, plasticizers, and mold release agents. The data generated may be used to make risk-based decisions of the potential impact that any identified substances may have on the final drug product and may aid in the selection of equipment/components. PM-3.2 provides information on extractables and leachables from polymeric materials. Nonmandatory Appendix P, P-4 provides an overview of bioprocessing equipment/component evaluation related to extractables and leachables characterizations.

SU-6 IDENTIFICATION

Single-use components and assemblies shall be designed and packaged to provide lot traceability. The traceability shall enable the owner/user to identify raw materials, processing conditions critical to support the manufacturer's specifications, and the date of manufacture.

SU-6.1 Labeling

The primary packaging of single-use components and assemblies shall be labeled with the following information:

(a) manufacturer
(b) part identifier
(c) lot identifier

Additional information for the label may be requested by the owner/user.

SU-7 CERTIFICATE OF CONFORMANCE

The single-use component or assembly manufacturer shall issue a Certificate of Conformance that contains the following information:

(a) manufacturer
(b) part identifier
(c) lot identifier
(d) date of manufacture and/or expiration date
(e) conformance information

Additional information for the Certificate of Conformance may be requested by the owner/user.

SU-8 INSPECTION AND PACKAGING

The packaging of single-use components and assemblies shall mitigate the risk of bioburden, particulates, or other contaminants (see SU-10 and Nonmandatory Appendix P, P-2). Inspection shall be performed to confirm the quality of the packaging and that the contents meet the specified criteria.

SU-8.1 Inspection

Single-use components and assemblies shall be inspected for the presence of particulates or other contaminants before primary packaging. This inspection shall take place in a controlled environment in accordance with the intended use of the final component or assembly.

SU-8.2 Packaging

The purpose of packaging of single-use components and assemblies is to control the potential introduction of bioburden, particulates, or other contaminants. The packaging shall not adulterate the component and assembly. Primary packaging shall take place in a controlled environment at a level suitable for the final use of the component or assembly. The packaging of

single-use components and assemblies shall be labeled according to SU-6.1.

(24) SU-9 STERILIZATION AND BIOBURDEN REDUCTION

Single-use assemblies and components shall be compatible with the intended bioburden reduction method.

The materials shall be compatible with the intended bioburden reduction method. The effects on physical and mechanical properties (e.g., appearance, tensile strength) and chemical characteristics of the materials used (e.g., leachable or extractable effects) shall be addressed (see PM-3). Lot-specific certification of processing shall be provided to the owner/user.

Bioburden reduction of single-use components and assemblies occurs prior to process contact. Bioburden reduction is typically accomplished by, but not limited to, the following:

(a) ionizing radiation
  (1) gamma irradiation
  (2) X-ray irradiation
  (3) electron beam (E-beam)
(b) steam sterilization
  (1) autoclaving
  (2) SIP
(c) chemical sterilization [ethylene oxide (ETO)]

The owner/user shall determine the appropriate level of documentation required for the given application.

When a bioburden reduction methodology is applied to a single-use component or assembly, the supplier-issued Certificate of Conformance shall indicate the methodology to which the component or assembly was subjected.

SU-9.1 Ionizing Radiation

Single-use assemblies that will be subjected to ionizing radiation shall be manufactured in a controlled environment. The maximum recommended ionizing radiation dose shall be specified by the manufacturer of the single-use assembly or component.

The degrees of validation are the following:

(a) validated sterility assurance level of 10-6 per a recognized standard (e.g., ISO 11137).

(b) irradiated to the specified dose range. No validation of the effectiveness is conducted. The supplier is not certifying a sterility assurance level per a recognized standard (e.g., ISO 11137). This is often referred to as bioburden control or microbial control.

SU-9.2 Steam Sterilization

(a) Single-use assemblies that will be autoclaved shall be manufactured in a controlled environment. See SD-6.2.4 for autoclave material requirements of single-use components and assemblies.

(b) Single-use assemblies used to connect single-use systems to multiuse (metallic) systems that are subjected to SIP shall meet the requirements in SC-1(e).

SU-9.3 Chemical Sterilization

Single-use assemblies that will be subjected to ethylene oxide shall be manufactured in a controlled environment. The allowable limits for residual ethylene oxide shall be considered when establishing the ETO cycle.

The degrees of validation are the followiing:

(a) validated sterility assurance level of 10-6 per a recognized standard (e.g., ISO 11135).

(b) ethylene oxide exposure to the specified operational range. No validation of the effectiveness is conducted. The supplier is not certifying a sterility assurance level per a recognized standard (e.g,. ISO 11135). This is often referred to as bioburden control or microbial control.

SU-10 SHELF LIFE, STORAGE, AND EXPIRATION DATE (24)

The shelf life of a single-use component or assembly is the duration under specified storage conditions from the date of manufacture to the last date the product can be placed in service and remain suitable for its intended use. The expiration date is the date after which the shelf life has been exceeded. The manufacturer shall, on request, provide the methodology used to determine shelf life or expiration date such as aging tests, stability tests, or other industry standards.

(a) Nonsterilized Components and Assemblies. The manufacturer shall provide an expiration date (preferred) or the manufacturing date and shelf life, plus storage requirements and any special handling requirements. Shelf life shall be based on raw material, component, or assembly data.

(b) Sterilized Components and Assemblies. The manufacturer shall provide expiration dates, storage requirements, and any special handling requirements. Shelf life shall be based on raw material, component or assembly data, sterilization method, and package integrity.

(c) Nonsterile Components Marketed for Use in Sterilized Assemblies. The component manufacturer should provide one of the following:

(1) expiration date or shelf life independent of sterilization date
(2) shelf life plus poststerilization shelf life

The shelf life of any assembly shall not be longer than the shelf life of any component in the assembly. Package integrity testing shall be performed per a relevant standard (e.g., ISO 11607). See SU-8.2.

SU-11 PARTICULATES

Single-use components and assemblies should be free of loose, nonembedded, and solid particulates as seen by direct visual observation without magnification. Particulates greater than or equal to 100 µm are considered to be visible. The TAPPI Size Estimation Chart may be used for reference. Particulates smaller than 100 µm, considered to be subvisible, should be minimized.

SU-11.1 General

Particulates may unintentionally be present on surfaces of the single-use article and may impact the manufacturing process or product. Particulate sources include machines, materials, methods, environment, and people. More information and characteristics of particulates may be found in Nonmandatory Appendix O, O-2.

SU-11.2 Particulate-Monitoring Program

The supplier shall have an established risk-based particulate-monitoring program. The program should include testing, trending analysis, particulate characterization, and analysis of particulate quantity and size.

SU-11.3 Mitigation Techniques

The materials, design, manufacturing operations, environment, and product use should be considered for their impact on particulate generation and control. The level of observation and particulate control should be appropriate for the degree of risk for the particular application (e.g., fill/finish).

SU-11.3.1 Suppliers. Suppliers shall implement controls to ensure their single-use products meet established particulate criteria. Typical controls include the following:

(a) proper use and maintenance of manufacturing equipment

(b) use of controlled environments for the manufacturing and assembly process such as a classified clean room or clean zone

(c) appropriate packaging; see SU-8

(d) training of manufacturing personnel on particulate control practices

(e) product inspection and documentation of batch records

(f) establishment of a particulate investigation process

SU-11.3.2 Owner/User. Owner/users should implement controls to ensure their use of single-use products meets established particulate criteria. Typical controls include the following:

(a) procedures to determine risk associated with particulate matter

(b) supplier quality agreements

(c) required incoming inspection documentation

(d) training of personnel in best practices for the handling and use of single-use products

(e) establishment of a particulate investigation process

SU-12 DESIGN CONFORMANCE (24)

Design conformance testing shall be specified, performed, and documented by the component or assembly manufacturer. Verified design aspects should include, but are not limited to, those listed in Table SU-12-1. Manufacturers shall specify or indicate testing frequency. Manufacturers shall provide a Certificate of Conformance to substantiate that the design aspects relevant to the component or assembly have been verified. Pertinent test data should be available for review on request.

The owner/user should assess design conformance to ensure the components and assemblies meet the user requirements. This assessment may be performed through design review, design qualification, or another method established by the owner/user.

Table SU-12-1
Single-Use Design Aspects

Design Aspect	Applicable ASME BPE Guidance Section
Physical and mechanical properties of thermoplastic polymers	PM-3.3
Chemical compatibility of thermoplastic polymers	PM-3.4
Animal-derived ingredients	SD-2.6
Integrity	SU-3
Biocompatibility	SU-4
Extractables and leachables	SU-5
Identification	SU-6
Sterilization (bioburden control)	SU-9
Shelf life, storage, and expiration date	SU-10
Particulates	SU-11
Microbial ingress	SC-2.1

CHAPTER 8
PROCESS COMPONENTS FOR SINGLE-USE

PART SC
COMPONENTS FOR SINGLE-USE

SC-1 STEAM-THROUGH AND STEAM-TO CONNECTORS

Steam-through and steam-to connectors are designed to connect single-use systems to multiuse (metallic) systems. Steam-through and steam-to connections shall

(a) form a hygienic clamp union, meeting the requirements of Parts DT and MC

(b) maintain a seal (see MC-4)

(c) be drainable (see Part SD)

(d) be sterilizable (see SU-9)

(e) be compatible with SIP, poststerilization (e.g., gamma irradiation) at 266°F (130°C) for 1 hr (exposed surfaces)

(f) meet the biocompatibility requirements of PM-3.1

(g) meet the Certificate of Conformance requirements of Table PM-2.2.1-1.

SC-2 ASEPTIC CONNECTORS

Aseptic connectors allow single-use assemblies to be joined while maintaining a sterile process contact surface before, during, and after connection, without regard to the manufacturing environment.

SC-2.1 Manufacturer Responsibilities

The manufacturer shall

(a) conduct microbial ingress testing to qualify that a sterile fluid path postconnection is not compromised

(b) define whether the connectors are dry connectors or wet connectors

(1) Dry means liquid cannot be in the connector. Pinch clamps or another suitable technique must be used to isolate the liquid from the connector prior to use.

(2) Wet means the connection can be made with liquid in the connector.

(c) provide product specifications including, but not limited to, the following:

(1) temperature ratings

(2) pressure ratings

(3) sterilization method compatibility (e.g., gamma, autoclave)

(4) product flow path cleanliness (particulates, endotoxins, bioburden)

(5) flow rates

(d) define the gender of the connector halves

(1) unique male and female halves

(2) genderless, where each half is identical

(e) define whether the connection is designed for one-time connection or multiple connections

(1) Connectors designed for a one-time connection shall incorporate an irreversible locking mechanism, unless it is specifically designed for aseptic disconnect.

(2) Connectors designed for multiple connections and disconnections shall have the maximum number of connections specified.

(f) provide assembly instructions to ensure proper connection

SC-2.2 Owner/User Responsibilities

The owner/user should

(a) review the manufacturer's specifications against the service requirements for all applicable process and sterilization conditions

(b) ensure the connection will be performed to a qualified procedure by a properly trained operator to maintain system integrity

SC-3 FLEXIBLE BIOPROCESS CONTAINERS (BAGS)

Flexible bioprocessing containers, also referred to as single-use bags, are available in 2D or 3D format, in different configurations and volume capacities. These bags are used in assemblies for preparation, storage, sampling, transfer, and transport of bioprocess fluids or powders. The bags have connection ports and are used in conjunction with tubing or tubing manifolds to allow for filling, dispensing, sampling, and other process functions. This section provides requirements on materials of construction and qualification.

SC-3.1 Materials

Multilayer films are often used to manufacture single-use bags. The manufacturer should identify the material of construction of all film and tie layers of the bag. For bags intended for process contact, the manufacturer shall identify all materials (e.g., primary materials, tie layers, and additives) that have the potential to adulterate the bag contents.

(24) **SC-3.1.1 Material Attributes and Characterization.** The single-use bag manufacturer shall provide physical and functional characterization of single-use bags (for examples, see Nonmandatory Appendix HH).

SC-3.2 Qualifications

The manufacturer shall provide the operating temperature and pressure limits of the single-use bag. The manufacturer shall specify appropriate sterilization methods, including range of exposure, poststerilization shelf life, and other limitations. The manufacturer should provide handling and safe use procedures, including hanging restrictions, filling limitations, and secondary containment recommendations.

(24) **SC-3.2.1 Physical Qualifications.** The single-use bag manufacturer shall provide single-use bag dimensions such as overall size and sizes and locations of accessories (e.g., inlets, outlets, impellers, sensors, handles).

The single-use bag manufacturer shall provide the nominal and maximum operating volume of the single-use bag. The single-use bag manufacturer should provide minimum functional volumes where relevant for the purposes of the operation (e.g., storage, mixing).

The single-use bag manufacturer shall provide application-specific dimensions required for assessing fluid contact area.

(24) **SC-3.2.2 Temperature and Pressure Qualifications.** The single-use bag manufacturer should provide maximum operating pressure conditions. Unless specifically stated, single-use bags are generally not intended for use with atmospheric pressures exceeding 0.2 psig (13.8 mbarg) at the top of the fluid.

Where applicable (e.g., 3D bags, applications under pressure), the single-use bag manufacturer shall provide specifications for a rigid outer container, ventilation, pre-use inflation, and port locations.

Single-use bag operating temperature ranges shall be specified by the single-use bag manufacturer, substantiating performance via an established testing program.

(24) SC-4 POLYMERIC HYGIENIC UNIONS

See MC-2.2.2.

SC-5 VALVES (24)

SC-5.1 General

(a) For the purpose of this section, valves intended for single-use applications are defined as valves that allow for the replacement of the single-use process contact components after each use.

(b) Process contact surfaces of valves requiring sterilization shall conform to SU-9.

(c) The internal geometry of valves should be designed to minimize holdup volume.

(d) Valves shall be compatible with chemical and thermal sanitization conditions where required and shall be capable of operating as required during those processes.

(e) Pneumatically controlled valves shall be designed to prevent air transfer from the actuator to the process.

(f) The valve supplier/manufacturer should provide performance data for the intended single-use process contact polymeric material type (e.g., platinum cured silicone, thermoplastic elastomer).

(g) For valve assemblies, the manufacturer shall specify an enclosure rating (e.g., ingress protection rating, washdown duty) when required.

(h) Installation of valves shall be as per the manufacturer's recommendations to ensure valve performance and to minimize holdup volume when applicable (e.g., orientation of a diaphragm valve).

SC-5.2 Pinch Clamps

(a) For the purpose of this subsection, pinch clamps (see Figure SC-5.2-1) are manually operated, self-supporting, lightweight components used in conjunction with tubing to create an internal sealing surface.

(b) Consideration should be given to the maximum number of actuations when using multiple cycles to assess fatigue caused by operation.

(c) The supplier/manufacturer shall provide tubing material types and sizes that can be used per clamp model to ensure sealing performance.

(d) As pinch clamps are not designed to be fixed in place, consideration should be given to the pinch clamp configuration and weight to avoid unintentional restriction of flow.

(e) Pinch clamps intended for sterilization shall conform to SU-9.

SC-5.3 Pinch Valves

(a) For the purpose of this subsection, pinch valves (see Figure SC-5.3-1) are used to control flow or pressure or to create a seal within elastomeric tubing.

(b) The pinch valve assembly used shall be suitable for the intended tubing, as recommended by the pinch valve assembly supplier/manufacturer, as pinch valve compression and cycling affects tubing performance.

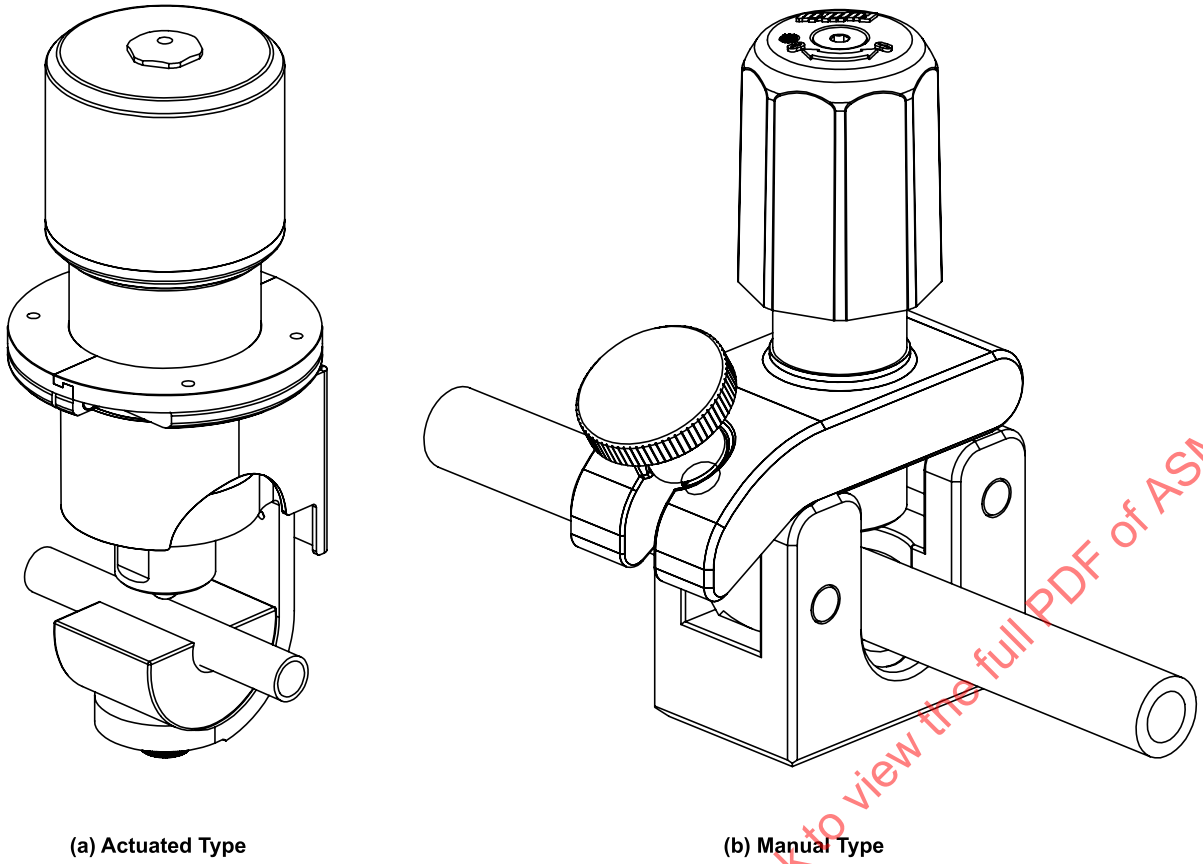
Figure SC-5.2-1
Typical Pinch Clamps

(a) Ratchet Type

(b) Thumbscrew Type

(c) Flow Control Type

SC-5.3-1
Typical Pinch Valves



(a) Actuated Type

(b) Manual Type

(c) A mechanism shall be included to ensure the sealing pinch point is protected from operator interaction.

(d) The tubing size range shall be specified to allow complete compression to form an internal seal. The amount of compression is dependent on the tubing material selected. The tubing size range is determined by the inner diameter and tubing wall thickness.

(e) The supplier/manufacturer shall specify the mounting options for assembly to equipment to ensure intended operation.

SC-5.4 Diaphragm Valves

(a) Diaphragm valves (see Figure SC-5.4-1) intended for single-use utilize a disposable body and diaphragm set and are generally used for flow, pressure, or proportional control.

(b) Weir diaphragm valves, where required, shall be installed at the optimum position and orientation to minimize internal holdup volume.

(c) Diaphragm valves shall be manufactured with appropriate mating connections for single-use components (e.g., hose barb, hygienic clamp union).

(d) The valve design should enable immediate leak detection between the process side and the environment.

(e) The valve actuator should be fitted with a leak detection port to indicate primary seal leakage.

(f) The single-use portion of a diaphragm valve assembly shall conform to SU-9.

(g) Once installed, the diaphragm and valve body should form a closed system to prevent product leakage.

SC-5.5 Material Requirements

SC-5.5.1 Process Contact

(a) Process contact materials shall conform with PM-2.2, PM-3.1, PM-3.2, SU-4, and SU-5.

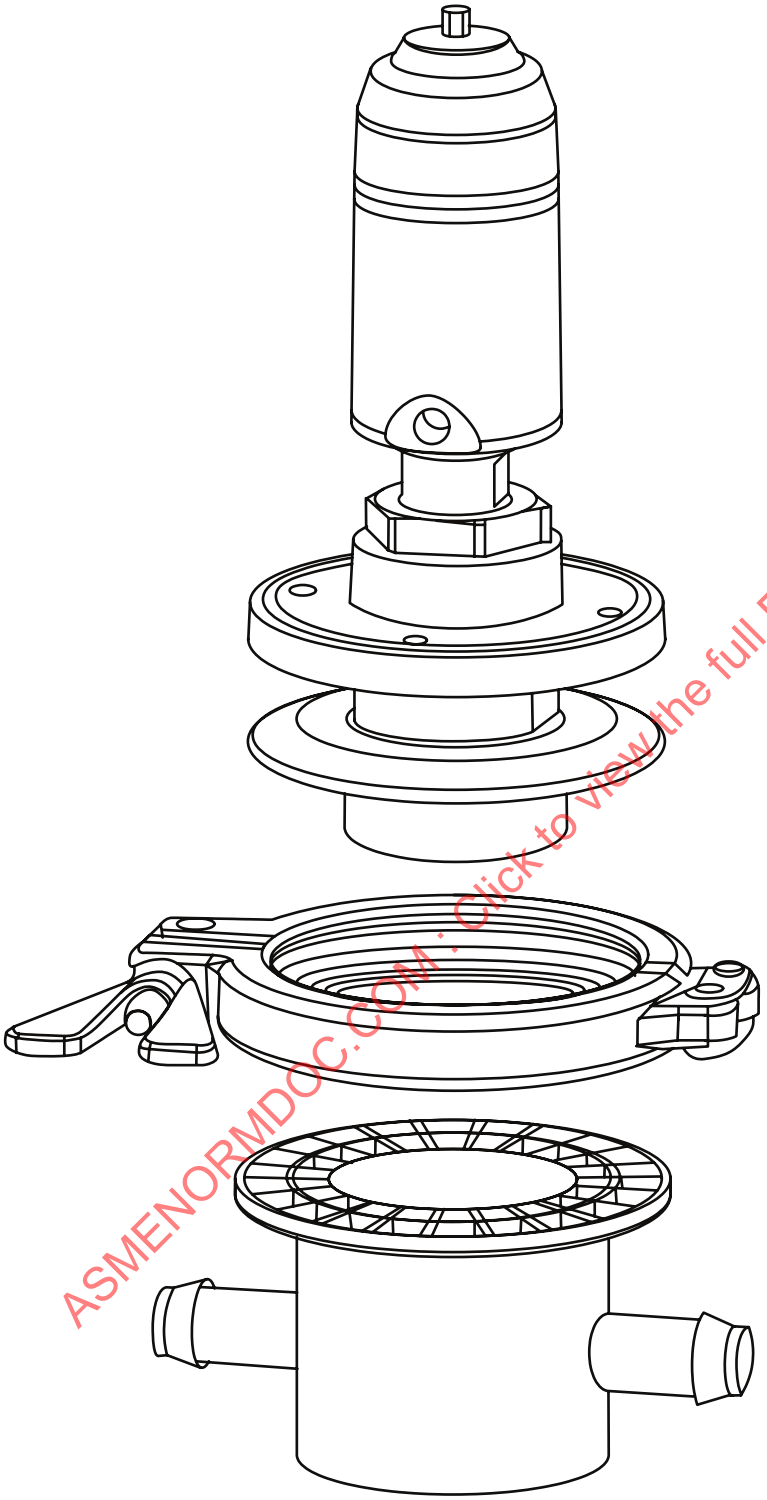
(b) Materials shall conform to SU-9.

SC-5.5.2 Non-Process Contact

(a) Non-process contact materials should be compatible with the conditions to which the materials will be exposed.

(b) Materials exposed to external cleaning shall be compatible with cleaning chemicals as per SD-2.4.4.2.

Figure SC-5.4-1
Typical Diaphragm Valve



(c) Materials exposed to a sterilization method shall conform to SU-9.

SC-5.6 Valve Performance

The valve assembly manufacturer shall specify and qualify valve performance. Performance specifications could include process temperature limits, system pressure limits, material compatibility, and duration of use.

SC-5.7 Identification Requirements

Process contact materials shall conform to SU-6. Interchangeable parts that can affect form, fit, or function shall be identified for their intended purpose (e.g., tubing size, material, material hardness).

CHAPTER 9
FABRICATION, ASSEMBLY, AND ERECTION FOR SINGLE-USE

PART SJ
JOINING METHODS FOR SINGLE-USE

SJ-1 GENERAL

The joining of components may be performed in many ways for single-use applications. Examples of these joining techniques include, but are not limited to, welding, heat sealing, over-molding, solvent bonding, mechanical connections, and adhesives. With any of these methods, the procedure for the joining of polymers, components, or assemblies shall be controlled to ensure repeatable results. The joint shall not leak, shall meet the pressure requirements for the intended use, and shall maintain the integrity of the component or assembly.

SJ-2 MECHANICAL HOSE BARB CONNECTIONS

This section applies to the mechanical joining of single-use assemblies using a hose barb, flexible tubing, and a retention device, commonly referred to as a hose barb connection. Flexible hose assemblies intended for repeated use are addressed in PM-4.3.2 and SD-3.2.

See Nonmandatory Appendix GG for additional design considerations.

SJ-2.1 Operating Conditions

The owner/user should define the operating temperature range, operating pressure range, and sterilization method (if applicable) for the intended use of the hose barb connection.

SJ-2.2 Assembly

Manual assembly of single-use hose barb connections shall follow documented standard operating procedures. Assembly equipment (e.g., tubing stretchers, fitting inserters, retention devices, and application tools) shall be maintained in a state of calibration. Fluids used to aid in the insertion of a hose barb into flexible tubing shall be identified by chemical type and meet the requirements of PM-2.1.

SJ-2.3 Qualification

Single-use hose barb connections shall be qualified by the supplier to ensure they meet performance criteria as stated in their specification. The supplier shall have an established testing program to substantiate performance of the mechanical connection. The testing should reference at least one of the following:

(a) *Pressure Testing*. Reference ASTM D1599, ISO 1402
(b) *Leak Testing*
  (1) *Pneumatic*. Reference ASTM E515
  (2) *Vacuum*. Reference ASTM D4991
  (3) *Hydraulic*. Reference ASTM 1003
(c) *Tracer Gas Testing*. Reference ASTM E499

SJ-3 THERMAL WELDING OF THERMOPLASTIC ELASTOMER TUBING

Thermoplastic elastomer (TPE) tubing is used as part of single-use assemblies when there is a need to join or separate the assembly from the single-use system or other process equipment without the use of mechanical fittings. Welding of rigid thermoplastic tubing and piping is addressed in MJ-9.

SJ-3.1 Specifications

Thermal welding shall be performed using the procedure provided by the welding equipment manufacturer. Tubing material, dimensions (e.g., inner and outer diameters), and tubing prewelding sterilization shall be compatible with the capabilities of the welding equipment.

SJ-3.2 Design Parameters

TPE tube welding equipment for closed processing shall be designed to

(a) fuse two integral tubing assemblies and maintain an aseptic flow path during the welding process to form one closed system

(b) maintain the flow and pressure characteristics of the assembly after fusing

SJ-3.3 Acceptance Criteria

The weld shall be evaluated to confirm it is leak free and meets the owner/user's acceptance criteria. Acceptance criteria may include

(a) tolerance requirements for tube-to-tube alignment
(b) presence of bubbles, gaps, contaminants or foreign material, and internal flash or occlusion of tubing lumen

PART SI
SINGLE-USE PROCESS INSTRUMENTATION

(24)

SI-1 PURPOSE AND SCOPE

The purpose of this Part is to provide the requirements for process instrumentation and their supporting components for single-use applications.

SI-2 SINGLE-USE PROCESS INSTRUMENTATION GENERAL REQUIREMENTS

Process instrumentation for single-use applications includes, but is not limited to, sensors and supporting components (e.g., optical viewing windows and port plates).

MANDATORY APPENDIX II
STANDARD UNITS

See Table II-1.

Table II-1
Standard Units

Quantity	U.S. Customary	SI Units
Length	inches (in.)	millimeters (mm)
Length	feet (ft)	meters (m)
Area	square inches (in.^{2})	square centimeters (cm^2)
Volume	cubic inches (in.^{3})	cubic centimeters (cm^3)
Volume	gallons (gal)	liters (L)
Pressure, gauge	pounds per in.^{2} (psi$_g$)	kilopascal (kPa$_g$)
Pressure, absolute	pounds per in.^{2} (psi$_a$)	kilopascal (kPa$_a$)
Vacuum	pounds per in.^{2} (psi)	kilopascal (kPa)
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)
Angle (plane angle)	degrees or radians	degrees or radians
Surface finish	microinch (μin.)	micron or micrometer (μm)
Slope	inches per foot (in./ft)	millimeters/meter (mm/m)
Flow rate, liquid	gallons per minute (gal/min)	liters per minute (L/min)
Flow rate, gas	std. cubic feet per hour (std. ft^3/hr)	std. liters per minute (std. L/min)
Speed/velocity	feet per second (ft/sec)	meters per second (m/s)
Coefficient of thermal expansion	inch per inch per degree [in./(in./°F)]	millimeters per millimeter per degree [mm/(mm/°C)]

MANDATORY APPENDIX III
SINGLE-USE COMPONENTS AND ASSEMBLIES (24)

DELETED

MANDATORY APPENDIX IV
NOMENCLATURE

Symbol	Definition	Units [Note (1)]		Reference		
		U.S.	SI	Paragraph/App.	Table/Figure	Equation
A	Distance of the annular space between the O.D. of a dip tube or shaft and the I.D. of a nozzle neck	in.	mm	...	Figure SD-3.4.3-1	...
D	Outside diameter of tube or pipe	in.	mm	...	...	...
	Diameter	in.	mm	SD-3.9.2.1 SD-3.9.2.2	...	...
d	Inside diameter	in.	mm		Figure SD-4.1.2.2-1	...
	I.D. of the extension or leg of tubing or fitting	in.	mm	SD-3.1.2.2	...	...
	Nominal dimension of a valve or instrument	in.	mm	SD-3.1.2.2	...	...
d_M	I.D. of instrument sensor measuring tube	in.	mm	...	Figure PI-4.1.3.3-1	...
d_S	I.D. of instrument sensor process connection	in.	mm	...	Figure PI-4.1.3.3-1	...
H	Height	in.	mm	...	Figure SD-4.1.2.2-1	...
L	Length	in., ft	mm, m	PM-4.2.3 SD-3.1.2.2	Table SD-3.1.2.2-1 Table SD-3.1.2.2-2 Figure SD-3.3.2.2-4 Figure SD-3.4.2-1 Figure SD-3.4.2-4	... ...
L_{min}	Minimum length or distance	in.	mm	...	Figure PI-9.1.3.4-1 Figure PI-9.1.3.4-2	...
L/A	Ratio of the nozzle neck length divided by the distance of the annular space between the O.D. of a dip tube or shaft and the I.D. of a nozzle neck	...	...	SD-3.4.3 SD-3.5.1	Figure SD-3.4.3-1	...

Symbol	Definition	Units [Note (1)]		Reference		
		U.S.	SI	Paragraph/App.	Table/Figure	Equation
L/d	Dead leg determination	...	...	SD-3.1.2.2 SD-3.3.2.2 SD-3.4.2 SD-3.7.3 SD-3.7.4 SD-3.15 SD-4.1.2.2 SD-6.1.4.2 SD-6.1.5.1 SD-6.3.5.2.1	Table SD-3.1.2.2-1 Table SD-3.1.2.2-2 Figure SD-3.1.2.2-1 Figure SD-3.3.2.2-4 Figure SD-3.4.2-1 Figure SD-3.4.2-4	...
Q	Flow rate	gpm	lpm	...	...	...
Q_L	Leak rate	...	mbar–L/s	SD-5.6.7	...	eq. (1)
R	Radius	in.	mm	...	Table DT-4.5.1-1 Table DT-4.5.2-1 Figure PI-8.1.3.4-1	...
R_a	Roughness average	µin.	µm	SD-4.1.2.2 SF-3.4 Nonmand. App. N	Table SF-2.2-1 Table SF-2.2-2 Table SF-2.4.1-1 Table SF-3.3-1 Table SF-3.4-1	...
S_L	Sensitive length	in.	mm	...	Figure PI-7.3.5-1	...
T	Temperature	°F	°C	PM-4.2.3	...	...
t	Time	sec, min	s, min	...	...	...
T_L	Tangent length	in.	mm	DT-4.1	Table DT-3-1 Table DT-4.1-1	...
T_W	Nominal wall thickness	in.	mm	...	Table MJ-6.3-2 Table MJ-8.4-1 Figure MJ-8.4-1 Table MJ-8.5-1 Figure MJ-8.5-1 Figure MJ-9.7.1-1	...
V	Volume	gal	L	SD-5.6.7	...	eq. (1)
W	Wavelength	...	nm	Nonmand. App. M-3	...	...
α	Coefficient of thermal expansion	in./in./°F	mm/mm/°C	PM-4.2.3	...	eq. (2) eq. (3)
	Primary angle	deg	deg	...	Figure PI-2.2.2-1	...

GENERAL NOTE: For reference to this Mandatory Appendix, see GR-11.
NOTE: (1) Use of the specific units of measure are not required by this Standard. However, while the units of measure are not required they are an essential element with regard to the equations represented in this Standard.

NONMANDATORY APPENDIX A
SLAG AND OXIDE ISLAND FORMATION IN WELDS

(24)

(a) Inert-gas shielded welding processes do not produce slag. See GR-11 and AWS A3.0 for definition of slag.

(b) Welds on stainless steel tubing can produce a thin film that appears as localized islands on the surface of the weld. In welds on nickel alloys, stainless steels, or welds alloyed with nickel filler metals, these films have been identified as high-melting-point nonmetallic oxides, typically referred to as oxide islands.

(c) Oxide islands encountered on welds in stainless steels and nickel alloys identified in Tables MM-2.1-1 through MM-2.1-3 are commonly found in one of the following forms:

(1) On stainless steels, a small, round, black spot at the termination of the weld bead, on the outside or inside surface, or both. This spot is generally unavoidable.

(2) On products made from cast or wrought stainless steels and nickel alloys, a thin film, gray or the same color as the weld surface, may be evident because it covers the weld ripples.

(3) On nickel alloys or stainless steels welded with nickel alloy fillers, a thin film, having varying color with tints from gray to dark brown, may be evident because it covers the weld ripples.

(d) Slag in or on welds may be the result of faulty weld preparation, such as contamination, poor cleaning, or faulty tack welding procedures.

(e) Slag may also result from melting base metals of certain compositions that include elements not normally reported on Material Test Reports. These elements include, but are not limited to, aluminum, calcium, cerium, and zirconium.

(f) The owner/user and contractor should investigate the origin of any slag found during weld examination, determine its acceptability, and agree on any corrective action.

NONMANDATORY APPENDIX B
MATERIAL AND WELD EXAMINATION/INSPECTION DOCUMENTATION

See Forms MEL-1, MER-1, and WEL-1 beginning on next page.

BPE **Form MEL-1 Material Examination Log**

Project Number/Name: _____ From (Supplier or Manufacturer): _____

A/E Project Number: _____ Date Received: _____

Received by (Company): _____ Person Receiving Material (Printed): _____

Staged Location of Material: _____ Person Receiving Material (Signature): _____

List only material received from a single source.

Manufacturer	Material or Alloy Type	Sample Description	Heat No. or Lot No.	Wall Thickness	O.D. Tolerance	Surface R_a	Visual [Note (1)]	Product Marking [Note (2)]	MTRs Verified	Quantity Received	Quantity Examined	Qty. Accept Qty. Reject	Examiner's Initials	Date Examined	NCR Number

Comments: _____

GENERAL NOTES:
(a) "A" or Acc. indicates a conformance with the applicable sections of Part DT.
(b) "R" or Rej. indicates a nonconformance with the applicable sections of Part DT.

NOTES:
(1) Per applicable sections of Part SF.
(2) Markings verified to be in accordance with DT-11.

☐ Attachments: ( ) Pages Approving Supervisor: _____ Date: _____

Copies: ☐ Owner ☐ A/E ☐ Contractors ☐ Consultants ☐ _____ ☐ _____ ☐ _____ ☐ _____ ☐ _____ ☐ File

BPE **Form MER-1 Material Examination Record**

Project Number/Name: _____ A/E Project Number: _____

Record Number: _____ Received by: _____ Date Received: _____

Owner/User: _____ Name and Date of Approval: _____

Customer Company Name: _____
(Enter the name of the company receiving the material.)

Address: _____
(Enter the address of the company receiving the material.)

Contact Names and Numbers: _____
[Enter the name(s) and contact information of personnel receiving the material.]

Supplier/Manufacturer Name: _____
(If receiving a product or material, enter the name of the company supplying the material.)

Address: _____
(If receiving a product or material, enter the address of the company supplying the material.)

Contact Information: _____
[If receiving material, enter the name(s) and contact information of personnel supplying the material.]

Project Information: _____ NCR Number: _____
(Related Specifications, Codes, and Standards) *(NCR report number if needed)*

Heat Number/Heat Code: _____ Material Specification: _____
[Record heat number(s) for the sample.] *(ASTM spec., customer spec.)*

P.O. Number: _____
(Enter associated purchase order number here.)

Packing List Number: _____
(Enter packing list and/or tracking number here.)

Lot Number: _____
(For multiple lot shipments, enter associated lot number here.)

Examiner's Information: _____
(Enter the name of the examiner, company of examiner, etc.)

Material/Alloy Type: _____
[Enter the type or grade of material (UNS S31603, N08367, etc.)]

Material Description: _____
[Enter the size, material product form (tubing, 90, 45, TEE, ferrule, valve, etc.)]

DT-11 Compliant: _____
(Record Accept or Reject after markings verification.)

Wall Thickness: _____
[Record Accept or Reject after physical examination of the lot (if required).]

O.D. Tolerance: _____
[Record Accept or Reject after physical examination of the lot (if required).]

Surface R_a: _____
[Record Accept or Reject after physical examination of the lot (if required).]

Visual Examination: _____
(Record Accept or Reject after physical examination.)

MTR(s) Verified: _____
(Record Accept or Reject for MTR compliance with specifications.)

Quantity Received: _____ Quantity Accepted: _____ Quantity Rejected: _____ Date Examined: _____

Comments: _____
(Record any notes for examination, and attach additional sheets if needed.)

Copies: ☐ Owner ☐ A/E ☐ Contractors ☐ Consultants ☐ _____ ☐ _____ ☐ File

Form WEL-1 Weld and Examination/Inspection Log

Project Number/Name: _____ Fabricating Contractor: _____

A/E Project Number: _____ Isometric/Drawing Number: _____

Owner/User: _____ Name and Date of Approval: _____

Weld Log				Examination				Inspection				
Weld No.	Weld Date	Welder or Welding Operator ID	Size	Type [Note (1)]	Accept/ Reject	Initials	Date	Type [Note (1)]	Accept/ Reject	Initials	Date	Comments [Note (2)]/Reject Cause

GENERAL NOTES:

(a) Welds shall be uniquely identified per applicable drawings.
(b) Rejected welds that can be rewelded shall use the same number with an "R" after it.
(c) Rejected welds that must be cut out and replaced with a new weld shall be assigned the same identifier followed by an "A" for the first, "B" for the second, etc. in consecutive order.
(d) If a weld is cut out for a reason other than a rejected weld, it shall be recorded as a "Deleted" weld in the Comments section. The replacement weld shall be assigned the next available identifier.
(e) Coupon welds may be listed with production welds or listed separately. Either way, the coupon weld should be identified with the symbol "CPN" as either a prefix or a suffix to the user's weld numbering format.

NOTES:

(1) VO = Visual O.D. only; VI = Visual O.D. and I.D.; B = Visual O.D. and Borescope I.D.
(2) Blind welds shall be indicated as "Blind" in the Comments section. Manual welds shall be indicated as "Manual" in the Comments section. Videotaped welds shall be indicated as "Video" in the Comments section. Any other requirements may be indicated in the Comments section.

Copies: ☐ Owner ☐ A/E ☐ Contractors ☐ Consultants ☐ _____ ☐ _____ ☐ _____ ☐ _____ ☐ _____ ☐ File

NONMANDATORY APPENDIX C
SLOPE MEASUREMENT AND JOINT MISALIGNMENT

C-1 GENERAL

(a) Slope measurement shall be made with a digital level or a digital protractor. The instrument used should be capable of displaying slope in degrees, percent, and in./ft (mm/m).

(b) Refer to the owner's manual for the proper procedure to perform the self-calibration routine. This must be performed immediately prior to use.

(c) Slope measurements shall only be made under the following conditions:

(1) before insulation has been installed

(2) after hangers/pipe supports have been installed, adjusted, and fixed in place

(3) before the introduction of any fluids, such as liquids or process gases (pure oxygen, nitrogen, steam, etc.)

(4) when the system is at ambient pressure and temperature

(d) For piping or tubing systems, slope measurements shall be made at the following locations:

(1) between hangers/pipe supports

(2) at each change in direction

(3) at any other location deemed necessary by the inspector, such as between welds or any apparent change in slope

(e) Slope should be measured only on runs that are approximately horizontal.

(f) Slope measurements may be made on either the top or bottom of the tubing/piping.

(g) For slope measurements made on skids or modules, ensure that the base is level in all directions. Then, make sure that all slope measurements are made relative to the base.

(h) Slope shall be verified after the fabricator has completed, or corrected, the piping installation and set the slope.

C-2 JOINT MISALIGNMENT

In order to meet O.D. misalignment criteria in this Standard, the accumulated tolerances in piping, tubing, and fittings may result in a welded joint with an I.D. misalignment. Should this occur, the owner/user, installation contractor, and inspection contractor shall apply good engineering judgment to determine the best solution for the application considering flow, orientation, and drainability.

The orientation of the piping, tubing, or fittings should be considered prior to final disposition of the weld joint prior to welding.

(a) Vertical Orientation

(1) Misalignment should be uniformly distributed around the circumference.

(2) Direction of flow should be considered when assembling the components.

(b) Horizontal Orientation. Misalignment should be oriented for drainability, normally accomplished by minimizing the I.D. misalignment at the bottom.

NONMANDATORY APPENDIX D
ROUGE AND STAINLESS STEEL

D-1 GENERAL

This Appendix provides methods to measure rouge in a system both in the process solution and on the actual product contact surface. It also suggests various fabrication and operation practices to minimize rouge formation and methods/techniques for its remediation.

For the definition of rouge and its classification, see GR-11.

D-2 CONSIDERATIONS FOR REDUCING ROUGE FORMATION

Tables D-2-1 and D-2-2 provide guidance on different variables and how they may contribute to the presence of rouge in a high-purity system. They are listed in the following categories:

(a) Category 1: Little Influence on the Formation of Rouge. There are theories that suggest other factors that may have a role in the formation of rouge. These variables are not listed in Tables D-2-1 and D-2-2.

(b) Category 2: Moderate Influence on the Formation of Rouge. There is industry data supporting these variables, and they should be considered.

(c) Category 3: Strong Influence on the Formation of Rouge. There is well-established industry data supporting these variables, and they should be considered.

D-2.1 System Fabrication

See Table D-2-1 for a discussion of fabrication variables that affect the amount of rouge formation.

D-2.2 System Operation

See Table D-2-2 for a discussion of operation variables that affect the amount of rouge formation.

D-3 EVALUATION METHODS TO MEASURE ROUGE

Rouge can be measured by its presence in the process fluid and/or its presence on the process contact surface.

D-3.1 Process Fluid Analyses

Fluid analyses provide a means of identifying the mobile constituents within a subject process system. They represent the current quality status of the media and the result of rouging.

Table D-3.1-1 provides descriptions, pros, and cons of various tests for the identification of mobile constituents.

D-3.2 Solid Surface Analyses

Surface analyses provide information on the nature, microstructure, and composition of surface layers. They may represent the future status of the media and the possible threat of rouging to the water quality.

Table D-3.2-1 provides descriptions, pros, and cons of various tests for the identification of the composition of surface layers.

D-4 METHODS TO REMEDIATE THE PRESENCE OF ROUGE IN A SYSTEM

Remediation (derouging) processes are designed to remove iron oxide and other surface constituents of rouge while minimizing damage to the surface finish. Rouge occurs on the surface, from corrosion, or precipitates onto the surface after migrating from other locations. These conditions are easily categorized by using the standard Classes I, II, and III rouge. The following sections describe remediation processes and the conditions under which they are performed.

D-4.1 Class I Rouge Remediation

Class I rouges are weakly attached to the surface and are relatively easily removed and dissolved. This rouge is generally hematite or red ferric iron oxide with low levels of other oxides or carbon content. Phosphoric acid is useful to remove light accumulations and may be blended with other acids and compounds including citric, nitric, formic, or other organic acids and surfactants to assist in its derouging effectiveness. Citric acid–based chemistries with additional organic acids are effective at rouge removal. The use of sodium hydrosulfite (i.e., sodium dithionite) is also fast and effective at removal of Class I rouge.

These chemistries are processed at elevated temperatures from 104°F to 176°F (40°C to 80°C) for between 2 hr and 12 hr. The process time and temperatures may depend on the severity of rouge accumulation, the system component's material of construction, and the concentration of chemistries. The concentration of each chemistry is based on proprietary testing and process design criteria.

Electrochemical cleaning is an alternative method of rouge removal that uses phosphoric acid and applied direct current where the process contact surface is anodic. As a cathode is moved over the process contact surface to be cleaned, rouge is readily removed. This process is very effective in removing all three classes of rouge but is limited to accessible parts of a system and is primarily performed on the product contact surfaces in vessels.

For specific Class I rouge remediation processes, see Table D-4.1-1.

D-4.2 Class II Rouge Remediation

Class II rouge consists mostly of hematite or ferric iron oxide with some amount of chromium and nickel oxides as well as small carbon content. It is removed with chemistries that are very similar to the above processes with the addition of oxalic acid, which improves the effectiveness in removal of this type of rouge. All of the above chemistries remove the rouge without damage to the surface finish with the exception of oxalic acid, which may etch the surface depending on conditions and concentration processed. Class II rouges are more difficult to remove than Class I and may require additional time, even though these processes are often run at slightly higher temperatures and increased concentrations.

For specific Class II rouge remediation processes, see Table D-4.1-1.

D-4.3 Class III Rouge Remediation

Class III rouge is much more difficult to remove than Class I and Class II rouge, due to both its chemical composition difference and its structural difference. These high-temperature deposits form magnetite iron oxide with some substitution of chromium, nickel, or silica in the compound structure. Significant amounts of carbon are generally present in these deposits due to reduction of organics present in the water, which sometimes produces the “smut” or black film that may form during derouging. The chemistries used to remove Class III rouge are very aggressive and will affect the surface finish to some degree. Phosphoric acid-based derouging systems are generally only effective on very light accumulation of the rouge. The strong organic acid blends with formic and oxalic acid are effective on some of these high-temperature rouges, and, being less aggressive, they produce much less potential for etching of the surface finish.

Citric and nitric blends with hydrofluoric acid or ammonium bifluoride will remove these Class III rouges more quickly but will definitely etch the surface wherever the base metal is subjected to the derouging fluid. The amount of etching or increase in surface finish roughness is dependent on process conditions, chemical concentration, and variability of the rouge thickness and level of surface finish roughness initially. The condition of use for these processes is highly variable in both temperature and time required to effectively remove all of the rouge and leave the surface prepared for cleaning and passivation. The less-aggressive chemistries are used at higher temperatures [140°F to 176°F (60°C to 80°C)] and require longer contact time (8 hr to 48-plus hr); the nitric acid-based fluoride solutions are often used at lower temperatures [ambient to 104°F (40°C)], while the citric acid-based fluoride solutions are used at higher temperatures and shorter contact times (2 hr to 24 hr).

For specific Class III rouge remediation processes, see Table D-4.1-1.

D-4.4 Remediation Variables

The times and temperatures given in D-4.1 through D-4.3 are in direct relation to the percent by weight of the base reactant(s). A change in a formulation will change the corresponding requirements. Different application methods include fluid circulation, gelled applications for welds or surfaces, and spraying methods for vessels and equipment. Rinsing of the surface after processing and proper waste disposal planning are critical to the derouging process. The waste fluids generated by these processes can be classified as hazardous due to chemical constituents or heavy metals content.

Rouge can effectively be removed from process contact surfaces to reduce the potential for oxide particulate generation into the process fluids. These derouging processes are required prior to proper cleaning and passivation of the stainless steel surface for restoration of the passive layer after corrosion. Analytical testing of utility fluids may be useful in identifying the level of particulate generation and levels of metal oxides contained in these fluids as corrosion degrades the surface.

Table D-2-1
Considerations That Affect the Amount of Rouge Formation During the Fabrication of a System

Variables	Considerations
Category 3 — Strong Influence on the Formation of Rouge [Note (1)]	
Alloy selection	Selection of the proper alloy (e.g., 316L-type or 6 moly-type stainless steel) should address the corrosive effects of the process conditions. For example, low-carbon stainless steel (316L-type) has better corrosion resistance than higher-carbon stainless steels (316-type). Beneficial alloys can mitigate premature or accelerated corrosion. Higher nickel content will enhance corrosion resistance.
Mechanical polishing/buffing	Striations from cold working techniques may include residual grinding/polishing debris in lapping inclusions. Cumulative increase of interior area due to surface finish inconsistency proportionally exposes more alloy to the mechanisms of corrosion and burden of passivation.
Electropolishing	Minimizes the exposure area of the alloy to oxidizing fluids or halides and minimizes the origins for micropitting by corrosion mechanisms.
Passivation	Impedes or retards corrosive development of stainless steel surfaces. The effectiveness of passivation methods in terms of depth and enhancement of surface alloy ratios (i.e., chrome to iron) determines the eventual propensity of an alloy to corrode and the rate of corrosion.
Alloy composition	(% molybdenum, chromium, nickel, etc.) The microstructure quality affects precipitation of impurities at grain boundaries. Migration of impurities to the alloy surface can either support corrosion cells or seed downstream corrosion. Weld joints on tubing and components with dissimilar sulfur concentrations may result in lack of penetration due to weld pool shift. The resulting crevice may become a corrosion initiation site.
Welding, welding conditions, purging, etc.	Improper welds can result in chromium-depleted heat-affected zones (HAZs) and other conditions that reduce corrosion resistance. Weld discontinuities create opportunities to trap fluid-borne impurities. Cracks resulting from poor welds will create breaches in the passive layer and form active corrosion cells. Proper purging prevents weld contamination by heat tint oxides and the concurrent loss of corrosion resistance. Passivation cannot reverse the effects of improper purging.
Product form and fabrication methods	The ferrite content can be greatly affected by the forming process (e.g., a forging will typically have much lower ferrite percentages than a casting). Barstock endgrain voids at the surface can enhance the potential of the alloy to pit and corrode. Minimization of differences in sulfur content will enhance the potential for successful welding.
Category 2 — Moderate Influence on the Formation of Rouge [Note (1)]	
Installation/storage environment	Unidentified corrosion due to the storage or installation environment, including carbon steel contamination, scratching, exposure to chemical contaminants, stagnated condensation or liquids, etc., may warrant a derouging step prior to passivation. Failure to detect instances of corrosion will marginalize the effect of a normal passivation.
Expansion and modifications to an established system	Oxide formations in newly commissioned systems can form at different rates than in older systems and initially generate migratory Class I rouge. Where oxide films exist in established systems, they are likely to be more stable, producing less migratory iron or chrome oxides. Because the newer system can generate and distribute lightly held Class I migratory hematite forms throughout the system, the corrosion origin and cause can be difficult to identify.

NOTE: (1) There is well-established industry data supporting this, and it needs to be considered.

Table D-2-2
Considerations That Affect the Amount of Rouge Formation During the Operation of a System

Variables	Considerations
Category 3 — Strong Influence on the Formation of Rouge [Note (1)]	
Corrosive process fluid (bleach, halides, etc.)	Corrosion cell inceptions at breaches in the passive layer, as in chloride corrosion cells, will progressively catalyze the corrosion mechanism. This has a very strong influence for applications such as high-salt buffer tanks, etc.
High-shear/velocity environment (pump impeller, sprayball, tees, etc.)	Erosive forces deplete or erode the passive layer and introduce base metal composition particles to the remainder of the system. Severe instances can cause pitting on the tips of pump impellers or fluid impingement spots on vessel walls. In pure steam systems, high-velocity sections can scour tubing walls, either preventing sustained buildup of stable magnetite layers or sloughing off fragments from developing oxide formations that are then transported downstream for possible corrosion seeding.
Operating temperature and temperature gradients	Operating temperature and temperature gradients will affect the eventual nature of oxide formations (e.g., Class I hematite versus Class III magnetite), the ease of removal, and the propensity to become stationary, stable, or lightly held and migratory. The nature of restoration by passivation and derouging may be largely determined by the operating temperature of the system. Established magnetite formations in pure steam systems may require a derouging step prior to the passivation steps.
Gaseous phase composition, including dissolved gases (O_2 and CO_2)	For monographed fluids (PW, WFI, and pure steam), the constituency of dissolved gases is generally believed to have an influence on rouge formation when within established conductivity and total organic carbon (TOC) limits in systems that have an adequate passive layer. It is possible for impurities to migrate across distillation and pure steam generation processes as dissolved gases. A variety of analytic spectrometry methods are available to identify these species. (See Tables D-3.1-1 and D-3.2-1.)
Application, process media (pure steam, WFI, buffer, media, CIP, etc.), frequency of operation	The nature of the oxide formation, potential for corrosion, remedial methods, and period of formation are greatly influenced by the application as noted in the other impact descriptions (temperature, corrosive process, etc.). In steam-in-place (SIP) systems, velocity, temperature, and trapping can have impacts on the composition and locations of rouge formations and migratory deposits. Adequately designed systems can minimize this impact. Poorly trapped pure steam headers, regularly exposed to pressure gradients, can introduce corrosion mechanisms and products through steam condensate. Long hold periods in high-salt buffer tanks and the effectiveness of the tank agitation can promote or accelerate rouge formation. SIP following inadequate CIP can create corrosion mechanisms and further aggravate removal methods.
System CIP, cleaning methods	Exposure to CIP cycles and the specific chemical cleaning solutions strongly affects the potential for rouge occurrence. System sections exposed to a cyclic CIP regime will be less likely to form or collect rouge. Significant factors include whether there is an acid or hot acid CIP cycle in the CIP recipe. The duration and temperature of the acid cycle can be important. Acid cycles with mild concentrations (e.g., 2% to 20% phosphoric acid) have been shown to maintain and restore passive layers.
Redox potential	The use of ozone to sanitize purified water or WFI systems has also demonstrated beneficial effects in impeding alloy corrosion.
Maintenance of the system	System components such as worn pure steam regulator plug seats, improper or misaligned gaskets, worn regulator and valve diaphragms, pump impellers (with worn tips), and eroded or cracked heat exchanger tube returns are believed to be sources of Class I rouge.

Table D-2-2
Considerations That Affect the Amount of Rouge Formation During the Operation of a System (Cont'd)

Variables	Considerations
Stagnant flow areas	A moving oxidizing fluid can maintain the passive layer. (Studies with nitrogen-blanketed WFI storage tanks have shown negative effects on passive layers as a result of minimizing oxygen in the fluid.) Liquid condensate that is not immediately removed from a pure steam conduit or that collects from improper valve sequencing can concentrate and transport surface oxidation products or steam contained solubles. These can concentrate and deposit at a branch terminus such as a vessel sprayball, dip tube, etc. These deposits are typically lightly held forms of hematite. Though easily removed, they can be difficult to remove in large vessels and appear to go against the common stipulation of "visually clean."
Pressure gradients	Pure steam systems only. Pressure changes in the distribution system will affect the amount of steam condensate as well as the quality of the steam. If system sections are exposed to pressure ranges, condensate that is not effectively removed from horizontal sections can be revaporized at higher pressures, which will lower the steam quality and transport any impurities borne in the steam condensate.
System age	This depends on how the system has been maintained in regard to frequency of passivation or derouging, CIP exposure, and formation of stable oxide layers. New systems have been observed to generate disproportionate amounts of Class I rouge formations in contrast to established systems. In pure steam systems, although oxide formations become stable with age, they can also thicken and be prone to particle sloughing in high-velocity sections. It should be noted that system time in use can have both beneficial and negative effects in regard to rouge formation and that regular system monitoring is important in identification of incipient corrosion.

NOTE: (1) There is well-established industry data supporting this, and it needs to be considered.

Table D-3.1-1
Process Fluid Analyses for the Identification of Mobile Constituents of Rouge

		Test Criteria	
Type of Test	Test Description	Pros	Cons
Ultra trace inorganic analysis (by ICP/MS)	Concentrations of trace metals in process solutions including pure water/steam are directly analyzed by inductively coupled plasma mass spectrometry (ICP/MS).	Noninvasive sample acquisition Highly quantitative information Provides strong ability to trend data	Baseline shall be determined for each system analyzed.
Standard particulate analysis (via light)	A liquid sample is subjected to a laser light, which scatters on contact with particles. The scattered light is collected, processed, segregated by channel, and displayed as a specific count for each size range analyzed.	Noninvasive sample acquisition Highly quantitative information Provides strong ability to trend data	Baseline shall be determined for each system analyzed.
Ultra trace inorganic analysis (by SEM/EDX)	Fluids are filtered via vacuum filtration, and particles are collected on a fine-pore filter medium. The particles are then analyzed by scanning electron microscopy for size, composition, and topographical features.	Provides highly detailed physical observation and elemental composition data for mobile particulates	Limited with respect to organic particulate identification
Fourier transform infrared spectroscopy (FTIR)	Organic analysis of liquid samples or extracts from wipe samples. Used to identify possible organic films or deposits	Potentially noninvasive sample acquisition Allows for organic identification of elastomers or alternate organic contaminants	Organic contaminants shall be profiled in a specific target compound library.

Table D-3.2-1
Solid Surface Analyses for the Identification of Surface Layers Composition

Type of Test	Test Description	Test Criteria	
		Pros	Cons
Microscopic and human visual analysis	Visual analysis via polarized light microscopy (PLM), scanning electron microscopy (SEM), or alternative microscopy instrumentation	Good test for morphology determination Can be coupled with energy dispersive X-ray (spectroscopy) (EDX) analysis for elemental composition information	Invasive test Requires the periodic removal of solid samples (e.g., coupons)
Scanning auger microanalysis (SAM) or auger electron spectroscopy (auger)	Surface metal elemental composition analysis. Provides for detailed qualitative elemental composition data on both the surface itself and the subsurface (or base metal)	Highly accurate method for positive identification and qualification of the surface metal composition Used to determine the depth and elemental composition of the surface including the passive layer itself	Invasive and destructive test Requires the periodic removal of solid samples (e.g., coupons)
Small spot electron spectroscopy for chemical analysis (ESCA) or X-ray photoelectron spectroscopy (XPS)	The sample is subjected to a probe beam of X-rays of a single energy. Electrons are emitted from the surface and measured to provide elemental analysis of the top surface layers.	Highly accurate method for the qualification and quantification of the surface metal composition Used to determine the depth and compositional analysis of the passive layer Provides excellent elemental analysis of the top surface layers, including which oxide(s) are present	Invasive and destructive test Requires the periodic removal of solid samples (e.g., coupons)
Reflection grade ellipsometry	Multicolor interferometry using light and its diffractive properties to assess surface conditions	Nondestructive analysis Known diffractive characteristics of elements could provide for qualitative analysis of surface chemistry properties	Invasive test Requires the periodic removal of solid samples (e.g., coupons) Field qualification of this method is still ongoing
Electrochemical impedance spectrometry	The analysis of electrochemical noise in order to quantify the state of corrosion of a metallic surface	Noninvasive, real-time quantification of metallic corrosion Provides strong ability to trend data	Field qualification of this method is still ongoing

Table D-4.1-1
Rouge Remediation Processes Summary

Derouging Processes: Specific				
Class of Rouge	**Description [Notes (1), (2)]**	**Comments [Notes (3), (4)]**	**Chemistry [Note (5)]**	**Conditions of Process [Notes (6), (7)]**
Class I Removal	Phosphoric acid	Effective at removing iron oxides without etching the process contact surface	5% to 25% phosphoric acid	2 hr to 12 hr at 104°F to 176°F (40°C to 80°C)
	Citric acid with intensifiers	Effective at removing iron oxides without etching the process contact surface	3% to 10% citric acid with additional organic acids	2 hr to 12 hr at 104°F to 176°F (40°C to 80°C)
	Phosphoric acid blends	Can be used at a variety of temperatures and conditions	5% to 25% phosphoric acid plus either citric acid or nitric acid at various concentrations	2 hr to 12 hr at 104°F to 176°F (40°C to 80°C)
	Sodium hydrosulfite (i.e., sodium dithionite)	Effective at removing iron oxides without etching the surface but may generate sulfide fumes	Up to 10% sodium hydrosulfite	2 hr to 12 hr at 104°F to 176°F (40°C to 80°C)
	Electrochemical cleaning	Useful in removing stubborn rouge without risk of etching the process contact surface	25% to 85% phosphoric acid	Limited to accessible parts of systems, primarily vessels Process times are approximately 1 min/ft^2
Class II Removal	Phosphoric acid	Effective at removing iron oxides without etching the surface	5% to 25% phosphoric acid	2 hr to 24 hr at 104°F to 176°F (40°C to 80°C)
	Citric acid with organic acids	Effective at removing iron oxides without etching the surface	5% to 10% citric acid with additional organic acids	2 hr to 24 hr at 104°F to 176°F (40°C to 80°C)
	Phosphoric acid blends	Can be used at a variety of temperatures and conditions	5% to 25% phosphoric acid plus either citric acid or nitric acid at various concentrations	2 hr to 24 hr at 104°F to 176°F (40°C to 80°C)
	Oxalic acid	Effective at removing iron oxides; may etch electropolished surfaces	2% to 10% oxalic acid	2 hr to 24 hr at 104°F to 176°F (40°C to 80°C)
	Electrochemical cleaning	Useful in removing stubborn rouge without risk of etching the process contact surface	25% to 85% phosphoric acid	Limited to accessible parts of systems, primarily vessels Process times are approximately 1 min/ft^2
	Sodium hydrosulfite (i.e., sodium dithionite)	Effective at removing iron oxides without etching the surface but may generate sulfide fumes	Up to 10% sodium hydrosulfite	2 hr to 12 hr at 104°F to 176°F (40°C to 80°C)

Table D-4.1-1
Rouge Remediation Processes Summary (Cont'd)

Derouging Processes: Specific				
Class of Rouge	**Description [Notes (1), (2)]**	**Comments [Notes (3), (4)]**	**Chemistry [Note (5)]**	**Conditions of Process [Notes (6), (7)]**
Class III Removal	Phosphoric acid blends	Can be used at a variety of temperatures and conditions	5% to 25% phosphoric acid plus either citric acid or nitric acid at various concentrations	8 hr to 48+ hr at 140°F to 176°F (60°C to 80°C)
	Oxalic acid	May etch metallic surfaces	10% to 20% oxalic acid	8 hr to 48+ hr at 140°F to 176°F (60°C to 80°C)
	Citric acid with organic acids	May etch metallic surfaces	5% to 10% citric acid with additional organic acids	8 hr to 48+ hr at 140°F to 176°F (60°C to 80°C)
	Citric acid with intensifiers	Will etch metallic surfaces	5% to 10% citric acid with additional organic acids and fluorides	8 hr to 48+ hr at 140°F to 176°F (60°C to 80°C)
	Nitric/HF or nitric/ammonium bifluoride	Will etch metallic surfaces	15% to 40% nitric acid with 1% to 5% HF or 1% to 5% NH_4HF_2	1 hr to 24 hr at ambient to 104°F (40°C)
	Electrochemical cleaning	Useful in removing stubborn rouge without risk of etching the process contact surface	25% to 85% phosphoric acid	Limited to accessible parts of systems, primarily vessels Process times are approximately 1 min/ft^2

NOTES:
(1) All of these derouging processes should be followed with a cleaning and passivation process of the treated surface.
(2) Application methods include fluid circulation, gelled applications for welds or process contact surfaces, and spraying methods for vessels and equipment.
(3) These derouging processes may produce hazardous wastes based on the metals content.
(4) Oily or loose black residue due to carbon buildup may be present on the process contact surfaces after derouging and may require special cleaning procedures to remove.
(5) Chemical percentages are based on weight percent.
(6) The time and correlating temperatures given above are in direct relation to the percent by weight of the base reactant(s). A change in a formulation will change those corresponding requirements.
(7) A deionized water rinse shall immediately follow each of the above chemical treatments.

NONMANDATORY APPENDIX E
PASSIVATION PROCEDURE QUALIFICATION

E-1 GENERAL

This Appendix provides basic information and offers guidelines for owner/users, equipment manufacturers, and service providers for newly manufactured or installed systems in accordance with the requirements of GR-1. This Appendix covers the preparation and execution of procedures associated with the chemical cleaning and degreasing, passivation, and final rinse(s) of specialized systems, as well as of bioprocessing equipment after assembly, erection, or modification. These procedures will apply to UNS S30400, UNS S30403, UNS S31600, and UNS S31603 stainless steels. Superaustenitic stainless steels and nickel alloys may require a modified procedure.

This Appendix defines a method for qualifying the passivation process used for system and process component surfaces.

This Appendix provides information on passivation procedures and testing of the surface resulting from various passivation procedures.

E-2 PURPOSE OF PASSIVATION TREATMENTS

Passivation, or the forming of a passive layer on the surface of stainless steel alloys, is a naturally occurring phenomenon on a clean surface when oxygen is present. The passive layer may be augmented by chemical treatment of the stainless steel surface.

A critical prerequisite in preparation for chemical passivation processes is a cleaning procedure. This procedure includes all operations necessary for the removal of surface contaminants (oil, grease, etc.) from the metal to allow the chemical passivation to be most effective. The purpose of the final chemical passivation process is to enhance the passive layer and provide an alloy surface free of free iron or other contaminants, allowing the alloy to be in the most corrosion-resistant state.

For improved corrosion resistance in the standard stainless steel grades (e.g., UNS S31603), the passivation treatment is most beneficial and important. With superaustenitic stainless steels and nickel alloys, passivation is less critical, provided the surfaces are clean and free of contaminants. At the owner/user's option, passivation may be performed to remove any free iron on process contact surfaces and to facilitate the formation of the passive layer.

In a discussion on passivation, it should be realized that the best passivation treatment or any surface treatment only puts the alloy in its most corrosion-resistant state for a particular environment. In other words, there are inherent corrosion-resistance limitations for any alloy, and the best passivation treatment does not replace the need for a more corrosion-resistant material for certain applications.

E-2.1 Why Passivation Is Necessary

Although stainless steel components may be clean and the passive layer intact prior to installation, welding destroys the passive film on the weld bead and the heat-affected zone (HAZ) of the weld. The distribution of elements across the weld and HAZ, including chromium, iron, and oxygen, are disturbed when the metal is melted so that the concentration of iron is elevated, while chromium, which is normally of higher percentage than iron in the passive layer, is reduced.

Discoloration and contamination (especially free iron) introduced during fabrication may also compromise corrosion resistance unless removed. Passivation after welding, by removing free iron, helps to restore the passive layer. It does not remove discoloration. Removal of discoloration requires a more aggressive acid than the usual nitric or citric acids used for passivation. Since the only postweld treatment normally used for installed piping systems is passivation, welding procedures that minimize discoloration are specified (see Part MJ of this Standard).

Fabrication, cutting, bending, etc., can result in contamination that leads to loss of corrosion resistance. Examples are embedded iron, heat tint, welding flux from covered electrodes, arc strikes, and painting/markings. Exposure to carbon steel or iron is particularly detrimental. By removing contamination, especially free iron, a passivation treatment can help to restore the natural passivity of stainless steel that is damaged by fabrication.

E-2.2 When Passivation Is Necessary

Passivation is necessary

(a) after welding and fabrication

(b) after welding of new components into a system

Table E-3.2-1
Minimum Surface Requirements for Process Qualification Samples (24)

Material	Test Method	Total Cr/Fe Ratio	Oxide Depth
UNS S31600 or UNS S31603	AES [Note (1)]	1.0 or greater	15 Å, min.
UNS S31600 or UNS S31603	GD-OES	1.0 or greater	15 Å, min.
UNS S31600 or UNS S31603	XPS/ESCA [Note (2)]	1.3 or greater	15 Å, min.

GENERAL NOTE: Additional alternative testing methods for cleanliness and passivation are shown in Table E-5-1.

NOTES:
(1) Test method as per SEMI F72.
(2) Test method as per SEMI F60.

E-3 PASSIVATION PROCEDURE

See SF-2.6.

E-3.1 Procedure Description

The passivation provider shall obtain welded and nonwelded sample component(s) or coupons from each passivation method used (e.g., circulation, spot, bath) for the purpose of demonstrating that the procedure is capable of providing the required surface characteristics, namely, cleanliness, surface chemistry, and corrosion resistance.

The passivation process used on the qualification component(s) or coupons shall be reproducible in the system for which it is intended.

The procedure description and qualification document shall be available for review by the owner/user or their designee. The owner/user shall be responsible for verifying that the passivation procedure to be used on their system or components has been qualified.

E-3.2 Procedure Qualification

The passivation provider shall develop a passivation procedure for each method used. The procedure shall be developed to ensure that essential variables used to obtain the qualification samples can effectively remove free iron and meet the requirements of Table E-3.2-1. Procedure qualification, as a minimum, shall include the following:

(a) Process Description. The following steps shall be described as a minimum (Table E-3.2-2 may be used as a guide):

(1) prepassivation survey and preparation
(2) cleaning
(3) passivation
(4) final rinsing
(5) verification

(b) Essential Variables (Conditions Under Which the Samples Were Processed). The following essential variables shall remain within the designated range:

(1) process time
(2) temperature of solution during process
(3) general chemistry of process fluids
(4) process endpoint determination
(5) conductivity of final deionized rinse water

(c) Procedure Qualification Coupon Testing

(1) AES (auger electron spectroscopy) testing at the weld, including the worst discoloration area in the weld and heat-affected zone, and on the base metal to meet the requirements of Table E-3.2-1

(2) GD-OES (glow discharge–optical electron spectroscopy) testing at the weld, including the worst discoloration area in the weld and heat-affected zone, and on the base metal to meet the requirements of Table E-3.2-1

(3) XPS (X-ray photoelectron spectroscopy), also known as ESCA (electron spectroscopy for chemical analysis), testing at the weld, including the worst discoloration area in the weld and heat-affected zone, and on the base metal to meet the requirements of Table E-3.2-1

Qualification of method shall be supported by documentation for each procedure. The actual values of the essential variables and coupon testing listed above shall be documented and maintained as part of the procedure.

E-3.3 Procedure Documentation Requirements

The passivation provider shall generate and provide the following documentation, as a minimum:

(a) process descriptions
(b) essential variables
(c) ESCA/XPS or AES or GD-OES testing for each procedure qualification sample produced

E-4 PASSIVATION QUALITY CONTROL (24)

E-4.1 Quality Control Surveillance

Quality control surveillance to ensure the written and qualified passivation procedure has been followed is essential. A thorough rinse with deionized or owner/user-approved water should follow the chemical treatment. It is good practice to continue rinsing until, as determined by conductivity analysis, the ionic contaminants, process chemicals, and by-products have been removed. This document shall be available for review by the owner/user or their designee.

(a) Written documentation that all requirements of the qualified procedure have been followed.

(b) Final rinse shall meet pre-established conductivity (quality) requirements.

E-5 EVALUATION OF CLEANED AND PASSIVATED SURFACES

There are no universally accepted tests to ensure that a component or system has been passivated or is in a passive condition. If the system/component has received the proper chemical passivation treatment, the documentation generated during the process should provide assurance that the components or system has received the specified treatment. As a guide to owner/users and others, to help determine whether an acceptable surface has been achieved following a particular cleaning or chemical passivation procedure, Table E-5-1 has been developed.

(24) E-5.1 Acceptance Criteria for Cleaned and Passivated Process Contact Surfaces (See Table SF-2.6-1)

Table E-5-1 may be used as a guide for acceptance criteria for cleaned and passivated components or systems. This matrix is a simplified compilation of testing methodologies that an owner/user may want to use in selecting a test or as a means to interpret a proposal from a testing company.

The matrix is divided into groups of four types of testing methods

(a) gross inspection of cleaned and passivated parts per ASTM A380/A967 (Pass/Fail)

(b) precision inspection of cleaned and passivated parts under ASTM A380/A967 (Pass/Fail)

(c) electrochemical field and bench tests

(d) surface chemical analysis tests

Groups 1 and 2 of Table E-5-1 reflect the two main divisions in ASTM A380 and ASTM A967. The most obvious type of examination of these methods is visual. The examiner shall look for a clean surface free of oxides, scale, weld discoloration/heat tint, stains, dirt, oil, grease, or any deposits that could prevent the chemical passivation solution from reaching the metal surface.

The test results from ASTM A967, which are exclusively for passivation, are all based on visual detection of staining or discoloration indicative of the presence of free iron. These test results are subjective and nonquantifiable. However, for some applications this may be all that is required. The visual acceptance criteria in ASTM A380 and ASTM A967 apply.

Groups 3 and 4 of Table E-5-1 reflect two distinct methods of quantitative testing. These tests are not contained in either of the ASTM standards. These tests are designed to provide a more quantifiable analysis of a passivated surface. The electrochemical field and bench tests in Group 3 in Table E-5-1, with the exception of cyclic polarization, are suitable for field tests such as those used for postpassivation testing of installed piping systems and passivated welded surfaces.

Passivation is capable of dramatically increasing the chromium-to-iron (Cr/Fe) ratio on the surface of 316L-type stainless steel when properly applied. One measurement of the degree of enhancement of the layer following a chemical passivation treatment is the total Cr/Fe ratio as determined by AES, GD-OES, or ESCA. The procedure is not readily adapted to field use but may be useful in developing the passivation procedure.

The total Cr/Fe ratio, regardless of test method, should be 1.0 or greater (see Table E-3.2-1); because of variability in accuracy, identical results obtained with the different test methods are not expected. The surface chemical analysis tests in Group 4 in Table E-5-1 include methods for evaluation of the thickness and chemical state of the passive layer on stainless steel. Cyclic polarization measurements (Group 3 in Table E-5-1) may also be used to provide a quantitative evaluation of the level of passivation. Cyclic polarization as well as the methodologies in Group 4 in Table E-5-1 might be applied to sacrificial coupons placed in systems subject to the complete passivation process.

Table E-3.2-2
Passivation Processes

Process Type	Process Description [Notes (1), (2)]	Comments [Note (3)]	Conditions of Process [Notes (4), (5)]	Chemistry [Note (6)]
		Precleaning		
Water flushing/ filtration processes	High-velocity DI (or owner/user-chosen) water flushing for removal of particles and construction debris	Removes debris prior to the passivation process	Ambient temperature for 5 min to 30 min per section; generally includes filtration of fluids	DI water
	High-velocity water flushing	Removes debris prior to the passivation process Chlorides in water are detrimental to austenitic stainless steels	Ambient temperature for 15 min to 60 min per section	DI water (recommended)
		Cleaning		
Cleaning/ degreasing processes	Phosphate cleaners	Removes light organic deposits Can leave phosphate surface contamination	1 hr to 4 hr at heated conditions depending on the solution and contamination level	Blends of sodium phosphates [monosodium phosphate (MSP), disodium phosphate (DSP), trisodium phosphate (TSP)] and surfactants
	Alkaline cleaners	Can be selected for specific organic contaminates		Blends of nonphosphate detergents, buffers, and surfactants
	Caustic cleaners	Effective at removal of heavy organic contamination or degreasing		Blends of sodium and potassium hydroxides and surfactants
	Isopropyl alcohol (IPA)	Effective as a degreaser Volatile Highly flammable and sensitive to static discharge	Hand swab or wipe surface at ambient conditions	70% to 99%
		Passivation		
Passivation processes	Nitric acid	Proven method under ASTM A380/ASTM A967 Can be processed at ambient conditions depending on formulation	30 min to 90 min at ambient temperature or higher, depending on concentration used	10% to 40% nitric acid

Table E-3.2-2
Passivation Processes (Cont'd)

Process Type	Process Description [Notes (1), (2)]	Comments [Note (3)]	Conditions of Process [Notes (4), (5)]	Chemistry [Note (6)]
		Passivation (Cont'd)		
Passivation processes (cont'd)	Phosphoric acid	Effective at removing iron oxides in addition to free iron	1 hr to 4 hr at heated conditions	5% to 25% phosphoric acid
	Phosphoric acid blends	Can be used at a variety of temperatures and conditions		5% to 25% phosphoric acid plus either citric acid or nitric acid at various concentrations
	Citric acid	Specific for free iron removal Should be processed at elevated temperatures Takes longer to process than mineral acid systems Meets or exceeds ASTM A967		10% citric acid
	Chelant systems	Should be processed at elevated temperatures Takes longer to process than mineral acid systems Removes iron oxides in addition to free iron Meets or exceeds ASTM A967		3% to 10% citric acid with various chelants, buffers, and surfactants
	Electropolishing	This process is generally limited to components rather than installed systems Process should be performed according to a qualified procedure This process removes metal from the surface Electropolishing should be performed in such a way as to meet or exceed ASTM B912	Exposure time shall be calculated to ensure 5 µm to 10 µm material removal from all surfaces requiring passivation Rinsing shall include a step to ensure removal of residual film that may adversely affect the appearance or performance of the product	Phosphoric acid-based electrolyte
		Oxidation		
Oxidation processes	Hydrogen peroxide	Oxidizes metal surface and sanitizes	30 min to 2 hr at ambient to 104°F (40°C)	3% to 10% hydrogen peroxide
	Hydrogen peroxide with peracetic acid blends	Oxidizes metal surface and sanitizes		1% to 2% blend

NOTES:
(1) Application methods include fluid circulation, gelled applications for welds or surfaces, and spraying methods for vessels and equipment.
(2) Special attention should be directed to removal of metal shavings and construction debris from locations such as sprayballs, diaphragm valves, heat exchangers, etc.
(3) These passivation processes may produce hazardous wastes based on the metals content, and local and state regulations.
(4) The time and correlating temperatures in the Table are in direct relation to the percent by weight of the base reactant(s). A change in a formulation may change those corresponding requirements.
(5) A deionized water rinse shall immediately follow each of the chemical treatments.
(6) Chemical percentages are based on weight percent.

Table E-5-1
Test Matrix for Evaluation of Cleaned and Passivated Surfaces

Type of Test	Test Description	Pros	Cons
Group 1. Gross Inspection of Cleaned and Passivated Parts per A380/ASTM A967 (Pass/Fail)			
Visual examination [CT (test for cleanliness), RT (test for the presence of rouge)]	Bench or field test. Visual examination is the direct or remote visual examination of, in this case, a passivated metallic surface.	Can be performed with minimal preparation and equipment Good general appearance review	Not quantitative Subjective interpretation of findings
Wipe test ASTM A380 (CT, RT)	Bench or field test. This test consists of rubbing a test surface with a clean, lint-free, white cotton cloth, commercial paper product, or filter paper moistened with high-purity solvent.	Useful for testing surfaces that cannot be readily accessed for direct visual examination Removable surface contamination can be easily identified and compared	Not quantitative Difficult to inspect hard-to-reach areas of large tube diameters There is also a risk of leaving errant fibers behind from the wipe or plug Can be detrimental to electropolished surfaces
Residual pattern test ASTM A380 (CT)	Bench or field test. After finish-cleaning, dry the cleaned surface per ASTM A380. The presence of stains or water spots indicates the presence of contaminants.	A simple test with rapid results	Not quantitative Not very sensitive
Water-break test ASTM F22	The water-break test is performed by withdrawing the surface to be tested, in a vertical position, from a container overflowing with water. The interpretation of the test is based on the pattern of wetting.	General cleanliness of surface is easily determined Useful in detecting hydrophobic contamination	Not quantitative This test identifies the presence of retained oils and greases The test is not applicable on all surfaces including, but not limited to, electropolished surfaces
ASTM A380 water-wetting and drying; ASTM A967 water immersion practice A [PT (test for passivation)]	Bench or field test. Immersed in, or flushed with distilled water then air dried. A modified version of this test requires a solution of 3% to 7% salt water, with a final rinse prior to inspection, using DI-quality water or better.	Staining is evidence of free iron, which is detected through visual examination Identifies possible pitting corrosion sites or embedded iron	Not quantitative
High-humidity test ASTM A380 and ASTM A967 Practice B (PT)	Bench test. Sample coupon is immersed or swabbed with acetone or methyl alcohol then dried in an inert atmosphere. The coupon is then subjected to 97% humidity at 100°F for 24 hr or more.	Staining is evidence of free iron, which is detected through visual examination	Not quantitative Not used for installed tubing Sample coupons can be used, but does not prove complete coverage Lengthy test Containment cabinet required
Salt spray test ASTM A967 Practice C (PT)	Bench or field test. This test is conducted in accordance with ASTM B117 subjecting the test area to a 5% salt solution for a minimum of 2 hr.	Rust or staining attributable to the presence of free iron particles embedded in the surface will become noticeable on visual examination of the metal surface	Not quantitative Longer-term testing is required to test for passive film quality or corrosion resistance However, exposures over about 24 hr may show light staining resulting from differences in micro finish texture
Group 2. Precision Inspection of Cleaned and Passivated Parts Under A380/ASTM A967 (Pass/Fail)			
Solvent ring test ASTM A380 (CT)	Bench test. Place a single drop of high-purity solvent on the surface to be evaluated, stir briefly, then transfer to a clean quartz microscope slide and allow the drop to evaporate. If foreign material has been dissolved by the solvent, a distinct ring will be formed on the outer edge of the drop as it evaporates.	Good test for organic contamination on the test surface	Not quantitative

Table E-5-1
Test Matrix for Evaluation of Cleaned and Passivated Surfaces (Cont'd)

Type of Test	Test Description	Pros	Cons
Group 2. Precision Inspection of Cleaned and Passivated Parts Under A380/ASTM A967 (Pass/Fail) (Cont'd)			
Black light inspection ASTM A380 (CT)	Bench test. This test requires the absence of white light and a flood-type ultraviolet light.	Suitable for detecting certain oil films and other transparent films that are not detectable under white light Good test for organic contamination on surface	Not quantitative Not practical when testing for passivation
Atomizer test ASTM A380 (CT)	Bench test. This test is conducted in accordance with ASTM F21 using DI-quality water or better. A variation of the water-break test, this test uses an atomized spray, rather than a simple spray or dip to wet the surface.	Test for presence of hydrophobic films This test is more sensitive than the water-break test	Not quantitative Requires direct visual examination
Ferroxyl test for free iron ASTM A380/potassium ferricyanide-nitric acid ASTM A967 Practice E (PT)	Bench or field test. Apply a freshly prepared solution of DI-quality water or better, nitric acid, and potassium ferricyanide to the coupon using an atomizer having no iron or steel parts. After 15 sec a blue stain is evidence of surface iron. Remove solution from the surface as soon as possible after testing, per ASTM A380 or ASTM A967. Test nonsystem coupons only.	Identification of free iron contamination on surface Very sensitive test	Not quantitative This test will only identify free iron on the surface and will not directly measure the improvements of the passive oxide layer This is a very sensitive test and shall be performed by personnel familiar with its limitations Either a sacrificial coupon is used for this test, or the test area is cleaned as described in the respective ASTM practice or specification Safety and disposal issues exist with the test chemical Easy to get a false-positive result
Copper sulfate test ASTM A380/ASTM A967 Practice D (PT)	Bench test. Prepare a 250-cm^3 solution consisting of 1 cm^3 of sulfuric acid (s.g. 1.84), 4 g copper sulfate, and the balance in DI-quality water or better. Apply this to a sacrificial coupon using a swab. Keep the surface to be tested wet for a period of 6 min with additional applications as needed.	Identification of free iron contamination on the test surface Is effective in detecting smeared iron deposits	Not quantitative Embedded iron is detected, but difficult to detect small discrete iron particles
Group 3. Electrochemical Field and Bench Tests			
Cyclic polarization measurements	This technique uses cyclic polarization measurements similar to the ASTM G61 test method to measure the critical pitting potential (CPP). The more noble (more positive) the CPP, the more passive the stainless steel surface. Similar results may be obtained with the ASTM G150 test that measures critical pitting temperature (CPT).	This test method provides a direct measurement of the corrosion resistance of a stainless steel surface. The measured CPP provides a quantitative measurement of the level of passivation The test equipment is relatively inexpensive	The method requires a potentiostat and corrosion software package to make the measurements To ensure reliable results, operators should be trained in electrochemical test techniques

Table E-5-1
Test Matrix for Evaluation of Cleaned and Passivated Surfaces (Cont'd)

Type of Test	Test Description	Pros	Cons
Group 3. Electrochemical Field and Bench Tests (Cont'd)			
Electrochemical pen (ec-pen) (PT)	The result is based on preset values. The size and shape of a writing instrument, the ec-pen makes electrolytic contact when placed on the test surface. Capillary action causes electrolyte to flow from the reservoir to the surface through a porous polymer body while preventing the electrolyte from leaking out of the pen. There is a stable electrode inside the pen mechanism. By simply positioning the ec-pen on the sample surface, electrolytic contact is established and electrochemical characterization is possible. The measured area is typically 1.5 mm^2.	Easy to handle, short sample preparation time, real-time results, and the possibility to run experiments on virtually any size object with various surface geometries The ec-pen is a portable instrument for the measurement of corrosion potential suitable for field use	This test does not quantify the passive layer, but instead provides a pass-fail indication of passivity The local test area needs to be cleaned and repassivated after testing
Koslow test kit 2026/3036 (PT)	Similar to the ec-pen, in that it measures the corrosion potential of the metal surface, the Koslow 2026/3036 consists of a meter, a probe, and an interconnecting cable. An electrical charge is first applied to the test piece, after which a moist pad is placed on the surface of the same test piece. The probe is pressed into the moist pad to complete the circuit. Within a couple of seconds the cell voltage result appears on the digital meter.	Measures corrosion potential at the surface	User sensitive
Group 4. Surface Chemical Analysis Tests			
Auger electron spectroscopy (AES) (PT, RT)	Secondary and auger electrons, in the targeted area of the test coupon, are bombarded with a primary electron beam, which is used as an excitation source. Photoelectrons are subsequently ejected from the outer orbital of atoms in the target material. The ejected photoelectrons are then detected by means of electron spectroscopy. The method by which the ejected photoelectrons are detected and analyzed is AES. This test is useful for surface analysis from 2 Å to a depth greater than 100 Å.	Provides quantitative analysis Using a scanning primary beam, secondary electron images yield information related to surface topography Auger electrons, when analyzed as a function of energy, are used to identify the elements present Elemental composition of the surface to a depth of 2 Å to 20 Å is determined and can be used in depth profiling applications	The specimen chamber shall be maintained at ultra-high vacuum (UHV) The specimen shall be electrically conductive Instrument is not readily available Expertise is needed for data interpretation

Table E-5-1
Test Matrix for Evaluation of Cleaned and Passivated Surfaces (Cont'd)

Type of Test	Test Description	Pros	Cons
Group 4. Surface Chemical Analysis Tests (Cont'd)			
Electron spectroscopy for chemical analysis (ESCA) also known as X-ray photoelectron spectroscopy (XPS) (PT, RT)	Using X-ray as an excitation source, photoelectrons are ejected from the inner-shell orbital of an atom from the target material. The ejected photoelectrons are then detected by means of XPS. The method by which the ejected photoelectrons are then detected and analyzed is ESCA (or XPS). Useful for surface analysis to a depth of 10 Å to 100 Å.	Provides quantitative analysis in measuring the following: *(a)* Elemental composition of the surface (10 Å to 100 Å usually) *(b)* Empirical formula of pure materials *(c)* Elements that contaminate a surface *(d)* Chemical or electronic state of each element in the surface *(e)* Uniformity of elemental composition across the top of the surface (also known as line profiling or mapping) *(f)* Uniformity of elemental composition as a function of ion beam etching (also known as depth profiling)	The specimen chamber shall be maintained at ultra-high vacuum (UHV) Instrument is not readily available The specimen shall be electronically conductive Expertise is needed for data interpretation
GD-OES (glow discharge–optical emission spectroscopy) (PT, RT)	GD-OES uniformly sputters material from the sample surface by applying a controlled voltage, current, and argon pressure. Photomultiplier tube detectors are used to identify the specific concentrations of various elements based on the wavelength and intensity of the light emitted by the excited electrons in each element when they return to the ground state.	The GD-OES method is particularly useful for rapid, quantitative depth profiling of thick- and thin-film structures and coatings	Relatively expensive Instrument not widely available

NONMANDATORY APPENDIX F
CORROSION TESTING

F-1 GENERAL

Corrosion testing may be used to determine whether the material manufacturer has used the appropriate processing variables during the fabrication of the raw product form. These variables include those primarily related to thermomechanical processing and heat treatment. The material can be evaluated based on weight loss or electrochemical response, or it can be measured by destructive testing techniques such as toughness testing. The standard ASTM tests that are commonly used are shown in Table F-1-1. However, there is no guarantee that a tested alloy will be appropriate for a specific environment even if it performs well in an industry-accepted test.

It is often appropriate to test a number of candidate alloys in a specific environment. Ideally the test selected should reflect the corrosion mode anticipated in production. These corrosion modes include general corrosion, crevice corrosion, pitting corrosion, and stress corrosion cracking.

F-2 CORROSION TESTS

For general corrosion, the most commonly used test method is ASTM G31, Standard Practice for Laboratory Immersion Corrosion Testing of Metals.

To rank materials based on their resistance to localized corrosion, such as pitting corrosion, the two most commonly used electrochemical methods are ASTM G61 and ASTM G150.

Other methods used to screen for more specific metallurgical problems such as the presence of sigma phase, chromium carbides, or improper heat treatment are described in Table F-1-1.

F-3 PITTING RESISTANCE EQUIVALENT (PRE) NUMBER

Where testing is not possible or desired, owner/users may use the PRE number as a guide to rank a material's corrosion resistance. Relative PRE number values for some wrought stainless steel and nickel alloys are shown in Table F-3-1. Notice that although different equations are used to calculate the PRE number for the two different alloy systems [see Table F-3-1, Notes (1) and (2)], the numbers may still be used to compare alloys for ranking purposes.

Since the PRE numbers are calculated based on composition, the listed values in Table F-3-1 are based on nominal composition only and are not representative of the ranges of PRE numbers that could result from the compositional ranges permitted by the applicable material specification. The values listed in Table F-3-1 are not representative of values that may be obtained by compositions specified by the owner/user. The owner/user is cautioned that PRE numbers should be developed from the specific composition of the heat intended for use in order to accurately rank or estimate the alloy's resistance to pitting. Consideration should be given to other factors that might reduce the corrosion resistance such as

(a) improper heat treatment
(b) surface finish and quality
(c) deleterious second phases
(d) welding

(24)

Table F-1-1
Corrosion Tests

Standard		Purpose of Test	Data Obtained	Typical Alloys Tested
ASTM A262	Practice A (oxalic acid test)	Qualitative test to determine susceptibility to intergranular attack associated with chromium carbide precipitates. Tests the effectiveness of final heat treatment. Used to screen specimens intended for testing in Practices B, C, and E	Comparative, visual examination of microstructure after testing only	Austenitic stainless steels
	Practice B (ferric sulfate–sulfuric acid test)	Quantitative test measuring weight loss due to intergranular corrosion associated with chromium carbide precipitates. Also tests for sigma phase in 321-type alloys. Tests the effectiveness of final heat treatment	Report weight loss only	Austenitic stainless steels
	Practice C (nitric acid test)	Quantitative test measuring weight loss due to intergranular corrosion associated with chromium carbide precipitates. Also tests for sigma phase in 316-, 316L-, 321-, and 347-type alloys. Tests the effectiveness of final heat treatment	Report weight loss only	Austenitic stainless steels
	Practice E (copper–copper sulfate–sulfuric acid test)	Qualitative test to determine susceptibility to intergranular attack associated with chromium carbide precipitates. Tests the effectiveness of final heat treatment	Pass or fail	Austenitic stainless steels
ASTM A923	Method A (sodium hydroxide etch test)	Detection of the presence of detrimental intermetallic phases. Used to screen specimens intended for testing in Method B and Method C	Visual examination. Pretest for subsequent methods	Duplex stainless steels
	Method B (Charpy impact test)	Used to test toughness characteristics that may result from processing irregularities	Impact toughness energy	Duplex stainless steels
	Method C (ferric chloride test)	Detects a loss of corrosion resistance associated with a local depletion of Cr, Mo, or both, as a result of the precipitation of chromium-rich and possibly molybdenum-rich phases	Report weight loss only	Duplex stainless steels
ASTM A1084	Method A (oxalic acid etch test)	Exploratory test for detection of the presence of detrimental intermetallic phases. Not used for screening specimens intended for testing in other methods	Visual examination	Lean duplex stainless steels
	Method B (Charpy impact test)	Used to test toughness characteristics that may result from processing irregularities	Impact toughness energy	Lean duplex stainless steels
	Method C (inhibited ferric chloride test)	Detects a loss of corrosion resistance associated with a local depletion of Cr, Mo, or both, as a result of the precipitation of chromium-rich and possibly molybdenum-rich phases	Report weight loss only	Lean duplex stainless steels

Table F-1-1
Corrosion Tests (Cont'd)

Standard		Purpose of Test	Data Obtained	Typical Alloys Tested
ASTM G48	Methods A and B (ferric chloride test)	Resistance to pitting or crevice corrosion	Report weight loss	Stainless steels, Ni-based alloys, and Cr-bearing alloys
	Methods C and D (ferric chloride test)	Resistance to pitting or crevice corrosion. Define the minimum temperature at which pitting or crevice corrosion initiates. Test the effects of alloying elements, final heat treatment, and surface finish of final product.	Report critical temperature	Ni-based and Cr-bearing alloys
	Methods E and F (ferric chloride test)	Resistance to pitting or crevice corrosion. Define the minimum temperature at which pitting or crevice corrosion initiates. Test the effects of alloying elements, final heat treatment, and surface finish of final product.	Report critical temperature	Stainless steels
ASTM G28	Method A	Tests the susceptibility to intergranular attack associated with composition and processing	Report weight loss only	Ni-based alloys
	Method B	Tests the susceptibility to intergranular attack associated with composition and processing, specifically subsequent heat treatments	Report weight loss only	Ni-based alloys
ISO 3651-2	Method A (copper–copper sulfate–sulfuric acid test	Qualitative test to determine susceptibility to intergranular attack associated with chromium carbide precipitates. Tests the intrinsic material resistance to intergranular corrosion or the effectiveness of final heat treatment	Pass or fail	Austenitic steels with >16% Cr and ≤3% Mo Ferritic steels with 16% to 20% Cr and ≤1% Mo Duplex steels with >16% Cr and ≤3% Mo
	Method B (35% sulfuric acid–copper sulfate test)	Qualitative test to determine susceptibility to intergranular attack associated with chromium carbide precipitates. Tests the intrinsic material resistance to intergranular corrosion or the effectiveness of final heat treatment	Pass or fail	Austenitic steels with >20% Cr and 2% to 4% Mo Duplex stainless steels with >20% Cr and >2% Mo
	Method C (40% sulfuric acid–copper sulfate test)	Qualitative test to determine susceptibility to intergranular attack associated with chromium carbide precipitates. Tests the intrinsic material resistance to intergranular corrosion or the effectiveness of final heat treatment	Pass or fail	Austenitic steels with >17% Cr and >3% Mo Austenitic steels with >25% Cr and >2% Mo Ferritic steels with >25% Cr and >2% Mo Duplex steels with >20% Cr and ≥3% Mo

(24)

Table F-3-1
PRE Numbers for Stainless Steels per Table MM-2.1-1 and for Nickel Alloys per Table MM-2.1-2

UNS Number	EN Designation	JIS Designation	PRE Number [Note (1)]
Austenitic Stainless Steels [Note (2)]			
S30400	...	...	20
...	1.4301	...	19
...	...	SUS304	20
S30403	...	...	20
...	1.4307	...	19
...	1.4306	...	20
...	...	SUS304L	20
S31600	...	...	23
...	1.4401	...	23
...	...	SUS316	23
S31603	...	...	23
...	1.4404	...	23
...	1.4435	...	26
...	...	SU316L	23
Superaustenitic Stainless Steels [Note (2)]			
N08904	...	...	35
...	1.4539	...	36
N08367	...	...	43
S31254	...	...	42
...	1.4547	...	42
N08926	...	...	42
...	1.4529	...	42
Duplex Stainless Steels [Note (2)]			
S32101	...	...	24
...	1.4162	...	24
S32205	...	...	35
...	1.4462	...	31
S32750	...	...	41
...	1.4410	...	41
Nickel-Based Alloys [Note (3)]			
N06625	...	...	41
...	2.4856	...	41
...	...	NCF625	41
N10276	...	...	45
...	2.4819	...	45
...	...	NW0276	45
N06022	...	...	46
...	2.4602	...	46
...	...	NW6022	46

GENERAL NOTES:
(a) Alloys listed between horizontal lines are not equivalent, but comparable.
(b) The below are industry-accepted formulas. Other formulas may be used at the owner/user's discretion.

NOTES:
(1) Calculation of PRE numbers is based on typical analyses for the respective alloys.
(2) For stainless steels, PRE number = %Cr + 3.3[%Mo + 0.5(%W)] + 16(%N).
(3) For nickel alloys, PRE number = %Cr + 1.5(%Mo + %W + %Nb).

NONMANDATORY APPENDIX G
FERRITE

G-1 GENERAL

Ferrite is a phase that may precipitate during solidification of austenitic stainless steels depending on the ratios of the alloying elements. The ferritic phase consists of crystals with a body-centered cubic (bcc) lattice in contrast to the face-centered cubic (fcc) lattice of the austenitic matrix. The presence of ferrite in austenitic stainless steel welds may reduce the corrosion resistance in some corrosive environments. However, a minimum ferrite level may be required to maintain specific properties of particular product forms (e.g., castings) or is deemed necessary to prevent hot cracking of heavy wall weldments (e.g., vessels made from plate).

The ferrite level of austenitic stainless steel base metal strongly depends on heat analysis, primarily the chromium to nickel ratio, product form, and final heat treatment. Whereas wrought 316L-type stainless steel materials in the solution annealed condition typically show very low ferrite levels of 0 vol.%–3 vol.%, CF8M and CF3M stainless steel castings may contain 10 vol. %–20 vol.% of ferritic phase in the austenitic matrix.

As-solidified austenitic stainless steel welds typically have higher ferrite levels than the base metal. This is caused by rapid cooling that prevents the ferrite to austenite transformation from proceeding to thermodynamic equilibrium. The ferrite level of as-solidified austenitic stainless steel welds can be determined from the WRC-1992 Constitution Diagram for Stainless Steel Weld Metals[1] using a chromium equivalent Cr (eq) = %Cr + %Mo + 0.7%Nb and a nickel equivalent Ni (eq) = %Ni + 35%C + 20%N + 0.25%Cu. Postweld heat treatment (e.g., solution annealing of welded tubing) reduces the amount of ferrite in the weld.

It should be recognized that many austenitic stainless steels with high nickel content and nickel alloys do not contain any ferrite in as-solidified welds.

Measuring of ferrite in production welds shall be in accordance with AWS A4.2M:2006 (ISO 8249:2006MOD).

G-2 INFLUENCE OF FERRITE IN BIOPHARMACEUTICAL SERVICE

Ferrite in the base metal and welds can have a beneficial or a negative effect depending on the particular service, but generally offers little concern for biopharmaceutical services. Laboratory corrosion tests in severe biopharmaceutical service have shown that increased amounts of weld metal ferrite somewhat lowers corrosion resistance.[2] However, in high-purity water systems, there have been no reported system failures related to delta ferrite content in welds.

G-3 CONTROL OF FERRITE CONTENT IN WELDS OF AUSTENITIC STAINLESS STEELS

Ferrite in welds of austenitic stainless steels can be controlled by one or more of the following methods:

(a) postweld solution annealing

(b) use of weld filler with increased nickel content

(c) increase of nickel equivalent by addition of approximately 1 vol.%–3 vol.% nitrogen to shielding gas

(d) selection of heats of materials with high nickel to chromium ratios, such as the European steel grade 1.4435 (see Table MM-2.1-1) with a restricted Cr(eq) to Ni(eq) ratio[3] as per BN2[4]

[1] Kotecki, D. J., and Siewert, T. A. (1992). "WRC-1992 Constitution Diagram for Stainless Steel Weld Metals: A Modification of the WRC-1988 Diagram." Welding Journal 71(5), 171-s–178-s.

[2] Morach, R., and Ginter, P. (1997, September). "Influence of Low δ-Ferrite Content on the Corrosion Behaviour of Stainless Steels." Stainless Steel World.

[3] Cr(eq) — 0.91 Ni(eq) ≤ 7.70, with

(a) Cr(eq) = %Cr + 1.5%Si + %Mo + 2%Ti, and

(b) Ni(eq) = %Ni + 0.5%Mn + 30%C + 30(%N–0.02)

[4] Basler Norm BN2 (N 11.265), Nichtrostender Stahl nach BN2, 1997.

NONMANDATORY APPENDIX H
ELECTROPOLISHING PROCEDURE QUALIFICATION

(24)

H-1 SCOPE

This Appendix defines a method for qualifying an electropolishing procedure.

H-2 PURPOSE

The purpose of this Appendix is to describe a standard method for qualifying an electropolishing procedure, including the minimum required tests and acceptance. The qualification process is not a guarantee that the final product will meet customer requirements.

Electropolishing is used to impart a surface that

(a) is free of contamination and undesirable metallurgical conditions

(b) takes advantage of a material's surface compositional characteristics by removal of damage or degradation from the component's manufacturing process

(c) optimizes corrosion resistance

H-3 ELECTROPOLISHING PROCESS

The electropolisher shall describe the overall process steps in a written document. This document identifies the processes required to produce an electropolished finish and should provide or reference information regarding the following:

(a) precleaning process
(b) electropolishing procedure specification(s)
(c) electrolyte conditions
(d) current density and time
(e) electrolyte solution controls
(f) rinsing process
(g) post-cleaning process
(h) final rinsing process
(i) inspection process

H-4 ELECTROPOLISHING PROCEDURE QUALIFICATION

The electropolisher shall develop a procedure for each method and generate the following document types:

(a) electropolishing procedure specification (EPPS) (see Form EPPS-1)

(b) electropolishing procedure qualification record (EPQR) (see Form EPQR-1)

The EPPS is a written qualified procedure specification that shall contain, as a minimum, the essential variables described herein. Each EPPS shall be qualified by testing, with test results recorded on an EPQR. Both documents shall be retained by the electropolisher to demonstrate that the process parameters used were tested and produced acceptable results for the application intended. These documents should be made available for review at the electropolisher's facility when the facility is audited.

To qualify a procedure, the electropolisher shall electropolish sample components or coupons using each electropolishing technique (e.g., submersion, spot, in situ) for the purpose of demonstrating that the method is capable of producing the required surface characteristics.

The documentation format for the EPPS and EPQR can be customized to accommodate a specific technique. Forms EPPS-1 and EPQR-1 are suggested formats that would be suitable for the submersion technique.

H-4.1 EPPS

The EPPS is a written qualified electropolishing procedure specification prepared to provide direction for the person performing the electropolishing operation. The document is used to identify the range of process parameters that are essential to ensure quality standards are met. The specification shall

(a) identify the alloy type (include a list of alloys that can be electropolished with this process)

(b) reference the supporting EPQR

(c) specify the acceptable ranges of the following essential variables:

(1) initial cleaning process (identify procedure used, minimum temperature and time)

(2) temperature range of electrolyte during process (minimum and maximum temperatures)

(3) electrolyte specific gravity (adjusted specific gravity range)

(4) current density range in amperes/square foot (amperes/square meter)

(5) voltage type (AC, DC positive, DC negative) and range

(6) current exposure time (the range of time that the surface is exposed to current)

(7) technique of electropolishing process (submersion, spot, moving cathode, moving anode, etc.)

Form EPPS-1 Suggested Format for Electropolishing Procedure Specification (EPPS)

Procedure Identification

EPPS no. _____ Revision _____ Date _____

Supporting EPQR(s) _____ Technique _____ Precleaning _____

Base Metal

Material category _____ UNS no. _____ Product form _____

Electrolyte

Product name _____

Manufacturer _____

Composition _____

Specific gravity of electrolyte (range) _____

Temperature of electrolyte (range) _____

Electrical Characteristics

Voltage type _____ Cathode material type _____

Characteristic	Units	Min.	Max.
Voltage range	volts		
Current density range	amperes/ft^2 (amperes/m^2)		
Cathode to anode distance	in. (mm)		
Time	minutes		

Technique

Pre-EP finish method _____

Initial cleaning _____

Electropolish _____

Rinse _____

Final cleaning _____

Company Name

Created by _____ Date _____
(Title)

Form EPQR-1 Suggested Format for Electropolishing Procedure Qualification Record (EPQR)

Procedure Identification

EPQR no. _____ Revision _____ Date _____

EPPS no. _____ Technique _____ Precleaning _____

Base Metal

Material category _____ UNS no. _____ Product form _____

Electrolyte

Product name _____

Manufacturer _____

Composition _____

Specific gravity of electrolyte _____

Percentage metal in electrolyte _____

Temperature of electrolyte _____

Electrical Characteristics

Voltage type _____ Cathode material type _____

Characteristic	Units	Actual
Voltage	volts	
Current density	amperes/ft^2 (amperes/m^2)	
Cathode to anode distance	in. (mm)	
Time	minutes	

Surface Conditions Before EP

Pre-EP Finish Method	Material Thickness or Weight	150X Photo, Y/N

Surface Conditions After EP

Visual	Material Thickness or Weight	Roughness R_a	150X Photo, Y/N

Test Summary

Total Cr/Fe Ratio	Passive Depth	Amount of Material Removed

Operator Name _____ ID no. _____ Witness by _____

Test evaluation by _____ Company _____ Lab test # _____

We hereby certify that the statements in this record are correct and that the test coupons were prepared and tested in accordance with the applicable requirements of ASME BPE, Appendix H.

Certified by _____ Date _____

(Title)

Table H-4.3-1
Procedure Qualification Acceptance Criteria for Test Coupons

Material	Minimum Material Removal, in. (μm)	Surface Designation [Note (1)]	Total Cr/Fe Ratio	Depth, Å [Note (2)]	Documented Surface Quality
Austenitic stainless steels [Note (3)]	0.0002 (5)	SF6 or better	1 to 1 or greater	15 min.	Before and after photos at 150X minimum magnification
Superaustenitic stainless steels [Note (3)]	0.0002 (5)	SF6 or better	1 to 1 or greater	15 min.	Before and after photos at 150X minimum magnification
Duplex stainless steels [Note (3)]	0.0002 (5)	SF6 or better	N/A	N/A	Before and after photos at 150X minimum magnification
Nickel alloys [Note (4)]	0.0002 (5)	SF6 or better	N/A	N/A	Before and after photos at 150X minimum magnification

NOTES:
(1) See Table SF-2.4.1-1 for electropolished Ra maximum acceptance criteria.
(2) Depth of chromium-enriched passive layer.
(3) Stainless steels listed in Tables MM-2.1-1 and MM-2.1-3.
(4) Nickel alloys listed in Tables MM-2.1-2 and MM-2.1-3.

(8) final rinsing/cleaning process (identify procedure used, minimum temperature and time)

(d) describe the essential variables for each technique used (e.g., submersion, spot, moving anode, moving cathode)

The electropolisher may also include any other information that may be helpful in achieving an acceptable electropolished surface.

H-4.2 EPQR

The EPQR is a record of the variables recorded during the electropolishing of the qualification component or coupon and the test results of the tested specimens. Recorded variables normally fall within a small range of the actual variables that will be used in production and identified on the EPPS used. The record shall

(a) document the essential variables for each technique to be qualified. Other variables used during the qualification process may be recorded at the organization's option.

(b) be certified accurate by the organization. The certification is the organization's verification that the information is a true record of the variables that were used during the electropolishing qualification process and that the test results conform with H-4.4.

(c) document the testing method performed on the qualification component or coupon was tested using methods in H-4.4 or other methods producing the same data. These methods shall meet the acceptance criteria in Table H-4.3-1 and SF-2.2.

(d) record the following data:

(1) alloy type

(2) final R_a

(3) thickness of material removed

(4) total Cr/Fe ratio after electropolishing

(5) depth of passive layer after electropolishing

(6) before and after photographs at 150X minimum

H-4.3 Procedure Qualification Acceptance Criteria

Procedure qualification acceptance criteria shall include the contents of Table H-4.3-1. The surface condition of the test specimen shall also meet acceptance criteria of the targeted surface finish designation defined in Part SF.

H-4.4 Testing Methods

Techniques to measure the test specimen include, but are not limited to, one of the following testing methods for each criterion:

(a) Minimum Material Removal

(1) calculated thickness removal using material density, specimen surface area, and measured mass loss due to electropolishing

(2) measured thickness removal due to electropolishing

(b) Surface Designation. Visual examination and surface roughness measurement after electropolishing

(c) Total Cr/Fe Ratio

(1) X-ray photoelectron spectroscopy (XPS/ESCA)

(2) auger electron spectroscopy (AES)

(d) Minimum Passive Layer Depth

(1) XPS/ESCA

(2) AES

(e) Documented Surface Quality

(1) before and after photos at 150X minimum magnification

(2) final condition photos using scanning electron microscopy (SEM)

NONMANDATORY APPENDIX J
VENDOR DOCUMENTATION REQUIREMENTS FOR NEW INSTRUMENTS

J-1 OVERVIEW

J-1.1 Section 1: VDR Definitions

This section identifies the vendor documentation requirements (VDR) number, document title, and definitions for the documentation (see Table J-1.1-1).

J-1.2 Section 2: Instrument Types and Required Documents

This section identifies the major instrument types and the required documentation, by VDR number (see Table J-1.2-1).

J-2 INSTRUCTIONS FOR USE

Together, these two sections are intended to be used by end-users, design and procurement agents, and vendors, to identify the documents required to support commissioning/qualification, installation, operation, and maintenance of instrumentation for the biopharmaceutical industry.

These documentation requirements may be modified, as necessary, to reflect the actual documents required for a particular instrument, based on the instrument's complexity, application, end-user's specific requirements, etc.

Table J-1.1-1
Vendor Documentation Requirements for New Instruments: Section 1, VDR Definitions

VDR #	Documentation	Definitions
1	Certified Arrangements/ Assembly Drawings	Provide Certified Arrangements/Assembly Drawings for the tagged component [or tagged packaged equipment (skid)] specified on the P.O. A "Certified Arrangement" or "Assembly Drawing" means that a statement, signed and dated by an authorized company representative, is included on (or with) the drawing, certifying the component (or skid) has been manufactured in accordance with stated applicable federal and state or internationally recognized regulatory requirements and the designated component (or skid), by tag number, conforms to the established industry standards and product specifications.
2	Catalog information, cut sheets, product bulletins	This information shall include the supplier's literature for the component being purchased. The literature shall include dimensions, materials of construction, and layout considerations such as orientation, typical utility requirements, power, and instrument air.
3	Detailed parts list/bill of material	Provide a complete listing of all subassemblies, parts, and raw materials that compose the final (finished) component (or skid). Include the quantity of each item.
4	Installation, operation, maintenance, and lubrication manual(s)	Provide manuals for the components (or skid) being purchased. Manuals should include installation guidelines, detailed operating instructions with operating ranges, settings, etc. Also, include step-by-step startup, operating, and shutdown procedures and maintenance procedures for all required maintenance/repairs and lubrication schedule.
5	Recommended spare parts for 1 yr normal maintenance	Spare parts list will include the vendors' recommended listing of spare parts required for 1 yr, assuming that the system is cycled once a week (50 times/yr); the list is to include the tag number (if applicable), a description of each part sufficient for ordering, and the vendor's part number.
6	Certified Performance Report	Provide a Certified Performance Report that states that the instrumentation by tag number and serial number conforms to the stated process ranges established in the stated specification. The Certified Performance Report must be signed and dated by an authorized person from the manufacturer or subsupplier who performed the test. Typically this testing is a destructive test, and the instrumentation being purchased was produced by the same manufacturing process with the same material supplier(s).
7	Wiring schematics	Provide drawings that show the following: *(a)* terminal strip/wiring numbering *(b)* starter, overloads, protective devices *(c)* ALL electrical components *(d)* instrumentation (electrical connections)
8	Instrument calibration reports	Calibration certificates or reports must be traceable to NIST or other internationally recognized and agreed-on calibration standards. They must also include the procedure used, calibration data/results, the calibration date, the person who performed the calibration, along with the serial number(s) of the standards or equipment used in the calibration process. All calibration certificates or reports must contain the instrument serial number.
9	Sizing calculations	Given two or three of the following parameters, provide the sizing calculations, designated by tag number, for the design flow: *(a)* type of liquid and viscosity *(b)* piping size *(c)* flow For relief devices, the calculation to show the relieving flow, set pressure, back pressure, vacuum, specific gravity, viscosity, coefficient of discharge, back pressure coefficient, viscosity (or other applicable) coefficient, calculated required area in square inches; summary to show the manufacturer, model number, and the selected area.
10	Material Test Report for metallic materials	The Material Test Report for process contact metallic materials shall conform to the requirements listed in Part GR. REQUIRED ONLY FOR HYGIENIC APPLICATIONS
11	Certificate of Conformance for elastomers	The Certificate of Conformance for process contact elastomer materials shall conform to the requirements listed in Part GR. REQUIRED ONLY FOR HYGIENIC APPLICATIONS
12	Certificate of Conformance for surface finish	The Certificate of Conformance for surface finish must be uniquely identified by tag number, serial number, and/or model number; state the associated surface finish value in R_a or BPE designation per Part SF; and whether any polishing compounds were used to meet the stated specification. If polishing compounds are used they shall be inorganic and animal source material-free as stated on the Certificate of Conformance. The Certificate of Conformance must be signed and dated by an authorized person from the manufacturer. REQUIRED ONLY FOR HYGIENIC APPLICATIONS

Table J-1.1-1
Vendor Documentation Requirements for New Instruments: Section 1, VDR Definitions (Cont'd)

VDR #	Documentation	Definitions
13	Certificate of Conformance for polymer-based materials	The Certificate of Conformance for process contact polymer-based materials shall conform to the requirements listed in Part GR. REQUIRED ONLY FOR HYGIENIC APPLICATIONS

Table J-1.2-1
Vendor Documentation Requirements for New Instruments: Section 2, Instrument Types and Required Documents

Instrument Types	Required Documents (VDR Number)
Analytical element: condition/density/pH/resistivity	2, 3, 4, 5, 7, 10, 11, 12, 13
Conservation vent valve	1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 13
Control damper: flow/humidity/pressure/temperature	2, 4
Control valve: analytical/flow/humidity/level/pressure/temperature	1, 2, 3, 4, 5, 7, 9, 10, 11, 12, 13
Controllers, indicating controllers	2, 3, 4, 5, 7
D/P transmitter: flow/level/pressure	2, 4, 7, 8, 10, 12
Damper actuator	2, 4, 7, 9
Electrical components	2, 4, 7
Flow element	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13
Flow orifice	2, 4, 10, 11, 12, 13
Flow switch: thermal	2, 3, 4, 5, 7, 10
Flow valve, automated valve assembly	1, 2, 3, 4, 5, 7, 10, 11, 12, 13
Indicator: flow/level	2, 3, 4, 5, 10, 11, 12, 13
Indicator: humidity/pressure/temperature	2, 4, 8, 10, 12
Level element	2, 3, 4, 5, 7, 10, 11, 12, 13
Level transmitter: microwave	2, 4, 7, 10, 11, 12, 13
Lighting	2, 4, 5, 7, 10, 12
Miscellaneous instruments: alarm/element/switch/transmitter	2, 4, 7
Positioner/transducer I/P: pressure/speed/temperature	2, 4, 7
Pressure element, pressure safety element	2, 4, 6, 10, 11, 12, 13
Pressure port	2, 4
Pressure safety (relief) valve	1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 13
Recorder, indicating recorder	2, 4, 5, 7
Regulator valve: temperature/pressure	1, 2, 3, 4, 5, 10, 11, 12, 13
Sight glass	2, 3, 4, 5, 10, 11, 12, 13
Smoke detector, motion detector	2, 3, 4, 5
Solenoid valve	2, 4, 7
Switch: current/limit	2, 4, 7
Switch: analytical/flow/level/pressure/vibration	2, 3, 4, 5, 7, 10, 11, 12, 13
Temperature element: RTD	2, 4, 7, 8, 10
Temperature switch	2, 4, 7, 10, 12
Thermowell	2, 10, 12
Transmitter: analytical/flow/humidity/level/pressure/temperature/weight	2, 3, 4, 5, 7
Weight element	2, 3, 4, 5, 7, 8

NONMANDATORY APPENDIX K
STANDARD PROCESS TEST CONDITIONS (SPTC) FOR SEAL PERFORMANCE EVALUATION

K-1 SEALING COMPONENT PERFORMANCE EVALUATION

K-1.1 Material and Component Testing

Standard process test conditions are presented here in order to assess sealing components (hygienic union seal materials and diaphragm valve component seals). A simulated steam-in-place (SIP) test cycle is presented in K-1.2.1. Other process considerations are presented in K-1.2.2. Any specific process conditions that fall outside the design of this standard test should be evaluated separately.

The specific material composition(s) used in the test article shall be evaluated against the process conditions to which it may be exposed, including routine sterilization and cleaning. For diaphragm valve testing, the test article should reflect the specific valve configuration to be used in the anticipated application. Other conditions or process parameters/chemicals, such as allowable extreme process upset conditions and nonroutine treatments (e.g., passivation, derouging), should also be considered. Form S-1, Application Data Sheet, defines a number of operational conditions (e.g., chemistry, temperature, pressure) to consider when developing nonstandard performance tests.

Before testing

(a) verify that the material/component's service temperature and pressure rating meet the desired process conditions, including sterilization and cleaning.

(b) verify that the material/component is compatible with the intended process and cleaning chemicals at the routine concentrations used, including consideration for extreme allowable process conditions, per Part PM.

K-1.1.1 Test Article Requirements

(a) The following information, at a minimum, shall be included in test reports:

(1) seal type
(2) seal size
(3) sample size
(4) maximum rated pressure of valve or seal
(5) for valves only
(-a) actuator model number and spring pressure
(-b) air pressure supplied to actuator
(-c) valve type
(-d) valve size
(-e) valve model number

(b) Test samples shall be representative of a certain model or product range of seals and shall be chosen randomly from those fabricated with the standard manufacturing process. Any modifications that may impact performance shall be included in the test report, e.g., travel stops. Knowledge of factors that impact material performance may help determine the minimum selection criteria of samples. Appropriate study design or supporting data are required to support all conclusions. Any differences or factors that impact material performance across the commercial product range shall be addressed. This includes, but is not limited to, seal materials of construction, size, shape, and manufacturing process.

K-1.2 Exposure Testing

Section K-1.2.1 presents a simulated SIP test describing a typical steam sanitization cycle that can be performed on test articles. Actuation requirements in K-1.2.1 apply to valve testing only.

K-1.2.1 Simulated Steam-in-Place Testing. Expose the material to multiple SIP cycles to establish a life expectancy for the application and configuration. The testing cycles should occur without intervention (e.g., retorquing of clamps or fasteners), beyond initial installation procedures. All deviations identified during the test program should be documented and analyzed, including their impact on the test results and conclusions.

The cycle will consist of the following:

(a) Initial Installation and Preparation. This typically includes assembly, cleaning, performance verification (routinely includes a thermal exposure cycle to allow the seals to set), seating of seals, and retorquing of valve clamps and fasteners, etc., per the manufacturer's procedures.

(b) Initial Performance Evaluation. Verify the initial performance of the sealing component per K-1.2.3.

(c) Steam-in-Place. Expose the system to a simulated SIP with saturated USP pure steam or equivalent (e.g., steam generated from DI/RO water or equivalent).

(1) System Temperature/Pressure. Minimum temperature of 266°F (130°C) representing 24 psig (1.65 barg) under saturated steam conditions (see SD-2.3.1.1)

(2) System Stabilization Time. Minimum of 5 min

(3) Test Exposure Time. Minimum of 30 min at greater than 266°F (130°C)

(4) Actuations. Minimum of 30 actuations (cycle time to allow for valve to move from fully open to fully closed and back) per cycle (at SIP temperature)

(d) Cooldown. Cool the system with a combination of ambient clean dry air and deionized, or better quality, water.

(1) Air Cooldown

(-a) System Pressure. Atmospheric pressure or above

(-b) Cooldown Target. Until the system reaches 122°F ± 9°F (50°C ± 5°C)

(2) Water Cooldown

(-a) System Pressure. Atmospheric pressure or above.

(-b) System Flow Target. Flow velocity target ≥ 5ft/sec (1.52 m/s) for line size up to 2 in. (50.8 mm). Record velocity used.

(-c) Cooldown Target. Until the system temperature is less than 86°F (30°C).

(-d) Actuations. Minimum of 15 actuations (cycle time to allow for valve to move from fully open to fully closed and back) at ambient temperature under flow conditions.

(e) Performance Evaluation. Assess the performance of the sealing component at appropriate intervals (e.g., initial, 10 cycles, 100 cycles, 500 cycles, and final) per K-1.2.3.

(f) Repeat Steps. Repeat steps in (c) and (d).

(g) Final Performance Evaluation. Assess the performance of the sealing component at the completion of testing per K-1.2.3.

K-1.2.2 Other Process Testing Considerations

K-1.2.2.1 Vacuum. The ability of the system to hold vacuum should be considered for routine process equipment, where applicable. Specific applications that require vacuum, such as autoclaves and lyophilizers, shall require the addition of a vacuum hold test requirement.

K-1.2.3 Performance Testing and Acceptance Criteria. Test the sealing components to evaluate their ability to maintain the component's integrity before, during, and after exposure (e.g., initial, 10 cycles, 100 cycles, 500 cycles, and final), using the test procedures and acceptance requirements of EN-12266-1 and as outlined below.

(a) For all sealing components, use test procedure and acceptance requirements for shell tightness, Test P11 of EN-12266-1.

(b) For valve sealing components, use test procedure and acceptance requirements of seat tightness, Test P12 of EN-12266-1 with maximum allowable seat leakage rate A.

(c) For all sealing components postexposure, complete and document a test for entrapment. The test should enable assessment of process media migration beyond the primary sealing point of the sealing component post-exposure. Testing should be performed at ambient temperature for 1 hr or as required at 90 psig (6.21 barg) (shell) or at the component design pressure, whichever is less, using a suitable soiling media (e.g., color dye, UV fluorescing solution). The assessment is to be made and photographically recorded on dismantling of the components.

K-1.3 Test Acceptance Criteria

K-1.3.1 Hygienic Fittings. The seal will be classified as a Level 10, 100, or 500 seal, if all of the following acceptance criteria are met after the corresponding number (10, 100, or 500) of SIP exposure/cooldown cycles:

(a) Pressure hold test shall be passed after the 10th, 100th, and/or 500th SIP exposure cycle.

(b) Conformance to MC-4.2 shall be established after the 10th, 100th, and/or 500th SIP exposure cycle (Intrusion Category I or II) for gaskets.

(c) The condition of the seal shall be examined after the 10th, 100th, and/or 500th SIP exposure cycle, and any direct visible changes (e.g., surface defects, compression marks, discoloration, or erosion) shall be recorded. Cracks, tears, or holes will be considered failures.

(d) Inspection at 0 (initial), 10 (through outlet), 100 (through outlet), and 500 (through disassembly of fittings) cycles.

K-1.3.2 Valve Diaphragms. The purpose of this section is to establish recommendations for evaluating diaphragm service life under specified process conditions in order to

(a) provide acceptance criteria for hygienic performance of diaphragms when conducting the performance evaluation test per this Appendix.

(b) provide additional observations that may be recorded after performing the test or when evaluating valve diaphragms that are in service.

K-1.3.2.1 General Requirements for Performance Evaluation Test for Valve Diaphragms, per This Appendix. Prior to testing, ensure that

(a) the manufacturer's installation and operational procedures are followed.

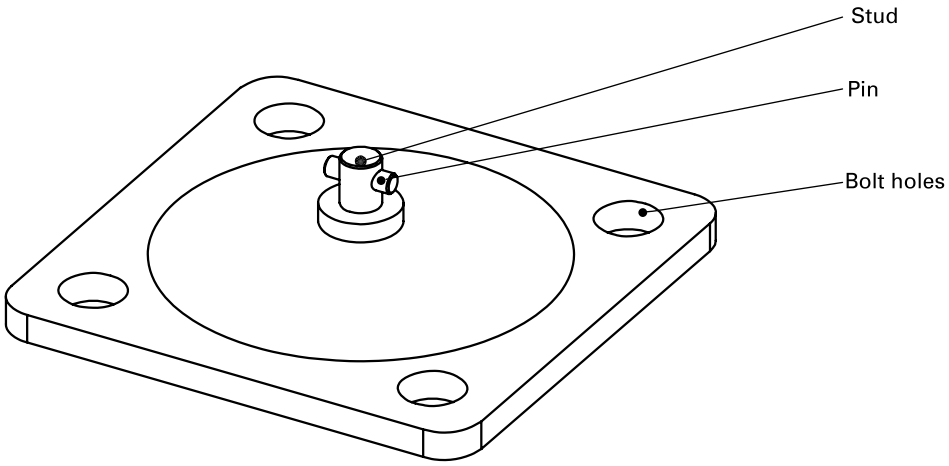
(b) a new diaphragm and new backing (if applicable) are used.

(c) the valve mating surfaces are dry and free of scratches and any residual material.

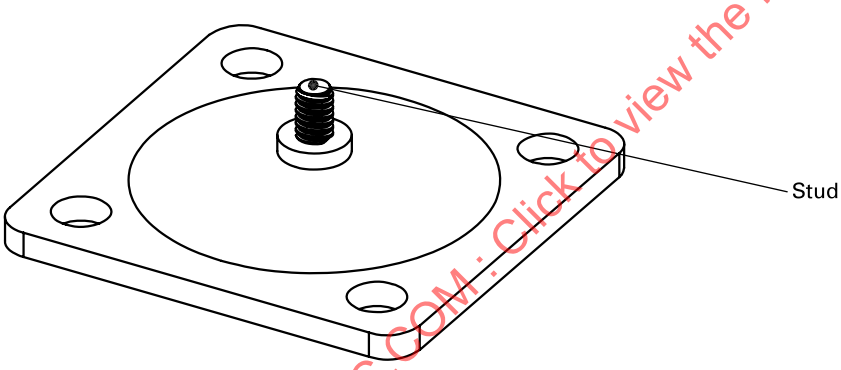
(d) the manual bonnet or actuator compressor is undamaged.

Figures K-1.3.2.1-1 through K-1.3.2.1-5 provide visual reference to the terminology used in this section.

Figure K-1.3.2.1-1
Weir-Style Diaphragm



(a) Bayonet Style



(b) Threaded Style