INTERNATIONAL STANDARD

ISO 13705

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Petroleum and natural gas industries — Fired heaters for general refinery service

Industries du pétrole et du gaz naturel — Réchauffeurs à brûleurs pour usage général dans les raffineries

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 13705 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum and natural gas industries*, Subcommittee SC 6, *Processing equipment and systems*.

Annexes D and E form a normative part of this International Standard. Annexes A, B, C, F, G and H are for information only.

Introduction

This International Standard is based on API standard 560, second edition, September 1995.

Users of this International Standard should be aware that further or differing requirements may be needed for individual applications. This International Standard is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This may be particularly applicable where there is innovative or developing technology. Where an alternative is offered, the vendor should identify any variations from this International Standard and provide details.

In International Standards, the SI system of units is used. Where practical in this International Standard, US Customary units are included in brackets for information.

A bullet (●) at the beginning of a clause or subclause indicates that either a decision is required or further information is to be provided by the purchaser. This information should be indicated on data sheets (see examples in annex A) or stated in the enquiry or purchase order. Decisions should be indicated on a check list (see example in annex B).

Petroleum and natural gas industries — Fired heaters for general refinery service

1 Scope

This International Standard specifies requirements and gives recommendations for the design, materials, fabrication, inspection, testing, preparation for shipment, and erection of fired heaters, air preheaters, fans and burners for general refinery service.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 8501-1, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

ISO 13704, *Petroleum and natural gas industries — Calculation of heater-tube thickness in petroleum refineries*

EN 10025[1)], *Hot rolled products of non-alloy structural steels — Technical delivery conditions*

AFBMA Standard 9[2)], *Load ratings and fatigue life for ball bearings*

AMCA 99-2404-78[3)], *Drive arrangements for centrifugal fans*

AMCA 201, *Fans and systems*

AMCA 210, *Laboratory methods of testing fans for aerodynamic performance rating*

ASME B17.1[4)], *Keys and keyseats*

ASME B31.3, *Process piping*

ASME Boiler and pressure vessel code, Section VIII, *Rules for construction of pressure vessels*

ASTM A 36[5)], *Standard specification for carbon structural steel*

1) European Committee for Standardization (CEN), Rue de Stassart 36, B-1050 Brussels, Belgium.

2) Anti-Friction Bearing Manufacturers Association, 1200 19th Street NW, Suite 300, Washington, DC 20036-2412, USA.

3) Air Movement and Control Assocation, 30 West University Drive, Arlington Heights, IL 60004, USA.

4) American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10017, USA.

5) American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

ASTM A 105, *Standard specification for carbon steel forgings for piping applications*

ASTM A 123, *Standard specification for zinc (hot-dip galvanized) coatings on iron and steel products*

ASTM A 143, *Standard practice for safeguarding against embrittlement of hot-dip galvanized structural steel products and procedure for detecting embrittlement*

ASTM A 153, *Standard specification for zinc coating (hot-dip) on iron and steel hardware*

ASTM A 161, *Standard specification for seamless low-carbon and carbon-molybdenum steel still tubes for refinery service*

ASTM A 181, *Standard specification for carbon steel forgings, for general-purpose piping*

ASTM A 182, *Standard specification for forged or rolled alloy-steel pipe flanges, forged fittings, and valves and parts for high-temperature service*

ASTM A 192, *Standard specification for seamless carbon steel boiler tubes for high-pressure service*

ASTM A 193, *Standard specification for alloy-steel and stainless steel bolting materials for high-temperature service*

ASTM A 194, *Standard specification for carbon and alloy steel nuts for bolts for high-pressure or high-temperature service, or both*

ASTM A 209, *Standard specification for seamless carbon-molybdenum alloy-steel boiler and superheater tubes*

ASTM A 210, *Standard specification for seamless medium-carbon steel boiler and superheater tube*s

ASTM A 213, *Standard specification for seamless ferritic and austenitic alloy-steel boiler, superheater and heat-exchanger tubes*

ASTM A 216, *Standard specification for steel castings, carbon, suitable for fusion welding, for high-temperature service*

ASTM A 217, *Standard specification for steel castings, martensitic stainless and alloy, for pressure-containing parts, suitable for high-temperature service*

ASTM A 234, *Standard specification for piping fittings of wrought carbon steel and alloy steel for moderate and high temperature service*

ASTM A 240, *Standard specification for heat-resisting chromium and chromium-nickel stainless steel plate, sheet, and strip for pressure vessels*

ASTM A 242, *Standard specification for high-strength low-alloy structural steel*

ASTM A 283, *Standard specification for low and intermediate tensile strength carbon steel plates*

ASTM A 297, *Standard specification for steel castings, iron-chromium and iron-chromium-nickel, heat resistant, for general application*

ASTM A 307, *Standard specification for carbon steel bolts and studs, 60 000 psi tensile strength*

ASTM A 320, *Standard specification for alloy steel bolting materials for low-temperature service*

ASTM A 325, *Standard specification for structural bolts, steel, heat treated, 120/105 ksi minimum tensile strength*

ASTM A 351, *Standard specification for castings, austenitic, austenitic-ferritic (duplex), for pressure-containing parts*

ASTM A 384, *Standard practice for safeguarding against warpage and distortion during hot-dip galvanizing of steel assemblies*

ASTM A 385, *Standard practice for providing high-quality zinc coatings (hot-dip)*

ASTM A 387, *Standard specification for pressure vessel plates, alloy steel, chromium-molybdenum*

ASTM A 403, *Standard specification for wrought austenitic stainless steel piping fittings*

ASTM A 447, *Standard specification for steel castings, chromium-nickel-iron alloy (25-12 class), for high-temperature service*

ASTM A 560, *Standard specification for castings, chromium-nickel alloy*

ASTM A 572, *Standard specification for high-strength, low alloy columbium-vanadium structural steel*

ASTM A 608, *Standard specification for centrifugally cast iron-chromium-nickel high-alloy tubing for pressure application at high temperatures*

ASTM B 366, *Standard specification for factory-made wrought nickel and nickel alloy fittings*

ASTM B 407, *Standard specification for nickel-iron-chromium alloy seamless pipe and tube*

ASTM B 564, *Standard specification for nickel alloy forgings*

ASTM B 633, *Standard specification for electrodeposited coatings of zinc on iron and steel*

ASTM C 27, *Standard classification of fireclay and high-alumina refractory brick*

ASTM C 155, *Standard classification of insulating firebrick*

ASTM C 332, *Standard specification for lightweight aggregates for insulating concrete*

ASTM C 401, *Standard classification of alumina and alumina-silicate castable refractories*

ASTM C 612, *Standard specification for mineral fiber block and board thermal insulation*

AWS[6)] D1.1, *Structural welding code — Steel*

AWS D14.6-96, *Specification for welding of rotating elements of equipment*

MSS SP-55[7)], *Quality standard for steel castings for valves, flanges and fittings, and other piping components — Visual method*

NFPA 70[8)], *National electrical code*

3 Terms and definitions

For the purposes of this International Standard, the following terms and definitions apply.

NOTE Terms and definitions related to centrifugal fans are given in annex E.

3.1
air heater
air preheater
heat transfer apparatus through which combustion air is passed and heated by a medium of higher temperature, such as the combustion products, steam or other fluid

6) American Welding Society, 550 NW Le Jeune Road, Miami, FL 33126, USA.

7) Manufacturers Standardization Society, 127 Park Street NE, Vienna, VA 22180, USA.

8) National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269-9101, USA.

3.2
anchor
tieback
metallic or refractory device that holds the refractory or insulation in place

3.3
arch
flat or sloped portion of the heater radiant section opposite the floor

3.4
atomizer
device used to reduce liquid fuel to a fine mist

3.5
backup layer
refractory layer behind the hot face layer

3.6
balanced draught heater
heater which uses forced-draught fans to supply combustion air and uses induced fans to remove flue gases

3.7
breeching
heater section where flue gases are collected after the last convection coil for transmission to the stack or the outlet ductwork

3.8
bridgewall
gravity wall
wall which separates two adjacent heater zones

3.9
bridgewall temperature
temperature of flue gas leaving the radiant section

3.10
burner
device which introduces fuel and air into a heater at the desired velocities, turbulence and concentration to establish and maintain proper ignition and combustion

NOTE Burners are classified by the type of fuel fired, such as oil, gas, or a combination of gas and oil, which may be designated as “dual fuel” or “combination”.

3.11
butterfly damper
single-blade damper which pivots about its centre

3.12
casing
metal plate used to enclose the fired heater

3.13
castable
insulating concrete poured or gunned in place to form a rigid refractory shape or structure

3.14
ceramic fibre
fibrous refractory insulation composed primarily of silica and alumina

NOTE Applicable forms include blanket, board, module, rigidized blanket, and vacuum-formed shapes.

3.15
convection section
portion of the heater in which the heat is transferred to the tubes primarily by convection

3.16
corbel
projection from the refractory surface generally used to prevent flue gas bypassing the tubes of the convection section if they are on a staggered pitch

3.17
corrosion allowance
additional material thickness added to allow for material loss due to corrosion

3.18
corrosion rate
rate of reduction in the material thickness due to chemical attack from the process fluid or flue gas or both

NOTE Corrosion rate is expressed in millimetres per year (mils per year).

3.19
crossover
interconnecting piping between any two heater-coil sections

3.20
damper
device for introducing a variable resistance in order to regulate the flow of flue gas or air

3.21
direct air preheater
heat exchanger which transfers heat directly between the flue gas and the combustion air

NOTE A regenerative air preheater uses heated rotating elements and a recuperative design uses stationary tubes, plates, or cast iron elements to separate the two heating media.

3.22
draught
negative pressure (vacuum) of the air and/or flue gas measured at any point in the heater

3.23
draught loss
pressure drop (including buoyancy effect) through duct conduits or across tubes and equipment in air and flue gas systems

3.24
duct
conduit for air or flue gas flow

3.25
fuel efficiency
total heat absorbed divided by the total input of heat derived from the combustion of fuel only (lower heating value basis)

NOTE This definition excludes sensible heat of the fuels and applies to the net amount of heat exported from the unit.

3.26
thermal efficiency
total heat absorbed divided by the total input of heat derived from the combustion of fuel (h_L) plus sensible heats from air, fuel and any atomizing medium

3.27
erosion
reduction in material thickness due to mechanical attack from a fluid

3.28
excess air
amount of air above the stoichiometric requirement for complete combustion

NOTE Excess air is expressed as a percentage.

3.29
extended surface
heat-transfer surface in the form of fins or studs attached to the heat-absorbing surface

3.30
extension ratio
ratio of total outside exposed surface to the outside surface of the bare tube

3.31
flue gas
gaseous product of combustion including excess air

3.32
forced-draught heater
heater for which combustion air is supplied by a fan or other mechanical means

3.33
fouling allowance
factor to allow for a layer of residue that increases pressure drop

NOTE 1 This residue is usually a build-up of coke or scale on the inner surface of a coil.

NOTE 2 The fouling allowance is used in calculating the fouled pressure drop.

3.34
fouling resistance
factor used to calculate the overall heat transfer coefficient

NOTE The inside fouling resistance is used to calculate the maximum metal temperature for design. The external fouling resistance is used to compensate the loss of performance due to deposits on the external surface of the tubes or extended surface.

3.35
header
return bend
cast or wrought fitting shaped in a 180° bend and used to connect two or more tubes

3.36
header box
internally insulated structural compartment, separated from the flue-gas stream, which is used to enclose a number of headers or manifolds

NOTE Access is afforded by means of hinged doors or removable panels.

3.37
heat absorption
total heat absorbed by the coils, excluding any combustion-air preheat

3.38
average heat flux density
heat absorbed divided by the exposed heating surface of the coil section

NOTE Average flux density for an extended-surface tube is indicated on a bare surface basis with extension ratio noted.

3.39
maximum heat flux density
maximum local rate of heat transfer in the coil section

3.40
total heat release
heat liberated from the specified fuel, using the lower heating value of the fuel

3.41
volumetric heat release
heat released divided by the net volume of the radiant section, excluding the coils and refractory dividing walls

3.42
higher heating value
h_H
gross heating value
total heat obtained from the combustion of a specified fuel at 15 °C (60 °F)

3.43
lower heating value
h_L
net heating value
higher heating value minus the latent heat of vaporization of the water formed by combustion of hydrogen in the fuel

3.44
hot face layer
refractory layer exposed to the highest temperatures in a multilayer or multicomponent lining

3.45
hot face temperature
temperature of the refractory surface in contact with the flue gas or heated combustion air

NOTE The hot face temperature is used to determine refractory or insulation thickness and heat transmitted.

3.46
indirect air preheater
fluid-to-air heat transfer device

NOTE The heat transfer can be accomplished by using a heat-transfer fluid, process stream or utility stream which has been heated by the flue gas or other means. A heat pipe air preheater uses a vaporizing/condensing fluid to transfer heat between the flue gas and air.

3.47
induced-draught heater
heater which uses a fan to remove flue gases and maintain a negative pressure in the heater to induce combustion air without a forced-draught fan

3.48
jump over
interconnecting pipework within a heater coil section

3.49
louvre damper
damper consisting of several blades, each of which pivots about its centre and is linked to the other blades for simultaneous operation

3.50
manifold
chamber for the collection and distribution of fluid to or from multiple parallel flow paths

3.51
metal fibre reinforcement
stainless steel needles added to castable for improved toughness and durability

3.52
monolithic lining
single-component lining system

3.53
mortar
refractory material preparation used for laying and bonding refractory bricks

3.54
multicomponent lining
refractory system consisting of two or more layers of different refractory types

NOTE Examples of refractory types are castable and ceramic fibre.

3.55
multilayer lining
refractory system consisting of two or more layers of the same refractory type

3.56
natural-draught heater
heater in which a stack effect induces the combustion air and removes the flue gases

3.57
normal heat release
design heat absorption of the heater divided by the calculated fuel efficiency

3.58
pass
stream
flow circuit consisting of one or more tubes in series

3.59
pilot
small burner that provides ignition energy to light the main burner

3.60
plenum
windbox
chamber surrounding the burners that is used to distribute air to the burners or reduce combustion noise

3.61
plug header
cast return bend provided with one or more openings for the purpose of inspection or mechanical tube cleaning

3.62
pressure design code
recognized pressure vessel standard specified or agreed by the purchaser

EXAMPLE ASME Boiler and Pressure Vessel Code, Section VIII.

3.63
pressure drop
difference between the inlet and the outlet static pressures between termination points, excluding the static differential head

3.64
primary air
portion of the total combustion air that first mixes with the fuel

3.65
protective coating
corrosion-resistant material applied to a metal surface

EXAMPLE Coating on casing plates behind porous refractory materials to protect against sulfur in the flue gases.

3.66
radiant section
portion of the heater in which heat is transferred to the tubes primarily by radiation

3.67
radiation loss
setting loss
heat lost to the surroundings from the casing of the heater and the ducts and auxiliary equipment (when heat recovery systems are used)

3.68
secondary air
air supplied to the fuel to supplement primary air

3.69
setting
heater casing, brickwork, refractory and insulation, including the tiebacks

3.70
shield section
shock section
tubes that shield the remaining convection-section tubes from direct radiation

3.71
sootblower
device used to remove soot or other deposits from heat-absorbing surfaces in the convection section

NOTE Steam is normally the medium used for soot blowing.

3.72
stack
vertical conduit used to discharge flue gas to the atmosphere

3.73
strake
spoiler
metal attachment to a stack which can prevent the formation of von Karman vortices that can cause wind-induced vibration

3.74
structural design code
structural design standard specified or agreed by the purchaser

EXAMPLES ICBO Uniform Building Code, ASCE standards, AISC Specification for design, fabrication and erection of structural steel for buildings.

3.75
target wall
re-radiating wall
vertical refractory firebrick wall which is exposed to direct flame impingement on one or both sides

3.76
temperature allowance
number of degrees Celsius (Fahrenheit) to be added to the process fluid temperature to account for flow maldistribution and operating unknowns

NOTE The temperature allowance is added to the calculated maximum tube-metal temperature or the equivalent tube-metal temperature to obtain the design metal temperature

3.77
terminal
flanged or welded connection to or from the coil providing for inlet and outlet of fluids

3.78
tube guide
device used with vertical tubes to restrict horizontal movement while allowing the tube to expand axially

3.79
tube retainer
device used to restrain horizontal radiant tubes from lifting off the intermediate tube supports during operation

3.80
tube support
tube sheet
device used to support tubes

3.81
vapour barrier
metallic foil placed between layers of refractory as a barrier to flue gas flow

4 General

4.1 Precautions

Care shall be excercised when using certain materials in the construction of fired heater components, in particular those where a dust hazard may be experienced. Manufacturer's recommendations and local and national safety requirements shall be followed in all cases.

4.2 Pressure design code

- The pressure design code shall be specified or agreed by the purchaser. Pressure components shall comply with the pressure design code and the supplemental requirements in this International Standard.

4.3 Local regulations

- The vendor shall comply with the applicable local rules and regulations specified by the purchaser.

4.4 Heater nomenclature

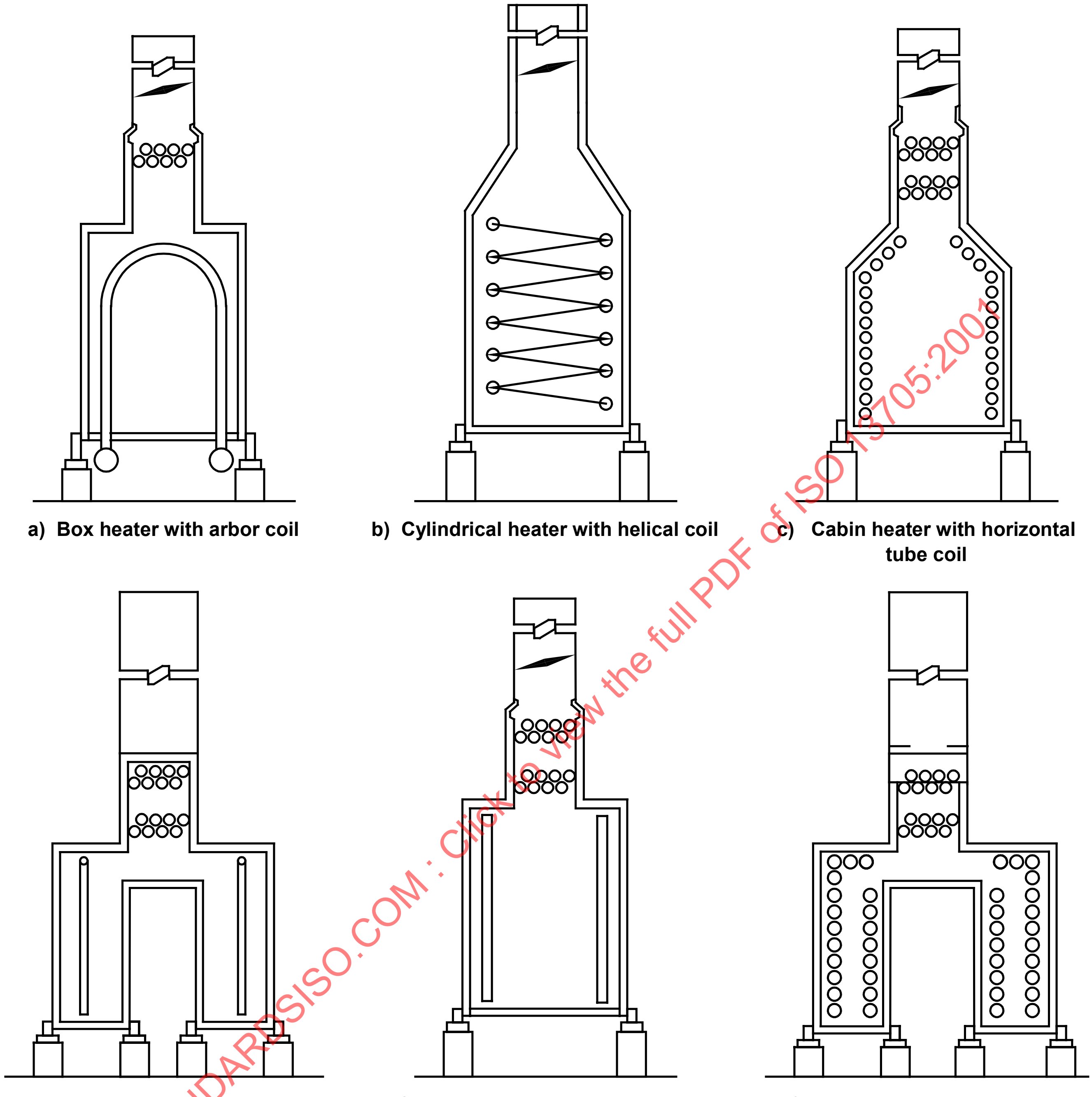
In a fired heater, heat liberated by the combustion of fuels is transferred to fluids contained in tubular coils within an internally insulated enclosure. The type of heater is normally described by the structural configuration, radiant tube coil configuration, and burner arrangement. Some examples of structural configurations are cylindrical, box, cabin and multicell box. Examples of radiant tube coil configurations include vertical, horizontal, helical and arbor. Examples of burner arrangements include upfired, downfired and wallfired. The wallfired arrangement can be further classified as sidewall, endwall and multilevel.

Figure 1 illustrates some typical heater types.

Figure 2 illustrates typical burner arrangements.

Various combinations of Figures 1 and 2 can be used. For example, Figure 1 c) can employ burner arrangements as in Figure 2 a), b) or c) Similarly, Figure 1 d) can employ burner arrangements as in Figure 2 a) or d).

Figure 3 shows typical components. Figures 4, 5 and 6 show typical combustion-air preheat systems.



a) Box heater with arbor coil

b) Cylindrical heater with helical coil

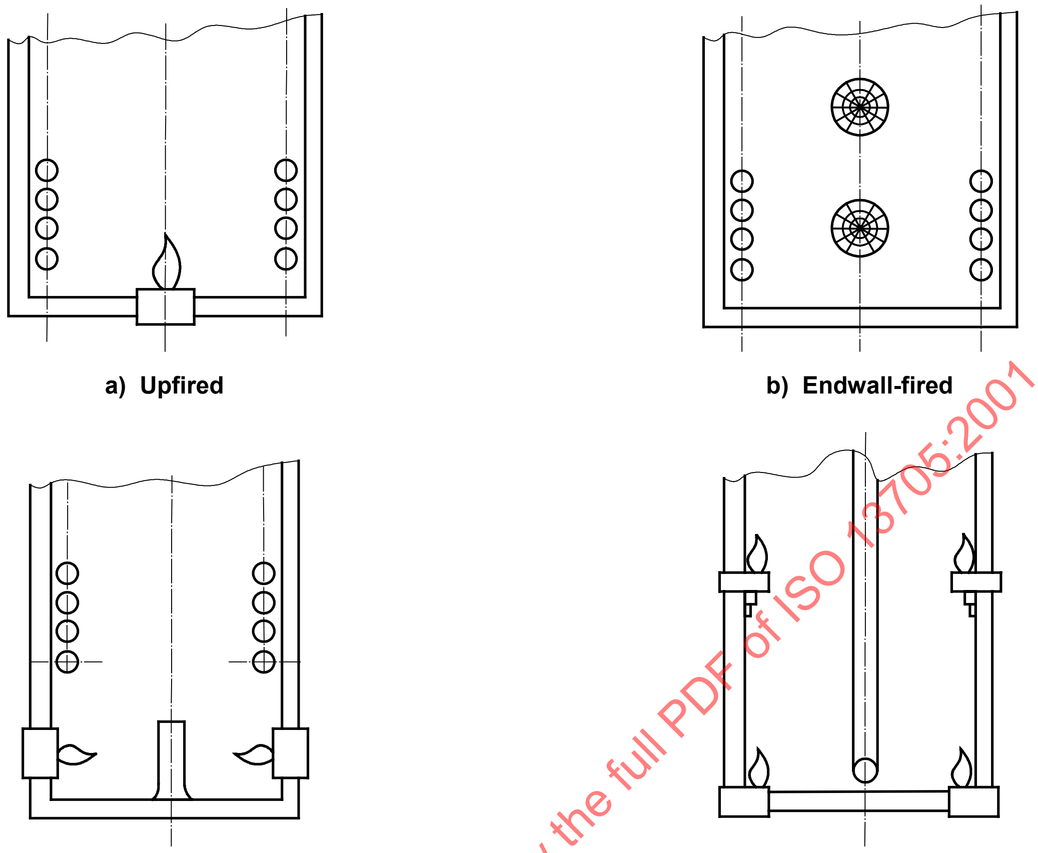
c) Cabin heater with horizontal tube coil

d) Box heater with vertical tube coil

e) Cylindrical heater with vertical coil

f) Box heater with horizontal tube coil

Figure 1 — Typical heater types



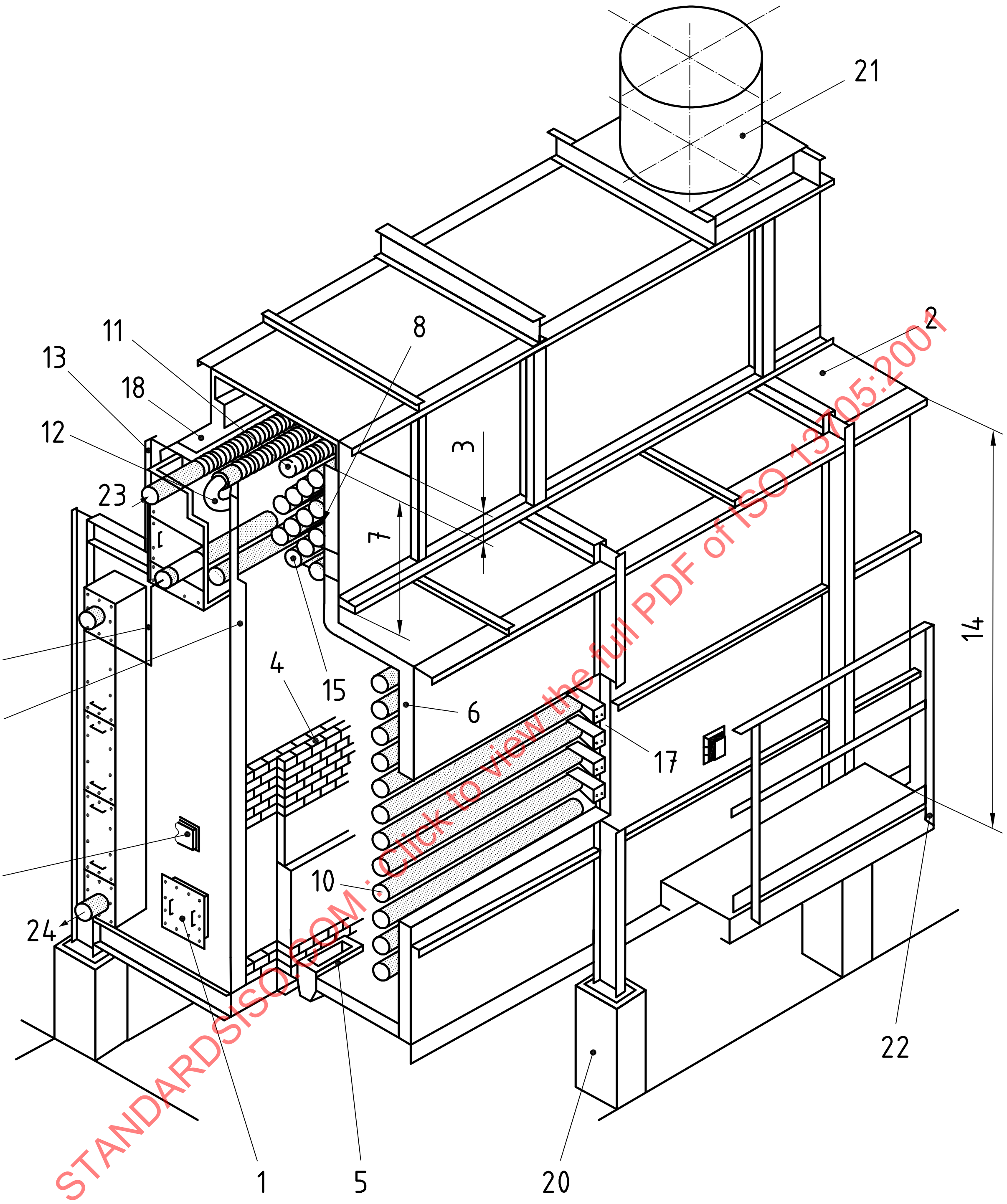
a) Upfired

b) Endwall-fired

c) Sidewall-fired

d) Sidewall-fired multi-level

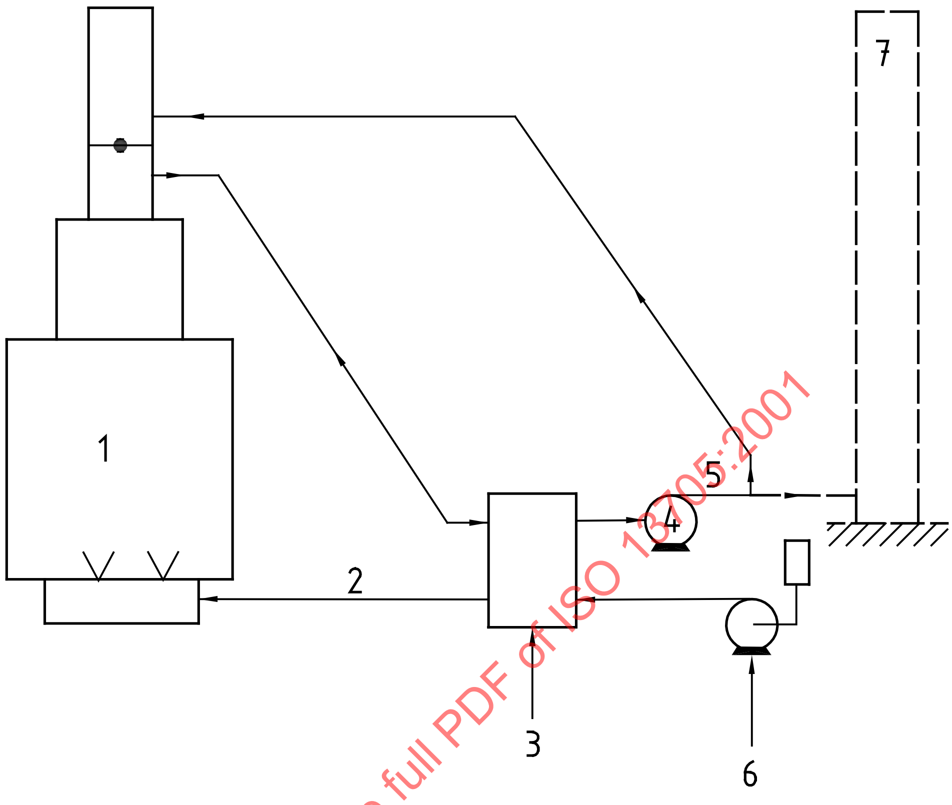
Figure 2 — Typical burner arrangements (elevation view)



Key

1	Access door	7	Convection section	13	Header box	19	End tube sheet
2	Arch	8	Corbel	14	Radiant section	20	Pier
3	Breeching	9	Crossover	15	Shield section	21	Stack/duct
4	Bridgewall	10	Tubes	16	Observation door	22	Platform
5	Burner	11	Extended surface	17	Tube support	23	Process in
6	Casing	12	Return bend	18	Refractory lining	24	Process out

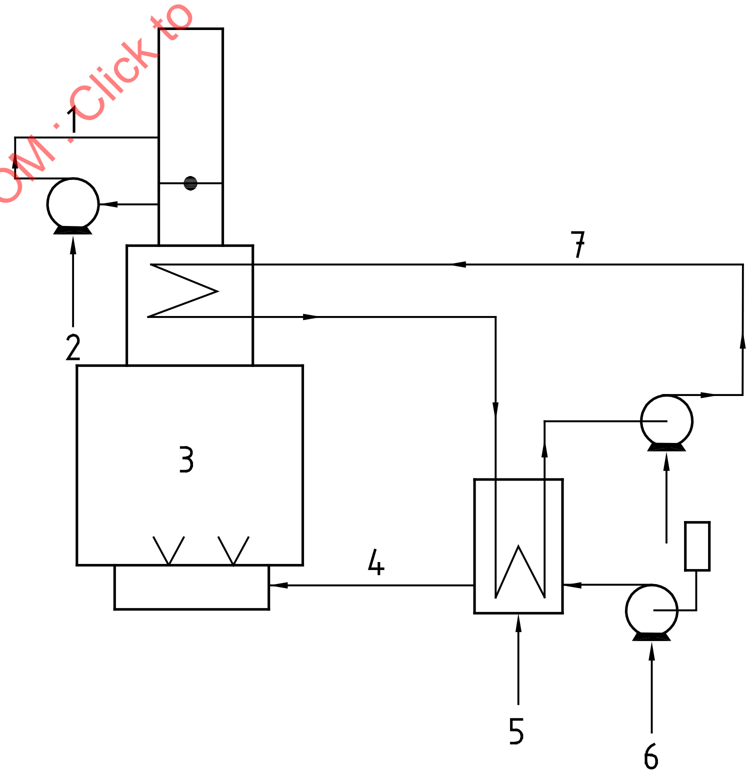
Figure 3 — Heater components



Key

1 Fired heater
2 Air
3 Air preheater
4 Induced-draught fan
5 Flue gas
6 Forced-draught fan
7 Separate stack (alternative)

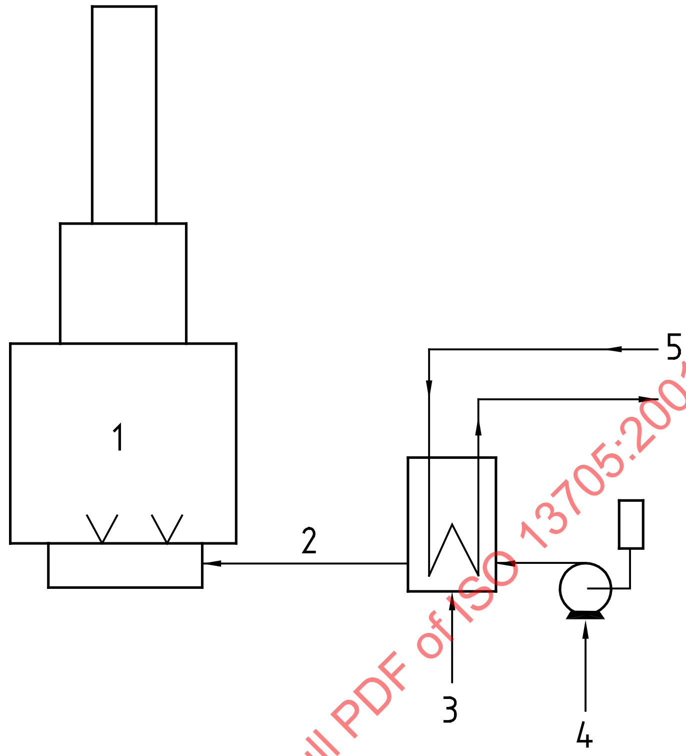
Figure 4 — Air preheat system using regenerative, recuperative or heat pipe unit



Key

1 Flue gas
2 Induced-draught fan
3 Fired heater
4 Air
5 Air preheater
6 Forced-draught fan
7 Heat medium

Figure 5 — System using indirect closed system air preheater with mechanical circulation



Key

1 Fired heater
2 Air
3 Air preheater
4 Forced-draught fan
5 Process or utility stream

Figure 6 — External heat source for air preheating

5 Proposals

5.1 Purchaser's responsibilities

5.1.1 The purchaser's enquiry shall include data sheets, check list, and other applicable information outlined herein. This information shall include any special requirements or exceptions to this International Standard.

5.1.2 The purchaser is responsible for the correct process specification to enable the vendor to prepare the fired heater design. The purchaser should complete, as a minimum, those items on the data sheet that are designated by an asterisk (*).

5.1.3 The purchase order shall state clearly the vendor's scope of work and extent of supply.

● **5.1.4** The purchaser's enquiry shall specify the number of copies of drawings, data sheets, specifications, data reports, operating manuals, installation instructions, spare parts lists, and other data to be supplied by the vendor, as required by 5.3 and 5.4.

5.2 Vendor's responsibilities

The vendor's proposal shall include:

a) for each heater, completed ISO data sheets for fired heater and associated equipment (see examples in annex A);

b) an outline drawing showing firebox dimensions, burner layout and clearances, arrangement of tubes, platforms, ducting, stack, breeching, air pre-heater and fans;

c) a full definition of the extent of shop assembly (format given in annex C may be used), including the number, size and mass of prefabricated parts and the number of field welds;

d) a detailed description of any exceptions to the specified requirements;

● e) a completed noise data sheet if the data sheet is supplied by the purchaser;

f) curves for heaters in vaporizing service, showing pressure, temperature, vaporization and bulk velocity as a function of the tube number;

g) time schedule for submission of all required drawings, data and documents;

h) a programme for scheduling the work after receipt of an order. This should include a specified period of time for the purchaser to review and return drawings, procurement of materials, manufacture and the required date of supply;

i) list of utilities and quantities required.

5.3 Documentation

5.3.1 Drawings for purchaser's review

The vendor shall submit for review the general arrangement drawings, coil drawings and data sheets for each heater. The documents shall include the following information:

a) heater service, the purchaser's equipment number, the project name and location, the purchase order numbers and the vendor's reference number;

b) coil terminal sizes, including flange ratings and facings; dimensional locations; direction of process flow; and allowable loads, moments and forces on terminals;

c) coil and crossover arrangements, tube spacings, tube diameters, tube wall thicknesses, tube lengths, material specifications, including grades for pressure parts only, and all extended surface data;

d) coil design pressures, hydrostatic test pressures, design fluid and tube wall temperatures, and corrosion allowance;

e) coil design code or recommended practice and fabrication code or specification;

f) refractory and insulation types, thicknesses, and service temperature ratings;

g) types and materials of anchors for refractory and insulation;

h) location and number of access doors, observation doors, burners, sootblowers, dampers, and instrument and auxiliary connections;

i) location and dimension of platforms, ladders, and stairways;

j) overall dimensions, including auxiliary equipment.

5.3.2 Foundation loading diagrams

The vendor shall submit for purchaser's review foundation loading diagrams for each heater. The diagram shall include the following information:

a) number and location of piers and supports;

b) baseplate dimensions;

c) anchor bolt locations, bolt diameters, and projection above foundations;

d) dead loads, live loads, wind or earthquake loads, reaction to overturning moments, and lateral shear loads.

5.3.3 Documents for purchaser's review

The vendor also shall submit to the purchaser the following documents for review and comment (individual stages of fabrication shall not proceed until the relevant document has been reviewed and commented upon):

a) structural steel drawings, details of stacks, ducts and dampers, and structural calculations;

b) burner assembly drawings and burner piping;

c) tube support details;

d) thermowell and thermocouple details;

e) welding, examination and test procedures and welder's test certificates;

f) installation and test procedures for refractories and insulation;

g) refractory thickness calculations including temperature gradients through all refractory sections and sources of thermal conductivities;

● h) decoking procedures, if required;

i) installation, operation and maintenance instructions for the heater and auxiliary equipment, such as air preheaters, fans, drivers, dampers and burners;

j) performance curves or data sheets for air preheaters, fans, drivers and burners and other auxiliary equipment;

k) noise data sheets, if data sheets are supplied by the purchaser;

l) plug header details.

5.3.4 Certified drawings and diagrams

After receipt of the purchaser's comments on the general arrangement drawings and diagrams, the vendor shall furnish certified general arrangement drawings and foundation loading diagrams. The vendor shall furnish design detail drawings, erection drawings, and an erection sequence. Drawings of auxiliary equipment shall also be furnished.

5.4 Final records

Within a specified timescale after completion of construction or shipment, the vendor shall furnish the purchaser with the following documents:

● a) data sheets and drawings representing the as-manufactured equipment. In the event field-changes are made, as-built drawings and data sheets shall not be provided unless specifically requested by the purchaser;

b) certified material reports, mill test reports or ladle analysis for all pressure parts and alloy-extended surfaces;

c) installation, operation and maintenance instructions for the heater and auxiliary equipment, such as air preheaters, fans, drivers, dampers and burners;

d) performance curves or data sheets for air preheaters, fans, drivers and burners and other auxiliary equipment;

e) bill of materials (major components);

● f) noise data sheets, if data sheets are supplied by the purchaser;

g) refractory dry-out procedures;

h) decoking procedures;

i) test certificates for tube support castings;

j) all other test documents, including test reports and non-destructive examination reports.

6 Design considerations

6.1 Process design

6.1.1 Heaters shall be designed for uniform heat distribution. Multipass heaters shall be designed for hydraulic symmetry of all passes.

6.1.2 The number of passes for vaporizing fluids shall be minimized. Each pass shall be a single circuit from inlet to outlet.

6.1.3 Average heat flux density in the radiant section is normally based on a single row of tubes spaced at two nominal tube diameters. The first row of shield-section tubes shall be considered as radiant service in determining the average heat flux density if these tubes are exposed to direct flame radiation.

6.1.4 Where the average radiant heat flux density is specified on the basis of two nominal diameters, the vendor may increase the flux rate for other coil arrangements, e.g. for three nominal diameters or double-sided firing, providing the maximum flux, including maldistribution, shall not exceed that based on two nominal diameters.

6.1.5 The maximum allowable inside film temperature for any process service shall not be exceeded in the radiant, shield or convection sections anywhere in the specified coil.

6.2 Combustion design

6.2.1 Margins provided in the combustion system are not intended to permit operation of the heater at greater than the design process duty.

6.2.2 Calculated fuel efficiencies shall be based on the lower heating value of the design fuel and shall include a radiation loss of 1,5 % of the calculated normal fuel heat release. Heaters employing flue gas/air preheat systems shall include a radiation loss of 2,5 % of the fuel heat release based on the lower heating value.

6.2.3 Unless otherwise specified by the purchaser, calculated efficiencies for natural-draught operation shall be based upon 20 % excess air if gas is the primary fuel, and 25 % excess air if oil is the primary fuel. In the case of forced-draught operation, calculated efficiencies shall be based on 15 % excess air for fuel gas and 20 % excess air for fuel oil.

6.2.4 The heater efficiency and tube wall temperature shall be calculated using the specified fouling resistances.

6.2.5 Volumetric heat release of the radiant section shall not exceed 125 kW/m^3 (12 000 Btu/h/ft^3) for oil-fired heaters and 165 kW/m^3 (16 000 Btu/h/ft^3) for gas-fired heaters based upon the design heat absorption.

6.2.6 Stack and flue-gas systems shall be designed so that a negative pressure of at least 25 Pa (0,10 in of water column) is maintained in the radiant and convection sections at 120 % of normal heat release with design excess air and maximum ambient temperature.

6.3 Mechanical design

6.3.1 Provisions for thermal expansion shall take into consideration all specified operating conditions, including short-term conditions such as steam-air decoking.

● **6.3.2** If specified by the purchaser, the convection-section tube layout shall include space for future installation of sootblowers, water washing, or steam-lancing doors.

● **6.3.3** If the heater is designed for heavy fuel-oil firing, sootblowers shall be provided for convection-section cleaning. If light fuel oils such as naphtha are to be fired, the purchaser shall specify if sootblowers are to be supplied.

6.3.4 The convection-section design shall incorporate space for the future addition of two rows of tubes, including the end and intermediate tubesheets. Placement of sootblowers and cleaning lanes shall be suitable for the addition of the future tubes. Holes in end tube sheets shall be plugged off to prevent flue gas leakage.

6.3.5 Vertical cylindrical heaters shall be designed with a maximum height-to-diameter (h/w) ratio of 2,75, where the height is that of the radiant section (inside refractory face) and the diameter is that of the tube circle, both measured in the same units.

6.3.6 For single-fired box-type floor-fired heaters with sidewall tubes only, an equivalent h/w factor shall be determined by dividing the height of the wall bank (or the straight tube length for vertical tubes) by the width of the tube bank and applying the following limitations:

Design absorption MW (Btu/h × 10^6)	h/w max.	h/w min.
Up to 3,5 (12)	2,00	1,50
3,5 to 7 (12 to 24)	2,50	1,50
Over 7 (24)	2,75	1,50

6.3.7 Shield sections shall have at least three rows of bare tubes.

6.3.8 Except for the first shield row, convection sections shall be designed with corbels or baffles to minimize the amount of flue gas bypassing the heating surface.

6.3.9 The minimum clearance from grade to burner plenum or register shall be 2 m (6,5 ft) for floor-fired heaters unless otherwise specified by the purchaser.

6.3.10 For vertical-tube vertical-fired heaters, the maximum radiant straight tube length shall be 18,3 m (60 ft). For horizontal heaters fired from both ends, the maximum radiant straight tube length shall be 12,2 m (40 ft).

6.3.11 Radiant tubes shall be installed with minimum spacing from refractory or insulation to tube centreline of 1,5 nominal tube diameters, with a clearance of not less than 100 mm (4 in) from the refractory or insulation. For horizontal radiant tubes, the minimum clearance from floor refractory to tube outside diameter shall be not less than 300 mm (12 in).

6.3.12 The heater arrangement shall allow for replacement of individual tubes or hairpins without disturbing adjacent tubes.

7 Tubes

7.1 General

7.1.1 Tube wall thickness for coils shall be determined in accordance with ISO 13704, in which the practical limit to minimum thickness for new tubes is specified. For materials not included, tube wall thickness shall be determined in accordance with ISO 13704 using stress values mutually agreed upon between purchaser and supplier.

7.1.2 Unless otherwise agreed between the purchaser and supplier, calculations made to determine tube wall thickness for coils shall include considerations for erosion and corrosion allowances for the various coil materials. The following corrosion allowances shall be used as a minimum:

a) carbon steel through C-1/2Mo: 3 mm (0,118 in);

b) low alloys through 9Cr-1Mo: 2 mm (0,080 in);

c) above 9Cr-1Mo through austenitic steels: 1 mm (0,040 in).

7.1.3 Maximum tube-metal temperature shall be determined in accordance with ISO 13704. The tube-metal temperature allowance shall be at least 15 °C (27 °F).

7.1.4 All tubes shall be seamless and should be in single continuous lengths. Electric flash welding shall not be used for intermediate welds. Tubes furnished to an average wall thickness shall be in accordance with suitable tolerances so that the required minimum wall thickness is provided.

7.1.5 Tubes, if projected into header box housings, shall extend at least 150 mm (6 in), in the cold position, beyond the face of the end tube sheet, of which 100 mm (4 in) shall be bare.

7.1.6 Tube size (outside diameter in inches) shall be selected from the following sizes: 2,375; 2,875; 3,50; 4,00; 4,50; 5,563; 6,625; 8,625; or 10,75. Other tube sizes should be used only if warranted by special process considerations.

7.1.7 If the shield and radiant tubes are in the same service, the shield tubes exposed to direct flame radiation shall be of the same material and thickness as the connecting radiant tubes.

7.2 Extended surface

● **7.2.1** The extended surface in convection sections may be studded (where each stud is attached to the tube by arc or resistance welding) or finned (where helically wound fins are high-frequency continuously welded to the tube). The purchaser shall specify or agree the type of extended surface to be provided. In the case of finning, the purchaser shall specify or agree whether the fins shall be solid or segmented.

7.2.2 Metallurgy for the extended surface shall be selected on the basis of maximum calculated tip temperature as listed in Table 1.

7.2.3 Extended surface dimensions shall be limited to those listed in Table 2.

Table 1 — Extended surface materials

Material	Studs		Fins	
	Maximum tip temperature		Maximum tip temperature	
	°C	(°F)	°C	(°F)
Carbon steel	510	(950)	454	(850)
2 1/4 Cr-1Mo, 5Cr-1/2 Mo	593	(1 100)	—	—
11-13 Cr	649	(1 200)	593	(1 100)
18Cr-8Ni stainless steel	815	(1 500)	815	(1 500)
25Cr-20Ni stainless steel	982	(1 800)	982	(1 800)

Table 2 — Extended surface dimensions

Fuel	Studs				Fins					
	Minimum diameter		Maximum height		Minimum normal thickness		Maximum height		Maximum number per unit length	
	mm	(in)	mm	(in)	mm	(in)	mm	(in)	per m	(per in)
Gas	12,5	(1/2)	25	(1)	1,3	(0,05)	25,4	(1)	197	(5)
Oil	12,5	(1/2)	25	(1)	2,5	(0,10)	19,1	(3/4)	118	(3)

7.3 Materials

Tube materials shall conform to ASTM specifications as listed in Table 3, or their equivalent agreed by the purchaser.

Table 3 — Tube materials and ASTM specifications

Material	Tube specification
Carbon steel	A 161, A 192, A 210, Gr A-1
Carbon-1/2Mo	A 161, A 209, Gr T1
1 1/4Cr-1/2Mo	A 213, Gr T11
2 1/4Cr-1Mo	A 213, Gr T22
3Cr-1Mo	A 213, Gr T21
5Cr-1/2Mo	A 213, Gr T5
5Cr-1/2Mo-Si	A 213, Gr TSb
7Cr-1/2Mo	A 213, Gr T7
9Cr-1Mo	A 213, Gr T9
9Cr-1Mo-V	A 213, Gr T91
18Cr-8Ni	A 213, TP 304, TP 304H
16Cr-12Ni-2Mo	A 213, TP 316, TP 316H
18Cr-10Ni-Ti	A 213, TP 321, TP 321H
18Cr-10Ni-Nb[a]	A 213, TP 347, TP 347H
Nickel alloy[b]	B 407
25Cr-20Ni	A 213, TP 310H
25Cr-20Ni	A 608, Gr HK40

[a] Formerly called columbium, Cb.

[b] Minimum grain size shall be ASTM #5 or coarser.

8 Headers

8.1 General

8.1.1 The design stress for headers shall be no higher than that allowed for similar materials as given in ISO 13704 and shall be reduced by casting quality factors if made from castings. Casting quality factors shall be in accordance with ASME B31.3.

8.1.2 Headers shall be of metallurgy equivalent to the tubes.

8.1.3 Headers shall be welded return bends or welded plug headers, depending on the service and operating conditions.

8.1.4 Headers shall have a corrosion allowance. This allowance shall not be less than that used for the tubes.

8.2 Plug headers

8.2.1 Plug headers shall be located in a header box and shall be selected for the same design pressure as the connecting tubes and for a design temperature equal to the maximum fluid operating temperature at that location, plus a minimum of 30 °C (55 °F).

8.2.2 Tubes and plug headers shall be arranged so that there is sufficient space for field maintenance operations such as welding and stress relieving.

8.2.3 If plug headers are specified to permit mechanical cleaning of coked or fouled tubes, they shall consist of the two-hole type. Single-hole, 180° plug headers may be installed only for tube inspection and draining.

8.2.4 If plug headers are specified to be used with horizontal tubes that are 18,3 m (60 ft) or longer, two-hole plug headers shall be used for both ends of the coil assembly. For shorter coils, plug headers shall be provided on one end of the coil with welded return bends on the opposite end.

8.2.5 If plug headers are specified for vertical tube heaters, two-hole plug headers shall be installed on the top of the coil and one-hole Y-fittings at the bottom of the tubes.

8.2.6 Headers and corresponding plugs shall be match-marked by 12 mm (0,5 in) permanent numerals and installed in accordance with a fitting location drawing.

8.2.7 Type 304 stainless steel thermowells, if required for temperature measurement and control, shall be provided in the plugs of the headers.

8.2.8 Tube centre-to-centre dimensions shall be as shown in Table 4.

Table 4 — Tube centre-to-centre dimensions

Tube outside diameter mm (in)	**Header centre-to-centre dimension** mm	(in)
60,3 (2,375)	101,6	4,00 [a, b]
73,0 (2,875)	127,0	5,00 [a, b]
88,9 (3,50)	152,4	6,00 [a]
101,6 (4,00)	177,8	7,00 [a]
114,3 (4,50)	203,2	8,00 [a]
127,0 (5,00)	228,6	9,00
141,3 (5,563)	254,0	10,00 [a]
152,4 (6,00)	279,4	11,00
168,3 (6,625)	304,8	12,00 [a]
193,7 (7,625)	355,6	14,00
219,1 (8,625)	406,4	16,00 [a]
273,1 (10,75)	508,0	20,00 [a]

NOTE Centre-to-centre dimensions are applicable only to manufacturer's standard header pressure ratings for 5 850 kPa (850 psig) nominal fittings.

[a] This centre-to-centre dimension equals two times the corresponding nominal size and is based on the centre-to-centre dimension for short-radius welded return bends.

[b] This centre-to-centre dimension is applicable only to welded plug headers.

8.2.9 Plugs and screws shall be assembled in the fittings with an approved compound on the seats and screws to prevent galling.

8.3 Return bends

8.3.1 Return bends should be used for the following conditions:

a) in clean service, where coking or fouling of tubes is not anticipated;

b) where leakage is a hazard;

c) where steam-air decoking facilities are provided for decoking of furnace tubes.

8.3.2 Return bends inside the firebox shall be selected for the same design pressure and temperature as the connecting tubes. Return bends inside a header box shall be selected for the same design pressure as the connecting tubes and for a design temperature equal to the maximum fluid operating temperature at that location plus a minimum of 30 °C (55 °F). Return bends shall be at least the same thickness as the connecting tubes.

8.3.3 Regardless of the location of the welded return bends, the heater design shall incorporate means to permit convenient removal and replacement of tubes and return bends.

8.3.4 Longitudinally welded fittings shall not be used.

8.4 Materials

8.4.1 Plug header and return bend material shall conform to the ASTM specifications listed in Table 5 or to other specifications if agreed by the purchaser.

8.4.2 Cast fittings shall have the material identification permanently marked on the fitting with raised letters or by using low-stress stamps.

Table 5 — Plug header and return bend materials (ASTM specifications)

Material	Forged	Wrought	Cast
Carbon steel	A 105	A 234, WPB	A 216, WCB
	A 181, class 60 or 70		
C-1/2Mo	A 182, F1	A 234, WP1	A 217, WC1
1 1/4Cr-1/2Mo	A 182, F11	A 234, WP11	A 217, WC6
2 1/4Cr-1Mo	A 182, F22	A 234, WP22	A 217, WC9
3Cr-1Mo	A 182, F21	—	—
5Cr-1/2Mo	A 182, F5	A 234, WP5	A 217, C5
9Cr-1Mo	A 182, F9	A 234, WP9	A 217, C12
18Cr-8Ni-Type 304	A 182, F304	A 403, WP304	A 351, CF8
18Cr-8Ni-Type 304H	A 182, F304H	A 403, WP304H	A 351, CF8
18Cr-10Ni-Ti- Type 321	A 182, F321	A 403, WP321	A 351, CF8C
18Cr-10Ni-Ti-Type 321H	A 182, F321H	A 403, WP321H	
18Cr-10Ni-Nb Type 347	A 182, F347	A 403, WP347	A 351, CF8C
18Cr-10Ni-Nb Type 347H	A 182, F347H	A 403, WP347H	
16Cr-12Ni-2Mo Type 316	A 182, F316	A 403, WP316	A 351, CF8M
16Cr-12Ni-2Mo Type 316H	A 182, F316H	A 403, WP316H	
Nickel alloy[a]	B 564	B 366	A 351, CT-15C
25Cr-20Ni	A 182, F-310	A 403, F-310	A 351, CK-20 A 351, HK40

[a] Minimum grain size shall be ASTM #5 or coarser.

9 Piping, terminals and manifolds

9.1 General

9.1.1 The minimum corrosion allowance shall be in accordance with 7.1.2.

9.1.2 All flanges shall be welding-neck flanges.

9.1.3 Piping, terminals and manifolds external to the heater enclosure shall be in accordance with ASME B31.3.

● **9.1.4** The purchaser shall specify if inspection openings are required; in which case, if agreed by the purchaser, terminal flanges may be used provided that pipe sections are readily removable for inspection access.

9.1.5 Threaded connections shall not be used.

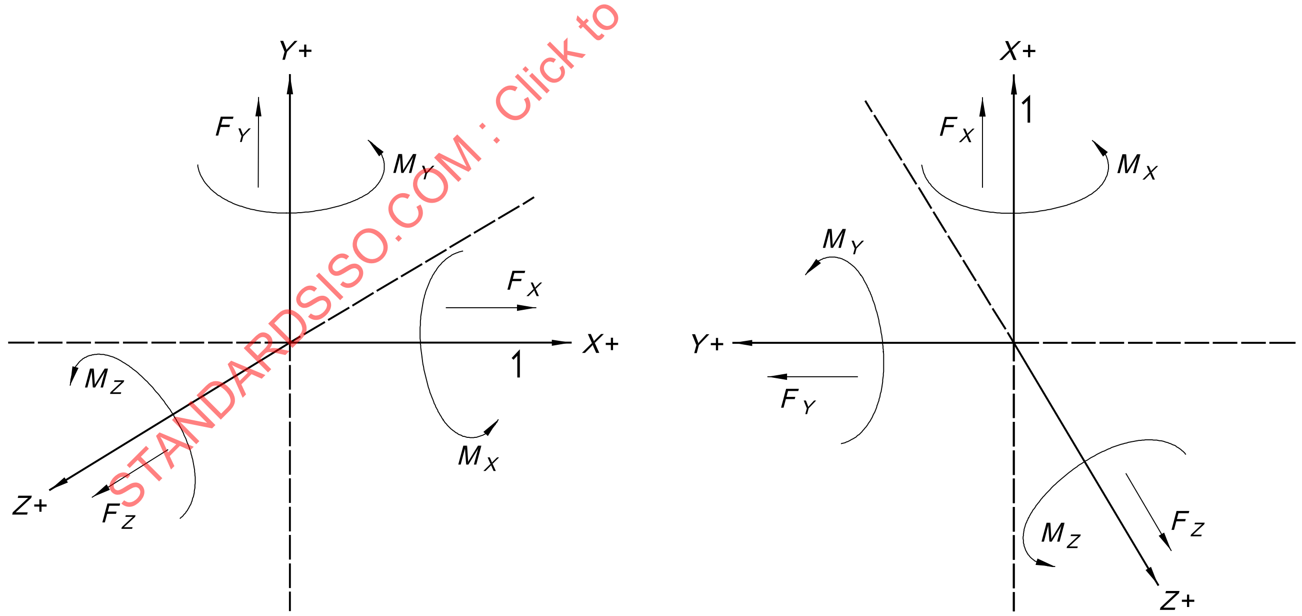
● **9.1.6** The purchaser shall specify if low-point drains and high-point vents are required; in which case they shall be accessible from outside the heater casing.

9.1.7 Manifolds and external piping shall be located so as not to block access for the removal of single tubes or hairpins.

9.1.8 Manifolds inside a header box shall be selected for the same design pressure as the connecting tubes and for a design temperature equal to the maximum fluid operating temperature at that location plus a minimum of 30 °C (55 °F).

9.2 Allowable movement and loads

Heater terminals shall be designed to accept the moments (M) and forces (F) shown in Figure 7 and Table 6, or the movements listed in Table 7.



a) Horizontal tubes b) Vertical tubes

Key

1 Tube centreline

Figure 7 — Diagram of forces

Table 6 — Allowable forces and moments

Pipe size	F_x		F_y		F_z		M_x		M_y		M_z	
DN (NPS)	N	(lb)	N	(lb)	N	(lb)	N·m	(ft·lb)	N·m	(ft·lb)	N·m	(ft·lb)
50 (2)	445	(100)	890	(200)	890	(200)	475	(350)	339	(250)	339	(250)
75 (3)	667	(150)	1 334	(300)	1 334	(300)	610	(450)	475	(350)	475	(350)
100 (4)	890	(200)	1 779	(400)	1 779	(400)	813	(600)	610	(450)	610	(450)
125 (5)	1 001	(225)	2 002	(450)	2 002	(450)	895	(660)	678	(500)	678	(500)
150 (6)	1 112	(250)	2 224	(500)	2 224	(500)	990	(730)	746	(550)	746	(550)
200 (8)	1 334	(300)	2 669	(600)	2 669	(600)	1 166	(860)	881	(650)	881	(650)
250 (10)	1 557	(350)	2 891	(650)	2 891	(650)	1 261	(930)	949	(700)	949	(700)
300 (12)	1 779	(400)	3 114	(700)	3 114	(700)	1 356	(1 000)	1 017	(750)	1017	(750)

Table 7 — Allowable movements

Dimensions in millimetres (inches)

	Horizontal tubes						Vertical tubes					
	Δx		Δy		Δz		Δx		Δy		Δz	
Radiant terminals	0	(0)	25	(1)	25	(1)	0	(0)	25	(1)	25	(1)
Convection terminals	0	(0)	13	(0,5)	13	(0,5)	—	—	—	—	—	—
NOTE The above movements are allowable in both directions (±)												

9.3 Materials

External crossover piping shall be of the same metallurgy as the preceding heater tube; internal crossover piping shall be of the same metallurgy as the radiant tubes.

10 Tube supports

10.1 General

10.1.1 The design temperature for tube supports and guides exposed to flue gas shall be based on design operation of the furnace as follows:

a) for the radiant and shock sections and outside the refractory, the flue-gas temperature to which the supports are exposed plus 100 °C (180 °F). The minimum design temperature shall be 870 °C (1 600 °F);

b) for the convection section, the temperature of the flue gas in contact with the support plus 55 °C (100 °F);

c) the maximum flue-gas temperature gradient across a single convection intermediate tube support shall be 250 °C (450 °F);

d) where the radiant tube support castings are shielded behind a row of tubes, the bridgewall temperature may be used.

No credit shall be taken for the shielding effect of refractory coatings on intermediate supports or guides.

10.1.2 Guides, horizontal radiant-section intermediate tube supports and top supports for vertical radiant tubes shall be designed to permit their replacement without tube removal and with minimum refractory repair.

10.1.3 The unsupported length of horizontal tubes shall not exceed 35 times the outside diameter or 6 m (20 ft), whichever is less.

10.1.4 The minimum corrosion allowance of each side for all exposed surfaces of each tube support and guide contacting flue gases shall be 1,3 mm (0,05 in) for austenitic materials and 2,5 mm (0,10 in) for ferritic materials.

10.1.5 The following shall apply to end tube sheets for tubes with external headers.

— Tube sheets shall be structural plate. If the tube sheet design temperature exceeds 425 °C (800 °F), alloy materials shall be used.

— Minimum thickness of tube sheets shall be 12 mm (0,5 in).

— Tube sheets shall be insulated on the flue-gas side with a castable having a minimum thickness of 75 mm (3 in) for the convection section and 125 mm (5 in) for the radiant section. (Anchors shall be made from austenitic stainless steel or nickel alloy as listed in Table 9.)

— Sleeves with an inside diameter at least 12 mm (0,5 in) greater than the tube or the extended surface outside diameter shall be welded to the tube sheet at each tube hole, to prevent the refractory from being damaged by the tubes. The sleeve material shall be austenitic stainless steel.

10.1.6 The following shall apply to the supporting of extended surface tubes.

— Intermediate supports shall be designed to prevent mechanical damage to the extended surface and shall permit easy removal and insertion of the tubes without binding.

— For studded tubes, a minimum of three rows of studs shall rest on each support.

— For finned tubes, at least five fins shall rest on each support.

10.2 Loads and allowable stress

10.2.1 Tube-support loads shall be determined as follows.

— Loads shall be determined in accordance with acceptable procedures for supporting continuous beams on multiple supports (e.g. AISC). Friction loads shall be based on a friction coefficient of not less than 0,30.

— Friction loads shall be based on all tubes expanding and contracting in the same direction. Loads shall not be considered to be cancelled or reduced due to movement of tubes in opposite directions.

10.2.2 Tube-support maximum allowable stresses at design temperature shall not exceed the following:

a) dead-load stress:

1) one-third of the ultimate tensile strength;

2) two-thirds of the yield strength (0,2 % offset);

3) 50 % of the average stress required to produce 1 % creep in 10 000 h.;

4) 50 % of the average stress required to produce rupture in 10 000 h.

b) dead-load plus frictional stress:

1) one-third of the ultimate tensile strength;

2) two-thirds of the yield strength (0,2 % offset);

3) the average stress required to produce 1 % creep in 10 000 h;

4) the average stress required to produce rupture in 10 000 h.

10.2.3 For castings, the allowable stress value shall be multiplied by 0,8.

10.2.4 Stress data shall be as presented in annex D.

10.3 Materials

10.3.1 Tube support materials shall be selected for maximum design temperatures as shown in Table 8. Other materials and alternative specifications shall be subject to the approval of the purchaser.

● **10.3.2** If the tube support design temperature exceeds 650 °C (1 200 °F) and the fuel contains more than 100 mg/kg total vanadium and sodium, the supports shall exhibit one of the following design details, as specified or agreed by the purchaser:

a) constructed of stabilized, 50Cr-50Ni metallurgy, without any coating;

b) for radiant or accessible supports only, covered with 50 mm (2 in) of castable refractory having a minimum density of 2 080 kg/m^3 (130 lb/ft^3).

Table 8 — Maximum design temperatures for tube support materials

Material	Casting	Plate	Maximum design temperature	
	ASTM specification	ASTM specification	°C	(°F)
Carbon steel	A 216 Gr WCB	A 283 Gr C	425	(800)
2 1/4Cr-1Mo	A 217 Gr WC 9	A 387 Gr 22, Class 1	650	(1 200)
5Cr-1/2Mo	A 217 Gr C5	A 387 Gr 5, Class 1	650	(1 200)
19Cr-9Ni	A 297 Gr HF	A 240, Type 304H	815	(1 500)
25Cr-12Ni		A 240, Type 309H	870	(1 600)
25Cr-12Ni	A 447 Type II		980	(1 800)
25Cr-20Ni		A 240, Type 310H	870	(1 600)
25Cr-20Ni	A 351 Gr HK40		1 090	(2 000)
50Cr-50Ni-Nb	A 560 Gr 50Cr-50Ni		980	(1 800)
For exposed radiant and shield-section tube supports, the material shall be 25Cr-12Ni or higher alloy				

11 Refractories and insulation

11.1 General

11.1.1 The temperature of the outside casing of the radiant and convection sections and hot ductwork shall not exceed 80 °C (175 °F) at an ambient temperature of 27 °C (80 °F) in still air. Radiant floors shall not exceed 90 °C (195 °F).

11.1.2 Walls, arches and floors shall be designed to allow for proper expansion of all parts. Where multilayer or multicomponent linings are used, joints shall not be continuous through the lining.

11.1.3 Any layer of refractory shall be suitable for a service temperature at least 165 °C (300 °F) above its calculated hot-face temperature. Minimum service temperature for refractories shall be 980 °C (1 800 °F) in the radiant and shield sections.

11.1.4 The floor hot surface shall be a 63 mm (2,5 in) thick layer of high-duty fireclay brick or a 75 mm (3 in) thick layer of castable of 1 370 °C (2 500 °F) service temperature and minimum cold crush strength of 3 450 kN/m^2 (500 psi) after drying at 110 °C (230 °F).

11.1.5 Burner blocks shall be suitable for an operating temperature of at least 1 650 °C (3 000 °F).

11.1.6 Target walls with flame impingement on both sides shall be constructed of high-duty firebrick of at least 1 540 °C (2 800 °F) rating. Bricks shall be laid dry or with mortared joints. Expansion joints shall be packed with ceramic fibre strips having a service temperature rating not less than 1 540 °C (2 800 °F).

11.1.7 Target walls with flame impingement on one side shall be of brick or of plastic refractory of equivalent maximum service temperature. Either may be backed by a castable or ceramic fibre board.

11.1.8 Access doors shall be protected from direct radiation by a refractory system of at least the same thermal rating and resistance as the adjacent wall lining.

11.1.9 Refractory anchors are not mandatory for floor castable unless required for shipping considerations.

11.1.10 Maximum temperatures for anchor tips are listed in Table 9.

Table 9 — Maximum temperatures for anchor tips

Anchor material	Maximum anchor temperature	
	°C	(°F)
Carbon steel	455	850
TP 304 stainless steel	760	1 400
TP 316 stainless steel	760	1 400
TP 309 stainless steel	815	1 500
TP 310 stainless steel	927	1 800
TP 330 stainless steel	1 038	1 900
Alloy 601 (UNS N06601)	1 093	2 000
Ceramic studs and washers	> 1 093	> 2 000

11.2 Brick and tile construction

11.2.1 Brick construction may be used for gravity walls, floors, or as hot-face layers.

11.2.2 Radiant chamber walls of gravity construction shall not exceed 7,3 m (24 ft) in height and shall be at least high-duty fireclay brick. The base width shall be a minimum of 8 % of wall height. The height-to-width ratio of each wall section shall not exceed 5 to 1. The walls shall be self-supporting and the base shall rest on the steel wall, not on another refractory.

11.2.3 Gravity walls shall be of mortared construction. The mortar shall be non-slagging, air-setting, chemically compatible with adjacent refractory, including at the rated temperature of the brick.

11.2.4 Vertical expansion joints shall be provided at gravity wall ends and required intermediate locations. All expansion joints shall be kept open and free to move. If the joint is formed with lapped brick, no mortar shall be used, that is, it shall be a dry joint.

11.2.5 Floor brick shall not be mortared. A 13 mm (0,5 in) gap for expansion shall be provided at 1,8 m (6 ft) intervals. This gap may be packed with fibrous refractory material in strip, not loose bulk, form.

11.2.6 Minimum service temperature for a hot-face brick layer shall be 1 430 °C (2 600 °F) on walls with expected flame impingement and 1 260 °C (2 300 °F) for other exposed-wall applications. Minimum service temperature for shielded walls shall be 1 095 °C (2 000 °F).

11.2.7 All brick linings on vertical flat casing shall be tied back to and supported by the structural steel framing members. All tie members shall be austenitic alloy material, except that pipe supports located in the backup layer may be carbon steel. At least 15 % of the bricks shall be tied back. Brick lining on cylindrical casing need not be tied back if the radius of curvature of the casing keys the bricks.

11.2.8 Brick linings shall be supported by metal support shelves (lintels) attached to the casing on vertical centres not to exceed 1,8 m (6 ft). Support shelves shall be slotted to provide for differential thermal expansion. Shelf material is defined by the calculated service temperature; carbon steel is satisfactory up to 370 °C (700 °F).

11.2.9 Expansion joints shall be provided in both vertical and horizontal directions of the walls, at wall edges and about burner tiles, doors and sleeved penetrations.

11.3 Castable construction

11.3.1 Hydraulic-setting castables are suitable as lining for all parts of fired heaters. If a castable construction of 1:2:4 volumetric mix of Lumnite-haydite-vermiculite is used, the maximum service temperature shall not exceed 1 040 °C (1 900 °F). If used as a hot face, it shall only be used in clean fuel applications. This castable shall be limited to 200 mm (8 in) maximum thickness on arches and walls.

11.3.2 For dual layer castable construction, the hot face layer shall be a minimum of 75 mm (3 in) thick. The anchoring systems shall provide independent support for each layer.

11.3.3 Anchoring penetration shall be not less than 70 % of the individual layer being anchored for castable thickness greater than 50 mm (2 in). The anchor shall not be closer than 12 mm (0,5 in) to the hot face.

11.3.4 The anchoring spacing shall be a maximum of three times the total lining thickness, but shall not exceed 300 mm (12 in) on a square pattern for walls and 225 mm (9 in) on a square pattern for arches. The anchor orientation shall be varied to avoid creating continuous shear planes.

11.3.5 Anchors for total castable thickness up to 150 mm (6 in) shall be at least 5 mm (3/16 in) in diameter. For greater castable thickness, the anchors shall be at least 6,3 mm (1/4 in) in diameter.

11.3.6 Castable linings in header boxes, breechings and lined flue-gas ducts and stacks shall not be less than 50 mm (2 in) thick.

• **11.3.7** In castable linings up to 50 mm (2 in) thick, the purchaser shall specify or agree whether bare carbon steel fencing or wire mesh shall be used for anchoring the lining.

11.3.8 Expansion joints shall be provided around burner blocks, brick and prefired shapes.

11.3.9 Metallic fibre may be added for reinforcement only in castables of density 970 kg/m^3 (55 lb/ft^3) or higher. Metallic fibres shall be limited to no more than 3 % mass fraction of the dry mixture.

11.3.10 Castables of low iron content (less than 1 % iron) or heavy-weight castable shall be used on exposed hot-face walls if the total heavy metals content, including sodium, within the fuel exceeds 250 mg/kg (250 ppm). Heavy-weight castables shall have a minimum density of 1 800 kg/m^3 (110 lb/ft^3) with an Al_2O_3 content of not less than 40 %. In aggregate, the Al_2O_3 content shall be not less than 40 % and the SiO_2 content shall not exceed 35 %.

11.4 Ceramic fibre construction

11.4.1 Ceramic fibre in layered or modular construction may be used in all heater areas except stacks, ducts and floors.

11.4.2 The hot face of layered ceramic-fibre blanket installations shall be a minimum of 25 mm (1 in) thick, 128 kg/m^3 (8 lb/ft^3) density, needled material. Ceramic fibre board, if applied as a hot-face layer, shall not be less than 38 mm (1,5 in) thick nor less than 240 kg/m^3 (14 lb/ft^3) density. Backup layer(s) of ceramic fibre blanket shall be needled material with a minimum density of 96 kg/m^3 (6 lb/ft^3). Ceramic fibre board size, if used as hot-face layer, shall be limited to maximum dimensions of 600 mm × 600 mm (24 in × 24 in) if temperatures of the flue gases are below 1 100 °C (2 000 °F) and 450 mm × 450 mm (18 in × 18 in) if temperatures of the flue gases exceed 1 100 °C (2 000 °F).

11.4.3 Any layer of ceramic fibre shall be suitable for a service temperature at least 280 °C (500 °F) above its calculated hot-face temperature.

11.4.4 The hot-face layer of a ceramic fibre blanket system shall be anchored at a maximum distance of 75 mm (3 in) from all edges.

11.4.5 The anchor spacing for arches shall not exceed the following rectangular pattern: 150 mm × 225 mm (6 in × 9 in) for 300 mm (12 in) wide blankets; 225 mm × 225 mm (9 in × 9 in) for 600 mm (24 in) wide blankets; 225 mm × 250 mm (9 in × 10 in) for 900 mm (36 in) wide blankets; and 225 mm × 270 mm (9 in × 10,5 in) for 1 200 mm (48 in) wide blankets.

11.4.6 The anchor spacing for walls shall not exceed the following rectangular pattern: 150 mm × 300 mm (6 in × 12 in) for 300 mm (12 in) wide blankets; 225 mm × 300 mm (9 in × 12 in) for 300 mm (24 in) wide blankets; and 270 mm × 300 mm (10,5 in × 12 in) for 1 200 mm (48 in) wide blankets.

11.4.7 Metallic anchor parts that are not shielded by tubes shall be completely wrapped with ceramic fibre patches or be protected by ceramic retainer cups filled with mouldable ceramic fibre.

11.4.8 Ceramic fibre blanket shall not be used as the hot-face layer if flue gas velocities are in excess of 12 m/s (40 ft/s). Wet blanket, ceramic fibre board, or ceramic fibre modules shall be used on hot-face layers with velocities greater than 12 m/s (40 ft/s) but less than 24 m/s (80 ft/s). Hot-face refractory with velocities greater than 24 m/s (80 ft/s) shall have castable or external lining.

11.4.9 Ceramic fibre blanket shall be installed with its longest dimension in the direction of gas flow. The hot-face layer of blanket shall be constructed with all joints overlapped. Overlaps shall be in the direction of gas flow. Hot-face layers of ceramic fibre board shall be constructed with tight butt joints.

11.4.10 Ceramic fibre blanket used in backup layers shall be installed with butt joints with at least 25 mm (1 in) compression on the joints. All joints in successive layers of blanket shall be staggered.

11.4.11 Ceramic fibre blanket modules shall be installed in soldier course (with batten strips) patterns. Parquet pattern may be used only on arches.

11.4.12 Module systems shall be installed so that joints at each edge are compressed to avoid gaps due to shrinkage.

11.4.13 Modules applied in arches shall be designed so that anchorage is provided over at least 80 % of the module width.

11.4.14 Anchors shall be attached to the casing before modules are installed.

11.4.15 Anchor assembly shall be located in the module at a maximum distance of 50 mm (2 in) from the module cold face.

11.4.16 Module internal hardware shall be austenitic stainless steel or nickel alloy (see Table 9).

● **11.4.17** If ceramic fibre construction is used with fuels having a sulfur content exceeding 10 mg/kg, the casing shall have an internal protective coating, specified or agreed by the purchaser, to prevent corrosion. The protective coating shall be rated for 150 °C (300 °F) service temperature.

11.4.18 A vapour barrier of austenitic stainless steel foil shall be provided if the fuel sulfur content exceeds 500 mg/kg. The vapour barrier shall be located so that the exposure temperature is at least 55 °C (100 °F) above the calculated acid dew point for all operating cases. Vapour-barrier edges shall be overlapped at least 175 mm (7 in); edges and punctures shall be sealed.

11.4.19 Ceramic fibre systems shall not be applied for services where the total heavy metals content in the fuel exceeds 100 mg/kg.

11.4.20 Ceramic fibre shall not be used in convection sections where sootblowers, steam lances or waterwash facilities are initially provided.

11.4.21 Anchors shall be installed before applying protective coating to the casing. The coating shall cover the anchors so that uncoated parts are above the acid dew-point temperature.

11.5 Multicomponent lining construction

11.5.1 Hot-face castable layers shall have a minimum thickness of 75 mm (3 in).

11.5.2 The anchoring system shall provide retention and support for each component layer.

11.5.3 Anchor types and installation for individual lining components shall meet the applicable requirements of 11.2, 11.3, and 11.4.

11.5.4 The material used in any layer shall be suitable for service temperature in accordance with 11.1.3 and 11.4.3.

11.5.5 Brick may be used for hot-face service or as a backup layer if the hot-face layer is brick.

11.5.6 Block insulation shall be made of ceramic fibre or calcium silicate with a minimum service temperature rating of 900 °C (1 650 °F). Block insulation shall only be used as a backup material, but shall not be used if the fuel sulfur content exceeds 1 % mass fraction in liquid fuel or 100 mg/kg hydrogen sulfide in gas fuel. Block insulation used as backup material in floor constructions shall be approved by the purchaser.

● **11.5.7** If insulating block or ceramic fibre is used as backup insulation, the casing shall have a protective coating, specified or agreed by the purchaser, if the fuel sulfur content exceeds 10 mg/kg. The protective coating shall be rated for 150 °C (300 °F) service temperature.

11.5.8 If used as backup for castable, block insulation or ceramic fibre blanket shall be sealed to prevent water migration from the castable.

11.5.9 The minimum density of insulating block and ceramic fibre blanket used as backup materials shall be 130 kg/m^3 (8 lb/ft^3).

11.6 Materials

11.6.1 Materials shall conform to the following ASTM specifications or equivalent:

a) fireclay brick, ASTM C 27;

b) insulating firebrick, ASTM C 155;

c) castable refractory, ASTM C 401, Class N, O, P, Q, or R;

d) vermiculite sieve analysis, ASTM C 332, Group 1 density;

e) insulating block (mineral slag wool, neutral pH), ASTM C 612 CL5;

f) haydite, ASTM C 332 Group II:

1) Poured application: Fine aggregate No. 4.

2) Gunned application: combined fine and coarse 10 mm (3/8 in) to Fine Aggregate No. 0.

11.6.2 The following materials shall have a composition as follows:

a) lumnite or calcium aluminate cement: the mass fraction of Al_2O_3 shall be at least 35 %;

b) ceramic fibre: the mass fraction of Al_2O_3 shall be at least 45 % and the remainder shall be primarily SiO_2 or ZrO_2.

12 Structures and appurtenances

12.1 General

● **12.1.1** The purchaser shall specify or agree the structural design code. Structures shall comply with the structural design code.

12.1.2 Minimum design loads for wind and earthquake shall conform to the structural design code.

12.1.3 Platform live loads shall be in accordance with the structural design code.

12.1.4 Structures and appurtenances shall be designed for all applicable load conditions expected during shipment, erection and operation. Cold weather conditions shall be considered, particularly when the furnace is not in operation. These load conditions shall include, but are not limited to, dead load, wind load, earthquake load, live load and thermal load.

12.1.5 Design metal temperature of structures and appurtenances shall be the calculated metal temperature plus 55 °C (100 °F), based on the maximum flue gas temperature expected for all operating modes with an ambient temperature of 27 °C (80 °F) in still air.

12.1.6 The effect of elevated design temperature on yield strength and modulus of elasticity shall be taken into account (see Table 10).

12.1.7 The material of the structures and appurtenances shall be adequate for all load conditions at the lowest specified ambient temperature when the furnace is not in operation.

12.2 Structures

12.2.1 All loads from the tubes and headers shall be supported by the structural steel and shall not be transmitted into the refractory.

12.2.2 Structural steel shall be designed to permit lateral and vertical expansion of all heater parts.

12.2.3 Heater casing shall be plate of a minimum thickness of 5 mm (3/16 in), which shall be reinforced against warping. Casing, if calculated to resist buckling stresses, shall have a minimum thickness of 6 mm (1/4 in). Floor and radiant roof plates shall have a minimum thickness of 6 mm (1/4 in).

12.2.4 Heater casing plate shall be seal-welded externally to prevent air and water infiltration.

● **12.2.5** The heater structure shall be capable of supporting ladders, stairs and platforms in locations where installed or where specified by the purchaser for future use.

12.2.6 Flat roof design shall allow for runoff of rainwater. This can be accomplished by arrangement of structural members and drain openings, by sloping the roof or with a secondary roof for weather protection. If pitched roofs are provided for weather protection, eaves and gables shall prevent the entry of windblown rain.

● **12.2.7** If fireproofing is specified by the purchaser, the main structural columns of the heater from the baseplate to the floor level plus the main floor beams shall be designed for the addition of 50 mm (2 in) of fireproofing.

12.2.8 Heaters with horizontal tubes that have return bends inside the firebox shall have removable end panels or panels in the sidewalls, to provide access to the return-bend welds.

12.2.9 Duct structural systems shall support ductwork independent of expansion joints during operation, when idle or with duct sections removed.

12.3 Header boxes, doors and ports

12.3.1 Header boxes

12.3.1.1 Each header box shall allow for the total tube expansion. A minimum clearance of 75 mm (3 in) shall be provided between the header box door refractory and the header in the hot position.

● **12.3.1.2** Header boxes enclosing plug headers shall have hinged doors or bolted end panels as specified by the purchaser.

12.3.1.3 Header boxes, including doors, shall be of 5 mm (3/16 in) minimum steel plate reinforced against warping. Header boxes shall be removable.

● **12.3.1.4** If specified by the purchaser, to minimize flue gas bypassing, horizontal partitions shall be provided in convection-section header boxes at a spacing no greater than 1,5 m (5 ft).

12.3.2 Doors and ports

12.3.2.1 Two access doors having a minimum clear opening of 600 mm × 600 mm (24 in × 24 in) shall be provided for each radiant chamber of a box or cabin heater.

12.3.2.2 One access door having a minimum clear opening of 450 mm × 450 mm (18 in × 18 in) shall be provided in the floor for vertical cylindrical heaters. A bolted and gasketed access door shall also be provided in any air plenum below the floor accessway. Where space is not available, access via a burner port is acceptable.

12.3.2.3 One access door having a minimum clear opening of 600 mm × 600 mm (24 in × 24 in), or 600 mm (24 in) in diameter, shall be provided in the stack or breeching for access to the damper and convection sections.

12.3.2.4 One tube-removal door having a minimum clear opening of 450 mm × 600 mm (18 in × 24 in) shall be provided in the arch of each radiant chamber of vertical tube heaters.

12.3.2.5 Observation doors and ports shall be provided for viewing all radiant tubes and all burner flames for proper operation and light-off.

12.3.2.6 Access doors shall be provided to ducts, plenums and at all duct connections to air preheaters and control dampers.

12.4 Ladders, platforms and stairways

12.4.1 Platforms shall be provided as follows:

a) at burner and burner controls that are not accessible from grade;

b) at both ends of the convection section for maintenance purposes;

c) at damper and sootblower locations for maintenance and operation purposes;

d) at all observation ports and firebox access doors not accessible from grade;

e) at auxiliary equipment, such as steam drums, fans, drivers, and air preheaters as required for operating and maintenance purposes;

f) at all areas necessary to meet the requirements of 15.5.

12.4.2 Vertical cylindrical heaters with shell diameters greater than 3 m (10 ft) shall have a full circular platform at the floor level. Individual ladders and platforms to each observation door may be used if shell diameters are 3 m (10 feet) or less.

12.4.3 Platforms shall have a minimum clear width as follows:

a) operating platforms, 900 mm (3 ft);

b) maintenance platforms, 900 mm (3 ft);

c) walkways, 750 mm (2,5 ft).

● **12.4.4** Platform decking shall have a minimum thickness of 6 mm (1/4 in) checkered plate or 25 mm × 5 mm (1 in × 3/16 in) open grating, as specified by the purchaser. Stair treads shall be open grating with checkered plate nosing.

12.4.5 Dual access shall be provided to each operating platform, except if the individual platform length is less than 6 m (20 ft).

12.4.6 An intermediate landing shall be provided if the vertical rise exceeds 9 m (30 ft) for ladders and 4,5 m (15 ft) for stairways.

12.4.7 Ladders shall be caged from a point 2,3 m (7,5 ft) above grade. A safety gate shall be provided for all ladders serving platforms or landings.

12.4.8 Stairs shall have a minimum width of 750 mm (2,5 ft), a minimum tread width of 240 mm (9,5 in), and a maximum riser of 200 mm (8 in). The slope of the stairway shall not exceed a 9 (vertical) to 12 (horizontal) ratio.

12.4.9 Headroom over platforms, walkways and stairways shall be a minimum of 2,1 m (7 ft).

12.4.10 Handrails shall be provided on all platforms, walkways and stairways.

12.4.11 Handrails, ladders and platforms shall be arranged so as not to interfere with tube handling. Where interference exists, removable sections shall be provided.

12.5 Materials

● **12.5.1** Materials for service at design ambient temperatures below – 30 °C (– 20 °F) shall be as specified by the purchaser. For ambient temperatures below – 20 °C (– 5 °F), special low temperature steels shall be considered.

12.5.2 The mechanical properties and the chemical composition of structural, alloy or stainless steels shall comply with ISO Standard requirements or their equivalent.

12.5.3 For metal temperatures lower than 425 °C (800 °F), stacks, ducts and breeching shall be constructed from one of the following structural grades of steel: EN 10025 (grades Fe360, Fe430, Fe510), ASTM (A 36, A 242, A 572), or their equivalent.

12.5.4 If metal temperatures exceed 425 °C (800 °F), stainless or alloy steels shall be used.

12.5.5 The mechanical properties of the steels at temperatures between 0 °C (32 °F) and 425 °C (800 °F) shall be determined according to the values given in Table 10.

12.5.6 If the minimum service temperature is –18 °C (0 °F) or higher, bolting material shall be in accordance with ASTM A 307, A 325, A 193-B7 or equivalent. Below –18 °C (0 °F), A 193-B7 bolts with A 194-2H nuts, A 320-L7 bolting or equivalent shall be used. No welding is permitted on A 320-L7 or A 193-B7 materials.

Table 10 — Minimum yield strength F_y and modulus of elasticity E for structural steel

	EN 10025 Fe 360		EN 10025 Fe 430		EN 10025 Fe 510		ASTM A 36		ASTM A 242		ASTM A 572	
T °C (°F)	F_y MN/m² (psi × 10³)	E GN/m² (psi × 10⁶)	F_y MN/m² (psi × 10³)	E GN/m² (psi × 10⁶)	F_y MN/m² (psi × 10³)	E GN/m² (psi × 10⁶)	F_y MN/m² (psi × 10³)	E GN/m² (psi × 10⁶)	F_y MN/m² (psi × 10³)	E GN/m² (psi × 10⁶)	F_y MN/m² (psi × 10³)	E GN/m² (psi × 10⁶)
20 (70)	235 (34,1)	210 (30,5)	275 (39,9)	210 (30,5)	355 (51,5)	210 (30,5)	248 (36,0)	200 (29,0)	290 (42,1)	192 (27,8)	344 (50,0)	207 (30,0)
200 (390)	207 (30,0)	202 (29,3)	242 (35,1)	202 (29,3)	312 (45,3)	202 (29,3)	200 (29,0)	193 (28,0)	261 (37,9)	186 (27,0)	296 (42,9)	200 (29,0)
250 (480)	196 (28,4)	198 (28,7)	229 (33,2)	198 (28,7)	295 (42,8)	198 (28,7)	192 (27,8)	189 (27,4)	254 (36,8)	182 (26,4)	283 (41,1)	196 (28,4)
300 (570)	183 (26,5)	192 (27,8)	214 (31,0)	192 (27,8)	276 (40,0)	192 (27,8)	183 (26,5)	185 (26,8)	246 (35,7)	177 (25,7)	271 (39,4)	191 (27,7)
350 (660)	169 (24,5)	185 (26,8)	197 (28,6)	185 (26,8)	255 (37,0)	185 (26,8)	175 (25,4)	180 (26,1)	238 (34,5)	171 (24,8)	264 (38,3)	186 (27,0)
425 (800)	161 (23,4)	173 (25,1)	178 (25,8)	173 (25,1)	230 (33,4)	173 (25,1)	161 (23,4)	176 (25,5)	229 (33,2)	161 (23,4)	248 (36,0)	173 (25,1)

13 Stacks, ducts and breeching

13.1 General

13.1.1 This clause applies to the structural design of ducts, breeching and self-supporting vertical steel stacks of circular or conical section.

● **13.1.2** The design of stacks, ducts and breechings shall be in accordance with the applicable provisions of the codes and standards specified by the purchaser and, as a minimum requirement, shall comply with this clause 13. If no specific design code is specified, one of the methods given in annex H should be adopted.

13.2 Design considerations

13.2.1 Stacks shall be self-supporting and shall be bolted to their supporting structure.

● **13.2.2** Stack intermediate construction shall be performed with full-penetration welding or, if agreed by the purchaser, shall be bolted.

13.2.3 Breeching and ducting shall be of welded or bolted construction.

13.2.4 External attachments to stacks shall be seal-welded.

13.2.5 Stacks, ducts and breeching mounted on concrete shall be designed to prevent concrete temperatures in excess of 150 °C (300 °F).

13.2.6 Connections between stacks and flue-gas ducts shall not be welded.

13.2.7 A corrosion-resistant metal cap should be provided at the top of the stack lining refractory to protect its horizontal surface from the weather.

13.2.8 Linings may be required in steel stacks for one or more of the following purposes:

a) fire protection;

b) to protect structural shell from gases of excessively high temperature;

c) corrosion protection;

d) to maintain the flue-gas temperature at least 20 °C (35 °F) above the acid dew point;

e) to reduce potential for aerodynamic instability.

13.2.9 The suitability of specialist linings other than refractory should be discussed with the manufacturers but consideration should be given to their strength, flexibility, thermal properties and resistance to chemical attack.

13.2.10 Castable linings shall be secured to stacks, ducts and breeching by suitable anchorage (see 11.3.7).

13.2.11 All openings and connections on the stack, duct or breeching shall be sealed to prevent air or flue-gas leakage.

13.2.12 Breeching shall have a minimum clear distance beyond the last (present or future) convection row of 0,8 m (2,5 feet) for access and flue-gas distribution. At least one take-off shall be provided every 12 m (40 ft) of convection-section tube length.

13.2.13 Stacks, ducts and breeching shall be designed for all applicable load conditions expected during shipment, erection and operation. Snow and ice shall be considered, particularly when the furnace is not in operation. These load conditions shall include, but not be limited to, dead load, wind load, earthquake load, live load and thermal load.

13.2.14 The combination of loads that could occur simultaneously to create the maximum load condition shall be the design load, but in no case shall individual loads create stresses that will exceed those allowed by 13.4. Wind and earthquake loads shall not be considered as acting simultaneously.

13.2.15 The minimum thickness of the stack shell plate shall be 6 mm (1/4 in), including corrosion allowance. The minimum corrosion allowance shall be 1,6 mm (1/16 in).

13.2.16 The minimum number of anchor bolts for any stack shall be eight.

13.2.17 Lifting lugs on stacks, if required, shall be designed for the lifting load as the stack is raised from a horizontal to a vertical position.

13.2.18 Design metal temperature of stacks, ducts and breeching shall be the calculated metal temperature plus 50 °C (90 °F), based on the maximum flue-gas temperature expected for all operating modes with an ambient temperature of 27 °C (80 °F) in still air.

13.2.19 The minimum thickness of breeching and duct plate shall be 5 mm (3/16 in).

13.2.20 Ducts and breeching shall be stiffened to prevent excessive warpage and deflection. Deflection of castable refractory lined ducts and breeching shall be limited to 1/360th of the span. Deflection of other ducts and breeching shall be limited to 1/240th of the span.

13.3 Design methods

Where no specific requirements are given by the purchaser, one of the methods given in H.2 or H.3 of annex H should be adopted

13.4 Static design

13.4.1 All stacks shall be designed as cantilever beam columns.

13.4.2 Linings shall not be considered as contributing to the strength of the stack, duct or breeching.

13.4.3 Discontinuities in the stack shell plate, such as conical-to-cylindrical junctions and non-circular transitions, shall be designed so that the combined membrane and bending stresses in the stack shell or stiffening rings do not exceed 90 % of the minimum yield strength of the respective materials at design temperature.

13.4.4 Openings cut into the stack shall be limited in size to a clear width no greater than two-thirds of the stack diameter. For two openings opposite each other, each chord shall not exceed the stack radius. Openings shall be reinforced to fully restore the required structural capacity of the uncut section.

13.4.5 Apertures in the stack shell plates, other than flue inlets, shall have the corners radiused to a minimum of 10 times the plate thickness.

13.4.6 Changes in cylindrical stack diameters shall be made with cones having an apex angle of 60° or less.

13.4.7 Ring stiffeners provided to carry wind pressure should be designed for the circumferential bending moments.

13.4.8 Circumferential bending moments due to wind pressure may be neglected in unstiffened cylindrical shells if the ratio $R/t \leqslant 160$, where R is the radius and t is the corroded thickness of the shell.

13.4.9 Stiffening rings are required if $t \leqslant (5M/9F_{ys})^{0,5}$ and shall be provided as follows:

a) ring spacing limits: $1 \leqslant H_s/D < 3$;

b) ring section modulus required: $Z \geqslant H_s M/(0,6\ F_{yr})$

where

M is the maximum circumferential moment per unit length of shell, in newton metres per metre (N·m/m) [inch-pounds per inch (in-lb/in)];

F_{ys} is the minimum yield strength of shell material at design temperature, in newtons per square millimetre (N/mm^2) [pounds per square inch (psi)];

t is the corroded shell thickness, in millimetres (inches);

H_s is the ring spacing, in millimetres (inches);

D is the shell diameter, in millimetres (inches);

Z is the section modulus of ring, in cubic millimetres (cubic inches);

F_{yr} is the minimum yield strength of ring stiffener at the shell design temperature, in newtons per square millimetre (N/mm^2) [pounds per square inch (psi)].

13.4.10 Stack deflection due to static wind loads shall not exceed 1 in 200 of stack height, based on the shell plate thickness less 50 % of the corrosion allowance and without considering the presence of a lining.

13.4.11 The permitted deviation (execution tolerance) from the vertical of the steel shell at any level above the base of the erected stack shall be determined from the following formula:

$$\delta = \frac{h}{1\,000\sqrt{1+50/h}} \quad \text{m}$$

or

$$\delta = \frac{h}{1\,000\sqrt{1+164/h}} \quad \text{(ft)}$$

where

h is the stack height, in metres (feet).

13.5 Wind-induced vibration design

13.5.1 A dynamic analysis shall be made to determine the stack's response to wind and earthquake action. If no specific requirements are given by the purchaser, the methods given in annex H should be adopted.

13.5.2 If the critical wind speed for the first mode of vibration of the stack is 1,25 times higher than the maximum (hourly mean) design wind speed (evaluated at the top of the stack), dynamic loads resulting from cross-wind response need not be included in the design load.

13.5.3 If analysis indicates that excessive vibrations due to cross-winds are possible, one of the following methods to reduce vortex-induced amplitudes shall be used.

a) Increase mass and structural damping characteristics (e.g. use of refractory lining).

b) Use a mass damper (e.g. tuned pendulum damper).

● c) Use aerodynamic devices (e.g. helical or vertical strakes as described in 13.5.4 and 13.5.5 or staggered vertical plates as described in 13.5.6), the choice of which shall be specified or agreed by the purchaser. Annex H gives recommendations regarding the application of spoilers or strakes.

d) Modify stack length and/or diameter until acceptable vibration characteristics are achieved.

13.5.4 When strakes are required to disrupt wind-induced vibration, they shall be used on at least the upper third of the stack height.

13.5.5 Helical strakes shall consist of three rectangular strakes of thickness 6 mm (1/4 in) at 120° spacing with a pitch of five diameters and a projection of 0,1 diameters.

13.5.6 Staggered vertical plates shall be not less than 6 mm (1/4 in) thick and not more than 1,5 m (5 ft) long. Three strakes shall be placed at 120° around the stack and shall project 0,10 diameters from the outside of the stack. Adjacent levels of strakes shall be staggered 30° from each other.

13.5.7 Where a stack is positioned within close proximity of other tall structures, consideration should be given to the possibility of buffeting effects.

13.5.8 Where a stack is positioned adjacent to another stack or tall cylindrical vessel, the minimum recommended spacing between centres is $4d$, where d is the largest diameter of the adjacent structures. Interference effects may be neglected for spacing between centres of greater than $15d$.

13.5.9 For a stack downwind of an adjacent stack or a tall vessel, interference effects shall be accounted for by an increase in wind load.

13.6 Materials

The material of the stack, breeching and duct shall be adequate for all load conditions at the lowest specified ambient temperature when the furnace is not in operation (see 12.5).

14 Burners and auxiliary equipment

14.1 Burners

14.1.1 Burner design, selection, spacing, location, installation and operation shall ensure against flame impingement on tubes, tube supports and flame exiting the radiant section of the heater throughout the entire operating range of the burners. The location and operation of burners shall ensure complete combustion within the radiant section of the heater.

14.1.2 Burners shall be designed in accordance with all local and national statutes and regulations.

14.1.3 For burner clearances, the data given in Table 11 shall be used for natural-draught burners and in Table 12 for forced-draught burners.

14.1.4 In addition to 14.1.3 above, the following shall apply.

a) The number and size of burners shall ensure that the visible flame length is a maximum of two-thirds of the radiant section height.

b) For horizontal opposed firing, the minimum visible clearance between directly opposed firing flame tips shall be 1,2 m (4 ft).

14.1.5 For burners outside the range given in Table 11 and Table 12, verifiable data shall be obtained before any design is finalized. For high heat releases, see 14.1.8 and 14.1.10.

14.1.6 For other types of burner (e.g. fan-shaped flame or radiant-wall flame), vendor or other verifiable data shall be obtained.

14.1.7 All burners shall be sized for a maximum heat release at the design excess air based on the following:

a) five or fewer burners, 120 % of normal heat release at design conditions;

b) six or seven burners, 115 % of normal heat release at design conditions;

c) eight or more burners, 110 % of normal heat release at design conditions.

● **14.1.8** For liquid-fuel-fired heaters with a maximum heat release greater than 4,4 MW (15×10^6 Btu/h), a minimum of three burners shall be used. Alternatively, if specified or agreed by the purchaser, a single burner with auxiliary guns may be used to permit gun maintenance without shutting down or upsetting the process.

14.1.9 Gas pilots shall be provided for each burner.

Table 11 — Minimum clearance guidelines for natural-draught operation

Burner type	Maximum heat release per burner		Minimum clearance							
			A		B		C		D	
			Vertical to centreline roof tubes or refractory (vertical firing only)		Horizontal from burner centreline to wall tubes centreline		Horizontal from burner centreline to unshielded refractory		Between opposing burners (horizontal firing)	
	MW	(Btu/h × 10^6)	m	(ft)	m	(ft)	m	(ft)	m	(ft)
Oil firing	1,0	(3,41)	4,3	(14,1)	0,8	(2,6)	0,56	(1,9)	6,5	(21,4)
	1,5	(5,12)	5,6	(18,5)	0,9	(3,0)	0,70	(2,3)	8,8	(29,0)
	2,0	(6,8)	7,0	(22,9)	1,1	(3,5)	0,83	(2,7)	11,2	(36,7)
	2,5	(8,5)	8,3	(27,4)	1,2	(3,9)	0,96	(3,1)	13,3	(43,6)
	3,0	(10,2)	9,7	(31,8)	1,3	(4,3)	1,09	(3,6)	14,8	(48,7)
	3,5	(11,9)	11,0	(36,2)	1,4	(4,7)	1,22	(4,0)	16,4	(53,8)
	4,0	(13,6)	12,4	(40,7)	1,6	(5,2)	1,35	(4,4)	18,0	(59,0)
Gas firing	0,5	(1,71)	2,6	(8,5)	0,6	(1,9)	0,44	(1,4)	3,4	(11,1)
	1,0	(3,41)	3,6	(11,9)	0,7	(2,4)	0,56	(1,9)	4,9	(16,2)
	1,5	(5,11)	4,6	(15,2)	0,8	(2,8)	0,70	(2,3)	6,5	(21,4)
	2,0	(6,82)	5,6	(18,5)	1,0	(3,2)	0,83	(2,7)	8,1	(26,5)
	2,5	(8,53)	6,7	(21,8)	1,1	(3,6)	0,96	(3,1)	9,6	(31,6)
	3,0	(10,24)	7,7	(25,2)	1,2	(4,1)	1,09	(3,6)	11,1	(36,4)
	3,5	(11,94)	8,7	(28,5)	1,4	(4,5)	1,22	(4,0)	11,9	(38,9)
	4,0	(13,65)	9,7	(31,8)	1,5	(4,9)	1,35	(4,4)	12,6	(41,5)
	4,5	(15,36)	10,7	(35,1)	1,6	(5,3)	1,48	(4,8)	13,4	(44,0)
	5,0	(17,06)	11,7	(38,5)	1,8	(5,7)	1,61	(5,3)	14,2	(46,6)

For horizontal firing, the distance between the burner centreline and the roof tube centreline or refractory shall be 50 % greater than the distances in column B.

For combination liquid and gas burners, the clearances shall be based on liquid fuel firing, except if liquid fuel is used for startup only.

For conventional gas burners, the longitudinal clearance may be decreased. This shall be achieved by multiplying dimensions in column A by a factor of 0,77 and column D by a factor of 0,67.

For intermediate firing rates, the required clearances may be achieved by linear interpolation.

Table 12 — Minimum clearance guidelines for forced-draught operations

Maximum heat release per burner		Horizontal distance to centreline of wall tubes from burner centreline	
MW	(Btu/h × 10^6)	m	(ft)
Oil firing			
2,00	(6,820)	0,932	(3,058)
3,00	(10,240)	1,182	(3,878)
4,00	(13,650)	1,359	(4,458)
5,00	(17,060)	1,520	(4,987)
6,00	(20,470)	1,664	(5,459)
8,00	(27,300)	1,919	(6,292)
10,00	(34,120)	2,143	(7,031)
12,00	(40,950)	2,346	(7,697)
Gas firing			
2,00	(6,820)	0,932	(3,058)
3,00	(10,240)	1,182	(3,878)
4,00	(13,650)	1,359	(4,458)
5,00	(17,060)	1,520	(4,987)
6,00	(20,470)	1,664	(5,459)
8,00	(27,290)	1,786	(5,860)
10,00	(34,120)	1,923	(6,309)
12,00	(40,950)	2,035	(6,677)

For horizontal firing, the distance between the burner centreline and the roof tube centreline or refractory shall be 50 % greater than the distances shown in the column above.

For combination liquid and gas burners, the clearances shall be based on liquid fuel firing, except if liquid fuel is used for start-up only.

For intermediate firing rates, the required clearances may be achieved by linear interpolation.

Lack of data does not allow other clearances to be specified.

At high peak flux, additional clearances may be required.

14.1.10 If a continuous pilot is provided, it shall meet the following requirements.

a) The pilot shall have a minimum heat release of 22 kW (75 000 Btu/h). The minimum heat release shall be approved by the purchaser, if it is for a high capacity burner whose heat release is 4,4 MW (15 × 10^6 Btu/h) or greater.

b) The pilot burner shall be provided with a continuous supply of air, under all operating conditions. This includes operation with the main burner out of service.

c) The pilot burner shall remain stable over the full firing range of the main burner. It shall also remain stable upon loss of main burner fuel, minimum draught, all combustion air flowrates and for all operating conditions.

● d) The pilot shall be positioned and sized to ensure that it is capable of lighting any of the main burner fuels. The purchaser shall specify the minimum main fuel flowrate during cold burner light-off.

e) The pilot shall be capable of re-lighting an individual main burner over the full range of fuel and combustion air flowrates when the fired heater is in service. This shall include light-off at design combustion air flowrate and low fuel flowrate.

14.1.11 Burner block installations shall be designed to expand and contract as a unit, independent of the heater refractory.

14.1.12 Burner tiles shall be supplied, pre-dried as required, so as to allow full firing after installation without further treatment. Burner tiles fabricated from water-based and hydrous materials shall be pre-dried to no less than 260 °C (500 °F).

14.1.13 The materials used for construction of a burner shall be chosen for strength, as well as temperature- and corrosion-resistance, for the anticipated service conditions. Burner components shall be designed in accordance with the minimum requirements shown in Table 13.

14.1.14 The burner shall maintain flame stability when operating at no less than 33 % of the maximum heat release settings without adjusting the air controls.

14.1.15 The burner shall be selected to use no less than 90 % of the maximum available draught loss for the maximum specified heat release.

14.1.16 The burner fuel valve and air registers shall be operable from grade or platforms. A means shall be provided to view the burner and pilot flame during light-off and operating adjustment.

● **14.1.17** If a natural-draught burner is to be used in forced-draught service, the purchaser shall specify the required heater capacity during natural-draught operation, if required.

14.1.18 Oil burners should be designed to operate at a normal kinematic viscosity of 15 mm^2/s (15 cSt) to 20 mm^2/s (20 cSt). The maximum shall not exceed 40 mm^2/s (40 cSt).

14.1.19 Atomizing steam shall be supplied dry at the burner, or with slight superheat.

14.1.20 If volatile fuels, such as naphtha or gasoline, are burned, a safety interlock shall be provided on each burner. The interlock design shall (in sequence) shut off the fuel, purge the oil gun, and shut off the purge medium before the gun can be removed.

14.1.21 Oil guns shall be removable while the heater is in operation.

● **14.1.22** The purchaser shall specify whether gas guns, diffusers or the complete burner assembly shall be removable.

Table 13 — Materials of construction

	Component	Operation	Material
Fuel gas (burner and pilot)	Fuel gas manifold and piping	Normal	Cast iron or carbon steel
		>100 mg/kg H_2S and either >150 °C (300 °F) fuel, or >205 °C (400 °F) combustion air	AISI 321L stainless steel
	Fuel gas riser pipe	Normal	Carbon steel
		>370 °C (700 °F) combustion air	AISI 304 stainless steel
		>100 mg/kg H_2S and either >150 °C (300 °F) fuel, or >205 °C (400 °F) combustion air	AISI 321L stainless steel
	Fuel gas tip	Normal	Cast iron or AISI 300 series stainless steel
		> 100 mg/kg H_2S and either >150 °C (300 °F) fuel, or >205 °C (400 °F) combustion air	AISI 321L stainless steel
	Premix Venturi	Normal	Cast iron or carbon steel
Fuel oil	Oil gun receiver and body	Normal	Ductile iron
	Oil gun tip	Normal	AISI 316 stainless steel
		Erosive oils	T-1 tool steel or similar
	Atomizer	Normal	Brass
		> 3 % (mass fraction) sulfur	AISI 303 stainless steel
	Atomizer body only	Erosive oils	Nitride-hardened alloy
	Other	Normal	Carbon steel
Burner housing	Exterior casing	Normal	Carbon steel
		Preheated combustion air	Insulated carbon steel
	Flame stabilizer or cone	Normal	AISI 300 series stainless steel
	Insulation and noise reduction linings	< 370 °C (700 °F) combustion air	Mineral wool
		$\geqslant$ 370 °C (700 °F) combustion air	Mineral wool covered with metal liner
	Other interior metal parts	Normal	Carbon steel
		$\geqslant$ 370 °C (700 °F) combustion air	ASTM A 242 or AISI 304 stainless steel
	Burner tile	Normal	> 40% alumina refractory
		High intensity combustor	> 85% alumina castable refractory/firebrick
	Oil firing tile	< 50 mg/kg V, Na	> 60% alumina refractory
		$\geqslant$ 50 mg/kg V, Na	> 90% alumina refractory
ASTM and AISI material grades are indicative of chemical composition; other grades may be used if they have similar properties			

14.2 Sootblowers

● **14.2.1** Sootblowers shall be automatic, sequential and/or fully retractable, as specified by the purchaser.

14.2.2 Individual sootblowers shall be designed to pass a minimum of 4 500 kg/h (10 000 lb/h) of steam with a minimum steam gauge pressure of 1 030 kPa (150 psi) at the inlet flange.

14.2.3 Retractable sootblower lances shall have two nozzles, an air bleed and check valve to stop flue gas entering. The minimum distance at any position between the lance outside diameter and the bare tube outside diameter shall be 225 mm (9 in).

14.2.4 Spacing of retractable sootblowers shall be based upon a maximum horizontal or vertical coverage of 1,2 m (4 ft) from the lance centreline, or five tube rows, whichever is less. The first (bottom) row of shield tubes may be neglected from sootblower coverage. Tube supports are considered as a limit to individual sootblower coverage.

14.2.5 Erosion protection shall be provided for convection-section walls located within the soot-blowing zones, using castable refractory with a minimum density of 2 000 kg/m^3 (125 lb/ft^3).

14.2.6 Retractable sootblower entrance ports (through the refractory wall) shall be provided with stainless steel sleeves.

14.3 Fans and drivers

Fans and drivers for use with fired heaters shall be designed and built in accordance with the requirements of annex E.

14.4 Dampers and damper controls

14.4.1 Butterfly dampers shall be limited to stacks and ducts having a maximum internal cross-sectional area of 1,2 m^2 (13 ft^2).

14.4.2 Louvre dampers shall have a minimum of one blade for every 1,2 m^2 (13 ft^2) of internal cross-sectional area in the stack or duct. The blades shall have approximately equal surface areas. Blades shall have opposed movement unless they are located at the fan suction, in which case there will be parallel closing movement opposite to the fan rotation.

14.4.3 Damper shafts and bolting shall be of the same materials as the blade.

14.4.4 Damper bearings and control mechanisms shall be external. Bearings shall be self-aligning, of non-lubricated graphite and mounted in the bearing manufacturer's standard housing.

● **14.4.5** Control dampers shall be designed to move to the position specified by the purchaser in the event of failure of either the damper-control signal or the motive force.

14.4.6 Dampers shall be equipped with a visual indicator of external blade position, on the damper shaft and on any remote control mechanism.

14.4.7 Dampers shall be furnished with a position control mechanism that is operable from grade and is capable of holding the damper blade in any position from fully open to fully closed. The damper controller shall provide positive action to translate the damper blade in either an open or closed direction.

14.4.8 Manual damper-operators shall be designed so that one person can, without excessive effort, position the damper blade in any desired position. Wire rope damper-operators shall be a minimum of 3 mm (1/8 in) diameter, austenitic stainless steel wire rope with galvanized hardware such as thimbles, turnbuckles and clamps.

14.4.9 Damper materials shall be limited to maximum service temperatures as follows:

a) carbon steel, 430 °C (805 °F);

b) 5Cr-1/2Mo, 650 °C (1 200 °F);

c) 18Cr-8Ni, 815 °C (1 500 °F);

d) 25Cr-12Ni, 980 °C (1 800 °F.)

14.4.10 Stack and flue-gas duct dampers shall have blades of minimum thickness of 5 mm (0,2 in).

15 Instrument and auxiliary connections

15.1 Flue gas and air

15.1.1 Flue-gas and combustion-air temperature

15.1.1.1 One connection shall be provided in the flue-gas exit of each radiant section for each 9 m (30 ft) of radiant box length or diameter. At least two connections shall be provided.

15.1.1.2 One connection shall be provided in the convection section, preceding the first process or utility coil, if multi-radiant-section heaters or multiple heaters have their flue gas combined to a common convection section, for each 9 m (30 ft) of convection tube length.

15.1.1.3 One connection shall be provided in the convection section immediately after each process or utility coil for each 9 m (30 ft) of convection tube length. A minimum of two connections shall be provided after the last convection coil.

15.1.1.4 Connections shall be provided in each stack and each take-off to a stack.

15.1.1.5 Connections shall be provided in the inlet and outlet air and flue-gas ductwork of an air heater and final combustion air to the burners.

15.1.1.6 The connections furnished shall be DN 40 (1½ NPS), 20 MPa (3 000 lb) screwed forged-steel couplings welded to the outside casing plate. If the refractory lining exceeds 75 mm (3 in) in thickness, the opening shall be lined with austenitic stainless steel pipe (schedule 80). A hex-head forged-steel screwed plug shall be furnished with each coupling.

15.1.2 Flue-gas and combustion-air pressure

15.1.2.1 Two connections shall be provided in each radiant section located 300 mm to 600 mm (1 ft to 2 ft) above the top of the floor refractory.

15.1.2.2 For heaters with horizontal firing, one connection shall be provided at the highest burner centreline on each burner wall.

15.1.2.3 Two connections shall be provided in each radiant section at the point of minimum draught.

15.1.2.4 A connection shall be provided in the convection-section outlet immediately after the final process or utility coil.

15.1.2.5 Connections shall be provided upstream and downstream of the draught-control dampers.

15.1.2.6 Connections shall be provided in the inlet and outlet ductwork connected with a fan.

15.1.2.7 Connections shall be provided in the inlet and outlet flue-gas and combustion-air ducting of a combustion air heater.

15.1.2.8 A connection of at least DN 15 (½ NPS) shall be provided at a suitable location downstream of any combustion air control damper in the burner windbox or plenum.

15.1.2.9 The connections furnished shall be DN 40 (1½ NPS), 20 MPa (3 000 lb) screwed forged-steel couplings welded to the outside casing plate. If the refractory lining exceeds 75 mm (3 in) in thickness, the opening shall be lined with austenitic stainless steel pipe (Schedule 80). A hex-head forged-steel screwed plug shall be furnished with each coupling.

15.1.3 Flue gas sampling

15.1.3.1 Connections shall be provided in the flue gas exit from each radiant section.

15.1.3.2 Connections shall be provided at the convection-section outlet.

15.1.3.3 Connections shall be provided in each stack and each take-off to a stack in compliance with environmental air quality monitoring requirements as specified by the appropriate regulatory body. Sampling point locations shall be determined according to environmental requirements regarding upstream and downstream flow disturbances.

15.1.3.4 The connections shall be DN 100 (4 NPS) schedule 80 pipe with a class PN 20 (ASME class 150) raised-face flange. The pipe shall be welded to the outside casing plate and project 200 mm (8 in) to the face of the flange. The heater vendor shall furnish for each connection a class PN 20 (ASME class 150) blind flange with appropriate gaskets for the temperature and corrosive conditions of the flue gas. The pipe shall extend 38 mm (1,5 in) into the heater from the hot face of the refractory lining.

● **15.1.3.5** Additional connections to meet applicable governmental or local environmental requirements shall be specified by the purchaser.

15.2 Process fluid temperature

● **15.2.1** The heater vendor shall provide fluid thermowell connections in the convection to radiant crossovers, if specified by the purchaser.

● **15.2.2** If process outlet thermowell connections are specified by the purchaser and individual outlets are provided by the heater vendor, the thermowell connections shall be furnished as part of the outlet piping system. If an outlet manifold is furnished, the specified thermowell connections shall be provided by the heater vendor.

15.2.3 Process fluid thermowell connections shall be DN 40 (1 1/2 NPS) raised-face flanges with a rating adequate for the fluid design pressure and temperature. The material shall be the same as the tube or pipe to which it is connected.

15.3 Auxiliary connections

15.3.1 Purge steam connections

15.3.1.1 Purge connections may also be used as snuffing steam connections.

15.3.1.2 A minimum of two purge connections shall be provided for each firebox. The connections shall be DN 40 (11/2 NPS) or DN 50 (2 NPS), 20 MPa (3 000 lb) screwed forged-steel pipe couplings, welded to the outside casing plate. The openings through the refractory shall be lined with a Schedule 80 austenitic stainless steel pipe.

15.3.1.3 Purge connections shall allow for flowrate providing a minimum of three firebox volume changes within 15 min.

15.3.1.4 Connections shall be located to preclude impingement on the heater coils and any ceramic fibre linings, and shall provide even distribution in the radiant section. The minimum size connection to header boxes shall be DN 20 (3/4 NPS). At least one DN 25 (1 NPS) connection shall be provided for each burner plenum chamber.

15.3.1.5 For forced-draught systems, the forced-draught fan can be used to purge the firebox in lieu of purge steam.

15.3.2 Vent and drain connections

15.3.2.1 Manifold or piping vents and drains shall be a welded coupling of minimum properties DN 25 (1 NPS), 40 MPa (6 000 lb), of the same metallurgy as the manifold or piping.

● **15.3.2.2** If water-washing of either radiant or convection tubes is specified by the purchaser, provisions shall be made for draining water to the outside of the heater using at least one DN 100 (4 NPS) connection with a cap.

15.3.2.3 For header boxes containing flanged or plug fittings, a screwed forged-steel drain connection with hex plug shall be provided of minimum properties DN 20 (¾ NPS), 20 MPa (3 000 lb).

15.4 Tube skin thermocouples

● **15.4.1** Tube skin thermocouples, if specified by the purchaser, shall be welded to a tube within a 60° arc on the tube wall, directly facing the flame envelope. Lead wire, insulators and protective sheaths shall be designed to accommodate all anticipated tube movement.

15.4.2 Protective sheaths shall be made gas-tight and constructed of Type 310 stainless steel or other alloy suitable for the operating conditions. Such sheaths shall be attached to the heater tubes by welded clips or bands. All thermocouple assemblies shall terminate on the exterior shell of the fired heater with a thermocouple head.

15.5 Access to connections

All instrument and sampling connections shall be accessible from grade, platforms or ladders.

Thermocouple connections considered as accessible from a platform or grade shall be no more than 2 m (6,5 ft) above the floor of the platform or the grade. Flue-gas sampling connections shall be no more than 1,2 m (4 ft) above the floor of the platform or the grade.

Connections considered as accessible from permanent vertical ladders shall be no more than 0,8 m (2,5 ft) from the centrelines of such ladders and at least 0,9 m (3 ft) below the top rung of such ladders.

16 Shop fabrication and field erection

16.1 General

● **16.1.1** The heater, all auxiliary equipment, ladders, stairs and platforms shall be shop-assembled to the maximum extent possible consistent with the available shipping, receiving and handling facilities specified by the purchaser. Individual sections shall be properly braced and supported to prevent damage during shipment. All blocking and bracing used for shipping purposes shall be clearly identified for field removal. Coil flange faces and other machined faces shall be coated with an easily removable rust preventive. Openings in pressure parts shall be covered to prevent entrance of foreign materials.

16.1.2 The vendor shall state the type of protection provided for refractory and insulation to avoid damage by handling or weather during shipment, storage, and erection.

16.1.3 All surfaces to be welded shall be free from scale, oil, grease, dirt, and other harmful agents. Welding operations shall be protected from wind, rain, and other weather conditions that may affect weld quality.

16.1.4 The heater steel structures shall be fabricated in accordance with the structural design code.

16.1.5 Coils shall be fabricated in accordance with the applicable provisions of the pressure design code.

16.2 Structural steel fabrication

16.2.1 General requirements

a) Welders for structural steel fabrication shall be qualified in accordance with the structural design code.

b) Seam welds between plates shall be continuous, full-penetration welds.

c) Horizontal exterior welds between plates and structural members shall have a continuous fillet weld on the top side and 50 mm (2 in) long fillet welds on 225 mm (9 in) centres on the bottom side. Diagonal and vertical exterior welds shall have continuous fillet welds on both sides.

d) Fillet welds shall be of uniform size with full throat and legs.

e) Welding filler materials shall be in accordance with the structural design code and shall have a chemical composition matching that of the base materials being joined.

● f) Impact test requirements and Charpy values shall be specified by the purchaser for all welds with design metal temperatures below – 30 °C (– 20 °F) and for submerged arc welds at design metal temperatures below – 18 °C (0 °F).

g) Circular and slotted bolt holes in columns and baseplates shall be drilled or punched. Baseplates shall be shop welded.

h) The minimum thickness of gusset plates shall be 6 mm (1/4 in).

i) Shop connections shall be bolted or welded. Field joints between casing plates and stack intermediate joints shall be welded unless full structural-strength flanged connections are supplied. All other field joints shall be bolted. Where field bolting is impractical, erection clips or other suitable positioning devices shall be furnished for field-welded connections.

j) The minimum size of bolts shall be 16 mm (5/8 in) in diameter, except where the flange width prohibits use of such size bolts. In no case shall bolts be less than 12 mm (1/2 in) in diameter.

k) Drain holes in structural members shall be a minimum of 12 mm (1/2 in) in diameter. Checkered plate flooring shall be furnished with one, 12 mm (1/2 in) diameter drain hole for every 1,4 m^2 (15 ft^2) of floor plate area.

l) The threads of bolts securing damper blades to the shaft shall be scored or tack-welded after installation.

m) Attachment of refractory anchors or tiebacks to heater casing shall be by manual or stud-gun welding. If manual welding is employed, welds shall be “all around”.

n) Suitable lifting lugs shall be provided for the erection of all sections where the section mass exceeds 1 820 kg (4 000 lb). The lifting load used shall be 1,5 times the section weight to allow for impact.

o) All structural steel and sub-assemblies shall be clearly marked with letters or numbers at least 50 mm (2 in) high for field identification. All loose items such as rods, turnbuckles, clevises, bolts, nuts and washers shall be shipped in bags, kegs or crates. Bags, kegs or crates shall be tagged with the size, diameter and length of contents so that tags for each item are individually identifiable. Tags used for marking shall be metal and markings shall be applied by stamping.

p) The erection drawings and a bolt list shall be furnished prior to the shipping of heater steel. Erection marks, size and length of field welds shown on erection drawings shall be in lettering at least 3 mm (1/8 in) high. The bolt list shall specify the number, diameter, length and material for each connection. A bill of material shall also be furnished showing the mass of sections over 1 820 kg (4 000 lb).

q) A minimum 5 % surplus number of bolts and nuts (size and material) used in the erection of the heater shall be furnished.

16.2.2 Heater stacks

The stack shall be sufficiently true so that the erected stack, when plumbed, exhibits a maximum vertical deviation of 25 mm (1 in) per 15 m (50 ft) of height.

The maximum perpendicular deviation from a straightedge applied to the stack shell shall not exceed 3 mm (1/8 in) in any 3 m (10 ft).

The difference between minimum and maximum diameters at any cross-section along the stack length shall not exceed 2 % of the nominal diameter for that section.

Plate misalignment at any stack joint shall not exceed 3 mm (1/8 in) or 25 % of the nominal plate thickness, whichever is less.

Vertical joint peaking shall not exceed a depth of 5 mm (3/16 in) when measured from a 600 mm (24 in) circumferential template centred on the joint.

Circumferential joint banding shall not exceed a depth of 8 mm (5/16 in) when measured from a 900 mm (36 in) straightedge centred on the joint.

16.3 Coil fabrication

16.3.1 Unless otherwise specified by the purchaser, the following welding processes are permitted, provided satisfactory evidence is submitted that the procedure is qualified in accordance with the pressure design code:

a) shielded metal arc with covered electrodes;

b) gas tungsten-arc, manual and automatic;

c) gas welding process for DN 50 (2 NPS) and smaller and for P-1 material;

d) gas metal-arc welding in the spray transfer range;

e) flux cored-arc welding with external shielding gas.

16.3.2 Permanently installed backing rings shall not be used.

16.3.3 An argon or helium internal purge shall be used for gas tungsten-arc root pass welding of 2,25Cr-1Mo and higher alloys, except that nitrogen may be used for austenitic stainless steels, unless otherwise specified by the purchaser. The root pass in carbon steel and in alloy steels lower than 2,25Cr-1Mo may be welded with or without an internal purge.

16.3.4 Each weld shall be uniform in width and size throughout its full length. Each weld shall be smooth and free of slag, inclusions, cracks, porosity, lack of fusion and undercut, except to the extent permitted by the referenced codes. In addition, the cover pass shall be free of course ripples, irregular surfaces, nonuniform head patterns, and high crowns and deep ridges or valleys between heads.

16.3.5 Butt welds shall be slightly convex and uniform in height, as specified in the applicable codes. Limitations on weld reinforcement shall apply to the internal surface as well as the external surface.

16.3.6 Repair welds shall be carried out in accordance with a repair procedure approved by the purchaser. Repairs shall not damage the adjacent base material.

16.3.7 Preheat temperature, interpass temperature and post-weld heat treatment shall be in accordance with the provisions of the applicable codes.

16.4 Painting and galvanizing

16.4.1 Heater steel shall be prepared in accordance with ISO 8501-1 and primed with one coat of inorganic zinc primer to a minimum dry film thickness (DFT) of 75 µm (0,003 in). Surfaces shall be painted in conditions in accordance with manufacturer's recommendations on temperature and relative humidity.

16.4.2 Un-insulated flue-gas ducts and stacks shall be primed with an inorganic zinc primer. Surface preparation and dry film thickness shall be in accordance with the paint manufacturer's recommendation.

● **16.4.3** If specified by the purchaser, platforms, handrails and toeboards, grating, stairways, fasteners, ladders and attendant light structural supports shall be hot-dipped galvanized. Galvanizing shall conform to the applicable sections of ASTM A 123, A 143, A 153, A 384 and A 385 or equivalent. Bolts joining galvanized sections shall be galvanized in accordance with ASTM A 153 or zinc-coated in accordance with ASTM B 633 or equivalent.

16.5 Refractories and insulation

16.5.1 Materials shall be stored in original containers, if possible, and shall be protected from moisture and from atmospheric and foreign contaminants. They shall be kept completely dry and at manufacturer's recommended storage temperature until used. Bricks shall be free of cracks, chips, spalling or other defects.

16.5.2 Prior to installation of refractory, all steel surfaces shall be cleaned to remove dirt, grease, paint, loose scale or other foreign materials.

16.5.3 Water used to install refractories shall be of potable quality and the temperature shall be between 7 °C (45 °F) and 32 °C (90 °F), unless the refractory manufacturer specifies otherwise.

16.5.4 All material shall be prepared and installed in accordance with the manufacturer's recommendations.

16.5.5 The mortar joints in firebrick construction shall be as thin as possible. In applying the mortar, the brick shall be dipped or troweled on two edges. Expansion joints shall be mortar-free. Brick should be placed against the mating surface and tapped gently to ensure uniform joints no more than 1,5 mm (1/16 in) wide.

16.5.6 Anchors with circular bases shall be welded all around. Other anchors shall be welded to casing along both sides.

16.5.7 Chain-link fence anchoring shall be pulled out and held in place after welding, and prior to castable application, to ensure proper position in the castable layer.

16.5.8 The following shall apply to castables.

— The surfaces to which castable is applied shall be kept above 7 °C (45 °F) and below 38 °C (100 °F) during installation and curing.

— For pneumatic application, the lining shall be applied in horizontal strips working upward from the bottom. It shall proceed continuously to the required thickness in a given area. If the installation is interrupted, the lining shall be cut back immediately to the casing surface. This cut shall be full depth at a 90° angle to the casing surface.

— Rebound materials shall not be re-used in applying linings.

— Scoring of the castable surfaces shall be in accordance with the vendor's specifications.

— Each layer of the castable shall be properly cured after installation. A resin-based membrane curing compound shall be applied immediately after the initial set, with a curing period of at least 24 h. Shop-installed castable shall not be handled or tested for 72 h after installation.

16.6 Field erection

16.6.1 It shall be the responsibility of the erector to ensure that the heater is erected in accordance with the specifications and drawings furnished by the vendor. The heater shall be erected in accordance with the applicable clauses of this International Standard.

16.6.2 Castable-lined panels shall be handled to avoid excessive cracking or separation of the refractory from the steel.

16.6.3 Care shall be taken to avoid refractory damage due to weather. Standing water or saturation of the refractory shall be prevented. Protection shall include cover to avoid rain impingement and shall allow drainage, proper fit and tightening of doors and header boxes.

16.6.4 Sections where refractory edges are exposed shall be protected against cracking of edges and corners. External blows to the steel casing shall be avoided.

16.6.5 Field joints between panels shall be sealed in accordance with the heater vendor's requirements.

16.6.6 Construction joints resulting from panel or modular construction shall have continuous refractory cover to the full thickness of the adjacent refractory.

17 Inspection, examination and testing

17.1 General

17.1.1 The purchaser, his designated representative, or both, reserve the right to inspect, after prior notice, all heater components and their assembled units at any time during the material procurement, fabrication and shop assembly to ensure materials and workmanship are in accordance with applicable standards, specifications, codes and drawings.

17.1.2 The vendor shall examine all individual heater components and their shop-assembled units to ensure that materials and workmanship are in accordance with applicable standards, specifications, codes and drawings.

● **17.1.3** If specified by the purchaser, pre-inspection meetings between the purchaser and the fabricator shall be held before start of fabrication.

17.2 Weld examination

17.2.1 Radiographic, ultrasonic, visual, magnetic-particle or liquid-penetrant examination of welds in coils shall be in accordance with the pressure design code.

17.2.2 The extent of examination of welds in coils, including return bends, fittings, manifolds and crossover piping, shall be as follows.

- The root passes of 10 % of all austenitic welds for each welder shall be liquid-penetrant examined following weld surface preparation in accordance with the pressure design code. If the required examination identifies a defect, further examination shall be performed.
- All welds in Cr-Mo steels and austenitic stainless steels shall be 100 % radiographed.
- 10 % of all carbon steel welds by each welder shall be 100 % radiographed. If the required examination identifies a defect, further examination shall be performed. For each weld found to be defective, radiographs shall be made promptly on welds made by the same welder that produced the defective welds.
- Acceptance criteria of welds shall be in accordance with the pressure design code.
- All longitudinal seam welds on manifolds shall be 100 % radiographed. In addition, these welds shall be examined by the liquid-penetrant method (for austenitic materials) or the magnetic-particle method (for ferritic materials).
- In cases where weld or material configuration makes radiographic examination difficult to interpret or impossible to perform, such as nozzle (fillet) welds, ultrasonic examination may be substituted. If ultrasonic examination is impractical, liquid-penetrant examination shall be performed (for austenitic materials) or magnetic-particle examination shall be performed (for ferritic materials).

17.2.3 Post-weld heat treatment shall be performed in accordance with the pressure design code.

17.2.4 Proposed welding procedures, procedure qualification records and welding consumable specifications for all pressure-retaining welds shall be in accordance with the pressure design code, and shall be submitted by fabricator for review, comment or approval by the purchaser.

17.2.5 Welder qualifications and applicable manufacturer's report forms shall be maintained. Examples include certified material mill test reports, AWS or other classification and manufacturer of electrode or filler material, welding specifications and procedures, positive materials identification documentation of alloy materials, and non-destructive examination procedures and results. Unless otherwise specified by the purchaser, records of examination procedures and examination personnel qualifications shall be retained for at least five years after the record is generated for the project.

17.3 Castings examination

● **17.3.1** Material conformance shall be verified by review of chemical and physical test results submitted by the manufacturer. The purchaser shall specify if positive materials identification shall be performed to verify these results.

17.3.2 Shield and convection section cast tube supports shall be examined as follows.

a) Tube supports shall be visually examined in accordance with MSS SP-55 and dimensionally checked. Tube supports shall be adequately cleaned to facilitate examination of all surfaces.

b) Intersections of all reinforcing ribs with the main member shall be either 100 % liquid-penetrant examined (if austenitic) or 100 % magnetic-particle examined (if ferritic). The examination procedures and acceptance criteria shall be in accordance with the pressure design code.

● c) Radiographic examination of critical sections shall be performed if specified by the purchaser, and the procedure and acceptance criteria shall be in accordance with the pressure design code.

● **17.3.3** Cast radiant tube supports, hangers and guides shall be visually examined for surface imperfections using MSS SP-55 as a reference for categories and degrees of severity. Defects shall be marked for removal or repair, or to warrant complete replacement of the casting. Dimensions shall be verified with checks based on the sampling plan agreed by the purchaser.

17.3.4 Cast return bends and pressure fittings shall be examined as follows.

a) All cast return bends and pressure fittings shall be visually examined for imperfections in accordance with MSS SP-55, and measured to confirm dimensions in accordance with reference drawings and the sampling plan agreed by the purchaser. Examination shall confirm proper and complete identification as specified in the purchase order.

b) All surfaces shall be suitably prepared for liquid penetrant examination (for austenitic materials) or magnetic particle examination (for ferritic materials). Examination and acceptance criteria shall be in accordance with the pressure design code.

● c) Cast return bends and pressure fittings shall be examined by radiography in accordance with the pressure design code. The sampling quantities and degree of coverage shall be as specified by the purchaser.

17.3.5 Machined weld bevels shall be examined by the liquid-penetrant method. Indications with any dimension greater than 1,5 mm ($^{1}/_{16}$ in) shall not be permitted.

17.3.6 Repairs shall meet the following requirements.

— Imperfections not meeting the acceptance criteria shall be removed and their removal verified by liquid-penetrant examination. If the cavity formed by removing an imperfection reduces the thickness to below that required for the design, the cavity shall be repaired by welding.

— All repairs shall be verified by liquid-penetrant examination, with the procedure and acceptance criteria in accordance with the pressure design code.

— Major repairs shall be verified by radiography in accordance with the pressure design code. A repair shall be considered major if the depth of the cavity before repair exceeds 20 % of the section thickness or if the length of the cavity exceeds 250 mm (10 in).

— Weld repairs shall be made using welding procedures and welders qualified in accordance with the pressure design code.

17.3.7 Bearing surfaces of all castings shall be free from sharp edges and burrs.

17.4 Examination of other components

17.4.1 Examination of heater steelwork shall be in accordance with the structural design code.

17.4.2 Refractory linings shall be examined throughout for thickness variations during application and for cracks after curing. Thickness variations are limited to a range of 6 mm (1/4 in) to 13 mm (1/2 in). Cracks which are 3 mm (1/8 in) or greater in width and penetrate more than 50 % of the castable thickness shall be repaired. Repairs shall be made by chipping out the unsound refractory to the backup layer interface or casing and exposing a minimum of three tieback anchors or to the sound metal, making a joint between sound refractory that is sloped of a minimum 25 mm (1 in) to the base metal (dove-tail construction) and then gunning, casting or hand-packing the area to be repaired.

17.4.3 Finned extended surface shall be examined to ensure fins are perpendicular to the tube within 15°. The maximum discontinuity of the weld shall be 65 mm (2,5 in) in 2,5 m (100 in) of weld. The attachment weld shall provide a cross-sectional area of not less than 90 % of the cross-sectional area of the root of the fin. Cross-sectional area is the product of the fin width and the peripheral length.

17.4.4 Fins and studs shall be examined to verify conformity with specified dimensions.

17.4.5 For rolled joint fittings, the fitting tube-hole inner diameter, the tube outer diameter and the tube inner diameter (before and after rolling) shall be measured and recorded in accordance with the fitting location drawing. These measurements shall be supplied to the purchaser.

17.4.6 Fabricated supports include both plate-fabricated and multicast techniques. Fabricated convection tube intermediate supports shall have support lug welds radiographed. Warping of the completed support shall be within the limits permitted by the structural design code.

17.5 Testing

17.5.1 Pressure testing

17.5.1.1 All assembled pressure parts shall be hydrostatically tested to a minimum pressure equal to 1,5 times the coil design pressure, multiplied by the ratio of the allowable stress at 38 °C (100 °F) to the allowable stress at the design tube metal temperature. The following test requirements also apply.

a) The maximum test pressure shall be limited to the extent that the weakest component shall not be stressed beyond 90 % of the material’s yield strength at ambient temperature.

b) Hydrostatic test pressures shall be maintained for a minimum period of 1 h to test for leaks.

● **17.5.1.2** If hydrostatic testing of pressure parts is not considered practical by agreement between the purchaser and the vendor, then pneumatic leak-testing shall be substituted, using air or a non-toxic non-flammable gas. The pneumatic test pressure shall be 430 kPa (60 psi) gauge or 15 % of the maximum allowable design pressure, whichever is less. The pneumatic test pressure shall be maintained for a length of time sufficient to examine for leaks, but in no case for less than 15 min. A bubble surfactant shall be applied to weld seams to aid visual leak detection.

17.5.1.3 Water used for hydrostatic testing shall be potable. For austenitic materials, the chloride content of the test water shall not exceed 50 mg/kg (50 ppm).

17.5.1.4 Unless the test fluid is the process fluid, the test fluid shall be removed from all heater components upon completion of hydrostatic testing.

17.5.2 Refractory testing

Installed castable linings shall undergo hammer tests to check for voids within the refractory material. For dual-layer linings, the hammer tests shall be conducted on each layer, after curing. Linings shall be struck with a 450 g (1 lb) machinist's ball peen hammer over the entire surface, using a grid pattern approximating the following:

a) for arch areas, 600 mm (24 in) centres;

b) for sidewall and floor areas, 900 mm (36 in) centres.

17.5.3 Studded tube testing

Each length of a studded tube assembly shall be randomly examined and inspected by hammer testing to verify the adequacy of the stud-to-tube weld.

17.5.4 Positive materials identification

17.5.4.1 Positive materials identification (PMI) is the process of verifying that the chemical composition of a metallic alloy is within the specified limits. It is normally performed on components after they have been installed (or at a stage after which it is no longer possible to mix up the materials).

● **17.5.4.2** PMI programme methods, degree of examination, PMI testing instruments, and tester qualifications shall be agreed upon between the purchaser and the vendor prior to manufacturing. PMI shall not be required for burner components, unless specified by the purchaser.

17.5.4.3 Unless superseded by the purchaser's requirements, 10 % of all alloy components shall be PMI-tested. If random testing is carried out, PMI shall be made on components from different heater numbers. The purchaser may alternatively choose to specify that a PMI test be made on each component.

17.5.4.4 Tabulation of tested items shall be included within all final data books, keyed to weld maps on as-built drawings and mill certification document stampings. Tested items shall be immediately marked.

Annex A
(informative)

Equipment data sheets

This annex includes data sheets for the following equipment items:

a) Fired heater data sheets (12 sheets: 6 in SI units, 6 in US Customary units).

b) Burner data sheets (6 sheets: 3 in SI units, 3 in US Customary units).

c) Air preheater data sheets (4 sheets: 2 in SI units, 2 in US Customary units).

d) Fan data sheets (4 sheets: 2 in SI units, 2 in US Customary units).

e) Sootblower data sheets (2 sheets: 1 in SI units, 1 in US Customary units).

See clause 5 for instructions on using the equipment data sheets. Note that the purchaser should complete, as a minimum, those items that are designated by an asterisk (*).

Fired Heater Data Sheet		**SI units**				
		rev.:	**date:**		**sheet 1 of 6**	
Purchaser/Owner:		**Item No.:**				
Service:		**Location:**				
1	unit:	* number required:				rev
2	manufacturer:	Reference:				
3	type of heater:					
4	*total heater absorbed duty, MW:					
5	**Process Design Conditions**					
6	*operating case					
7	heater section					
8	*service					
9	heat absorption, MW					
10	*fluid					
11	*flowrate, kg/s					
12	*flowrate, m^3/h					
13	*pressure drop, allowable (clean/fouled), kPa					
14	pressure drop, calculated (clean/fouled), kPa					
15	*avg. rad. sect. flux density, allow., W/m^2					
16	avg. rad. sect. flux density, calc., W/m^2					
17	max rad. sect. flux density, W/m^2					
18	conv. sect. flux density (bare tube), W/m^2					
19	*velocity limitation, m/s					
20	process fluid mass velocity, $kg/s{\cdot}m^2$					
21	*maximum allow./calc.inside film temperature, °C					
22	*fouling factor, $m^2{\cdot}K/W$					
23	*coking allowance, mm					
24	**Inlet conditions:**					
25	*temperature, °C					
26	*pressure, kPa (ga)					
27	*liquid flowrate, kg/s					
28	*vapour flowrate, kg/s					
29	*liquid relative density (at 15 °C)					
30	*vapour relative molecular mass					
31	*viscosity, (liquid/vapour), mPa·s					
32	*specific heat, (liquid/vapour), kJ/kg·K)					
33	*thermal conductivity, (liquid/vapour), W/m·K					
34	**Outlet conditions:**					
35	*temperature, °C					
36	*pressure, kPa (ga)					
37	*liquid flowrate, kg/s					
38	*vapour flowrate, kg/s					
39	* liquid relative density (at 15 °C)					
40	*vapour relative molecular mass					
41	*viscosity, (liquid/vapour), mPa·s					
42	*specific heat, (liquid/vapour), kJ/kg·K)					
43	*thermal conductivity, (liquid/vapour), W/m·K					
44	**Remarks and special requirements:**					
45	*distillation data or feed composition:					
46	short-term operating conditions:					
47						
48	**Notes:**					
49						
50						

Fired heater data sheet				**SI units**			
				rev:	date:	sheet 2 of 6	
Combustion Design Conditions							
1	operating case						rev
2	*type of fuel						
3	*excess air, percent						
4	calculated heat release (h_L), MW						
5	fuel efficiency calculated, percent (h_L)						
6	fuel efficiency guaranteed, percent (h_L)						
7	radiation loss, percent of heat release (h_L)						
8	flue-gas temperature leaving:	radiant section, °C					
9		convection section, °C					
10		air preheater, °C					
11	flue-gas quantity, kg/s						
12	flue-gas mass flowrate through convection section, kg/s·m^2						
13	draught	at arch, Pa					
14		at burners, Pa					
15	*ambient air temperature, efficiency calculation, °C						
16	*ambient air temperature, stack design, °C						
17	*altitude above sea level, m						
18	volumetric heat release, (h_L), W/m^3						
19	*emission limits (dry):	mg/m^3 (corrected to 3% O_2)		NO_x:	CO:	SO_x	
20		kJ/kg (h_L) (h_H)		UHC:	particulates:		
21	**Fuel characteristics:**						
22	*gas type		*liquid type		*other type		
23	* h_L	kJ/m^3	* h_L	kJ/kg	* h_L	kJ/kg kJ/m^3	
24	* h_H	kJ/m^3	* h_H	KJ/kg	*h_H	kJ/kg kJ/m^3	
25	*press. @ burner	kPa (ga)	*press. @ burner,	kPa (ga)	*press. @ burner,	kPa (ga)	
26	*temp. @ burner	°C	*temp. @ burner,	°C	*temp. @ burner,	°C	
27	*relative molecular mass		*viscosity @ °C	mPa·s			
28			*atomizing steam temp.	°C			
29			*pressure,	kPa (ga)			
30	component	mole fraction %	component	mass fraction	component	mass fraction	
31							
32							
33							
34			*vanadium (mg/kg)				
35			*sodium (mg/kg)				
36			*sulfur				
37			*ash				
38	**Burner data:**						
39	manufacturer:		size/model No.:		number:		
40	type:		location:		orientation:		
41	heat release per burner, MW		design:	normal:	minimum:		
42	pressure drop across burner @ design heat release, Pa:						
43	distance burner centreline to tube centreline, horizontal, mm:				vertical, mm:		
44	distance burner centreline to unshielded refractory, horizontal, mm:				vertical, mm:		
45	pilot, type:		capacity, MW:		fuel:		
46	ignition method:						
47	flame detection, type:			number:			
48	**Notes:**						
49							
50							

Fired heater data sheet			SI units			
			rev:	date:	sheet 3 of 6	
Mechanical Design Conditions						
1	*plot limitations:		*stack limitations:			rev
2	*tube limitations:		*noise limitations:			
3	*structural design data:	wind velocity:	*wind occurrence:			
4		snow load:	*seismic zone:			
5	*minimum/normal/maximum ambient air temperature, °C:		*relative humidity, %			
6	heater section:					
7	service:					
8	**Coil design:**					
9	*design basis: tube wall thickness (code or spec.)					
10	rupture strength (minimum or average)					
11	*stress-to-rupture basis, HR					
12	*design pressure, elastic/rupture, kPa					
13	*design fluid temperature, °C					
14	*temperature allowance, °C					
15	corrosion allowance, tubes/fittings, mm					
16	hydrostatic test pressure, kPa					
17	*post-weld heat treatment (yes or no)					
18	*percent of welds fully radiographed					
19	maximum (clean) tube metal temperature, °C					
20	design tube metal temperature, °C					
21	inside film coefficient, $W/m^2 \cdot K$					
22	**Coil arrangement:**					
23	tube orientation: vertical or horizontal					
24	*tube material (specification and grade)					
25	tube outside diameter, mm					
26	tube wall thickness, (minimum) (average), mm					
27	number of flow passes					
28	number of tubes					
29	number of tubes per row (convection section)					
30	overall tube length, m					
31	effective tube length, m					
32	bare tubes: number					
33	total exposed surface, m^2					
34	extended surface tubes: number					
35	total exposed surface, m^2					
36	tube layout (in line or staggered)					
37	tube spacing, cent. to cent.: horiz. × diag. (or vert.)					
38	spacing tube cent. to furnace wall (min.), mm					
39	corbels (yes or no)					
40	corbel width, mm					
41	**Description of extended surface:**					
42	type: (studs) (serrated fins) (solid fins)					
43	material					
44	dimensions (height × diameter/thickness), mm					
45	spacing (fins/m) (studs/plane)					
46	maximum tip temperature, (calculated), °C					
47	extension ratio (total area/bare area)					
48	**Plug type headers:**					
49	*type					
50	material (specification and grade)					
51	nominal rating					
52	*location (one or both ends)					
53	welded or rolled joint					
54	**Notes:**					
55						
56						

Fired heater data sheet					SI units	
		rev:	date:		sheet 4 of 6	
Mechanical Design Conditions (continued)						
1	heater section:					rev
2	service:					
3	**Return bends:**					
4	type					
5	material (specification and grade)					
6	nominal rating or schedule					
7	*location (f. b. = fire box, h. b. = header box)					
8	**Terminals and/or manifolds:**					
9	*type (bev. = bevelled, manif. = manifold, flg. = flanged)					
10	inlet: material (specification and grade)					
11	size/schedule or thickness					
12	number of terminals					
13	flange material (ASTM specification and grade)					
14	flange size and rating					
15	outlet: material (specification and grade)					
16	size/schedule or thickness					
17	number of terminals					
18	flange material (specification and grade)					
19	flange size and rating					
20	*manifold to tube connection (welded, extruded, etc.)					
21	manifold location (inside or outside header box)					
22	**Crossovers:**					
23	*welded or flanged					
24	*pipe material (specification and grade)					
25	pipe size/schedule or thickness					
26	*flange material					
27	flange size/rating					
28	*location (internal/external)					
29	fluid temperature, °C					
30	**Tube supports:**					
31	location (ends, top, bottom)					
32	material (specification and grade)					
33	design metal temperature, °C					
34	thickness, mm					
35	type and thickness of insulation, mm					
36	anchor (material and type)					
37	**Intermediate tube supports:**					
38	material (specification and grade)					
39	design metal temperature, °C					
40	thickness, mm					
41	spacing, m					
42	**Tube guides:**					
43	location:					
44	material:					
45	type/spacing:					
46	**Header boxes:**					
47	location:	hinged door/bolted panel:				
48	casing material:	thickness, mm:				
49	lining material:	thickness, mm:				
50	anchor (material and type):					
51	**Notes:**					
52						
53						
54						

Fired heater data sheet			SI units		
			rev:	date:	sheet 5 of 6

Mechanical Design Conditions (continued)

1	**Refractory design basis**:						rev
2	ambient temperature, °C:	wind velocity, m/s		casing temperature, °C:			
3	**Exposed vertical walls:**						
4	lining thickness, mm:	hot-face temperature, design/calculated, °C:					
5	wall construction:						
6							
7	anchor (material & type):						
8	casing material:	thickness, mm:		temperature, °C:			
9	**Shielded vertical walls:**						
10	lining thickness, mm:	hot-face temperature, design/calculated, °C:					
11	wall construction:						
12							
13	anchor (material & type):						
14	casing material:	thickness, mm:		temperature, °C:			
15	**Arch:**						
16	lining thickness, mm:	hot-face temperature, design/calculated, °C:					
17	wall construction:						
18							
19	anchor (material & type):						
20	casing material:	thickness, mm:		temperature, °C:			
21	**Floor:**						
22	lining thickness, mm:	hot-face temperature, design/calculated, °C:					
23	floor construction:						
24							
25	casing material:	thickness, mm:		temperature, °C:			
26	minimum floor elevation, m:	free space below plenum, m:					
27	**Convection section:**						
28	lining thickness, mm:	hot-face temperature, design/calculated, °C:					
29	wall construction:						
30							
31	anchor (material & type):						
32	casing material:	thickness, mm:		temperature, °C:			
33	**Internal wall:**						
34	type:	material:					
35	dimension, height/width:						
36	**Ducts:**	**Flue gas**			**Combustion air**		
37	location:	breeching					
38	size, m or net free area, m^2:						
39	casing material:						
40	casing thickness, mm:						
41	lining: Internal/external						
42	Thickness, mm						
43	Material						
44	anchor (material & type)						
45	casing temperature, °C.						
46	**Plenum chamber (air):**						
47	casing material:	thickness, mm:		size, mm:			
48	lining material:			thickness, mm:			
49	anchor (material & type):						
50	**Notes:**						
51							
52							

	Fired heater data sheet			SI units		
				rev:	date:	sheet 6 of 6
	Mechanical Design Conditions (continued)					
1	**Stack or stack stub:**					
2	number:	self-supported or guyed		location:		
3	casing material:	*corrosion allow., mm:		minimum thickness, mm:		
4	inside metal diameter, m:	height above grade, m:		stack length, m:		
5	lining material:			thickness, mm:		
6	anchor (material and type)					
7	extent of lining:	internal or external:				
8	design flue-gas velocity, m/s	flue-gas temp., °C:				
9	**Dampers:**					
10	location					
11	type (control, tight shut-off, etc.)					
12	material: blade					
13	material: shaft					
14	multiple/single leaf					
15	provision for operation (man. or auto.)					
16	type of operator (cable or pneumatic)					
17	**Miscellaneous:**					
18	platforms: location	number	width	length/arc	stairs/ladder	access from
19						
20						
21						
22						
23						
24	type of flooring:					
25	doors:		number	location	size	bolted/hinged
26	access					
27						
28	observation					
29						
30	tube removal					
31						
32	instrument connections:			number	size	type
33	flue-gas/combustion-air temperature					
34	flue-gas/combustion-air pressure					
35	flue-gas sample					
36	snuffing steam/purge					
37	O_2 analyser					
38	CO or NO_x analyser					
39	vents/drains					
40	process fluid temperature					
41	tube skin thermocouples					
42						
43						
44	painting requirements:					
45	internal coating:					
46	galvanizing requirements:					
47	are painters trolley and rail included:					
48	special equipment:	sootblowers:				
49		air preheater:				
50		fan (s):				
51		other:				
52	**Notes:**					
53						
54						
55						
56						

Burner data sheet	SI units		
	rev:	date:	sheet 1 of 3
Purchaser/owner:	**Item No.:**		
Service:	**Location:**		

1	**General data:**		rev
2	type of heater		
3	altitude above sea level, m		
4	air supply:		
5	ambient/preheated air/gas turbine exhaust		
6	temperature, °C (min./max./design)		
7	relative humidity. %		
8	draught type: forced/natural/induced		
9	draught available, Pa: across burner		
10	draught available, Pa: across plenum		
11	required turndown		
12	burner wall lining thickness, mm		
13	heater casing thickness, mm		
14	firebox height, m		
15	tube circle diameter, m		
16	**Burner data:**		
17	manufacturer		
18	type of burner		
19	model/size		
20	direction of firing		
21	location (roof/floor/sidewall)		
22	number required		
23	minimum distance burner centreline, mm		
24	to tube centreline (horizontal/vertical)		
25	to adjacent burner centreline (horizontal/vertical)		
26	to unshielded refractory (horizontal/vertical)		
27	burner circle diameter, m		
28	pilots:		
29	number required		
30	type		
31	ignition method		
32	fuel		
33	fuel pressure, kPa		
34	capacity, MW		
35	**Operating data:**		
36	fuel		
37	heat release per burner, MW (h_L)		
38	design		
39	normal		
40	minimum		
41	excess air @ design heat release, (%)		
42	air temperature, °C		
43	draught loss, Pa		
44	design		
45	normal		
46	minimum		
47	fuel pressure required, kPa		
48	flame length @ design heat release, m		
49	flame shape (round, flat, etc.)		
50	atomizing medium/oil ratio, kg/kg		
51	**Notes:**		
52			
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Burner data sheet					SI units			
			rev:		date:		sheet 2 of 3	
Gas Fuel Characteristics								
1	fuel type							rev
2	massic heat value (h_L), kJ/m^3							
3	relative density (air = 1,0)							
4	relative molecular mass							
5	fuel temperature @ burner, °C							
6	fuel pressure: available @ burner, kPa (ga)							
7	fuel gas composition (mole fraction, %)							
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20		total						
21	**Liquid Fuel Characteristics**							
22	fuel type							
23	massic heat value (h_L), kJ/kg							
24	relative density (at 15 °C)							
25	h/c ratio (by mass)							
26	viscosity, @	°C, mPa·s						
27	viscosity, @	°C, mPa·s						
28	vanadium, mg/kg							
29	potassium, mg/kg							
30	sodium, mg/kg							
31	nickel, mg/kg							
32	fixed nitrogen, mg/kg							
33	sulfur, mass fraction (%)							
34	ash, mass fraction (%)							
35	water, mass fraction (%)							
36	distillation:	ASTM initial boiling point, °C						
37		ASTM mid-point, °C						
38		ASTM end-point, °C						
39	fuel temperature @ burner, °C							
40	fuel pressure available @ burner, kPa							
41	atomizing medium:	air/steam/mechanical						
42		temperature, °C						
43		pressure, kPa						
44	**Notes:**							
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Burner data sheet			SI units	
			rev: date: sheet 3 of 3	
Miscellaneous				
1	burner plenum:	common/integral		rev
2		material		
3		plate thickness, mm		
4		internal insulation		
5	inlet air control:	damper or registers		
6		mode of operation		
7		leakage, %		
8	burner tile:	composition		
9		minimum service termperature, °C		
10	noise specification			
11	attenuation method			
12	painting requirements			
13	ignition port:	size/No.		
14	sight port:	size/No.		
15	flame detection:	type		
16		number		
17	scanner connection:	size/No.		
18	safety interlock system for atomizing medium and oil			
19	performance test required (yes or no)			
20	**Emission limits:**			
21	firebox bridgewall temperature, °C.			
22	NO_x	* ml/m³ (d) or kg/kJ (h_L) (h_H)		
23	CO	* ml/m³ (d) or kg/kJ (h_L) (h_H)		
24	UHC	* ml/m³ (d) or kg/kJ (h_L) (h_H)		
25	particulates	* ml/m³ (d) or kg/kJ (h_L) (h_H)		
26	SO_x	* ml/m³ (d) or kg/kJ (h_L) (h_H)		
27				
28	*corrected to 3% O_2 (dry basis @ design heat release)			
29				
30	NOTE 1 At design conditions, minimum of 90% of the available draught with air register fully open shall be utilized across the burner. In addition, a minimum of 75% of the air side pressure drop with air registers fully open shall be utilized across burner throat.			
31				
32				
33	NOTE 2 Vendor to guarantee burner flame length.			
34	NOTE 3 Vendor to guarantee excess air, heat release and draught loss across burner.			
35				
36				
37				
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Air preheater data sheet	SI units		
	rev:	date:	sheet 1 of 2
Purchaser/owner:	**Item No.:**		
Service:	**Location:**		

							rev
1	manufacturer:						rev
2	model:						
3	number required:						
4	heating surface, m^2						
5	mass, kg						
6	approximate dimensions: ($h \times w \times l$) m						
7	**Performance data**						
8	operating case						
9							
10	air side:	flowrate entering, kg/s					
11		inlet temperature, °C					
12		outlet temperature, °C					
13		pressure drop: allowable, mbar					
14		pressure drop: calculated, mbar					
15		heat absorbed, MW					
16	flue-gas side:	flowrate, kg/s					
17		inlet temperature, °C					
18		outlet temperature, °C					
19		pressure drop: allowable, mbar					
20		pressure drop: calculated, mbar					
21		heat exchanged, MW					
22	air bypass rate, kg/s						
23	total air flowrate to burners, kg/s						
24	mix air temperature, °C						
25	flue-gas composition, mole fraction, % ($O_2/N_2/H_2O/CO_2/SO_x$)						
26	flue-gas specific heat, kJ/kg·K						
27	flue-gas acid dew point temperature, °C						
28	minimum metal temperature: allowable, °C						
29	minimum metal temperature: calculated, °C						
30	**Miscellaneous:**						
31	minimum ambient air temperature, °C						
32	site elevation above sea level, m						
33	relative humidity, %						
34	external cold air bypass (yes/no)						
35	cold-end thermocouples (yes/no) number required						
36	access doors: number/size/location						
37	insulation (internal/external):						
38	cleaning medium:	steam or water					
39		pressure, kPa					
40		temperature, °C					
41							
42	**Mechanical design:**						
43	design flue-gas temperature, °C.						
44	design pressure differential, mbar						
45	seismic factor						
46	painting requirements						
47	leak test						
48	structural wind load, kg/m^2						
49	air leakage (guaranteed maximum), %						
50							
52	**Notes:** (all data on per unit basis)						
53							
54							

Air preheater data sheet	SI units			
	rev:	date:	sheet 2 of 2	
Construction Data				

1	I cast iron:			rev
2	number of passes			
3	number of tubes per block			
4	number of blocks			
5	type of surface			
6	tube material			
7	tube of thickness, mm			
8	glass block (yes/no)			
9	number of glass tubes			
10	air crossover duct: number			
11	bolted/welded			
12	supplied with clips			
13	water wash: yes/no			
14	type (off-line or on-line)			
15	location			
16				
17	II plate type:			
18	number of passes			
19	number of plates per block			
20	number of blocks			
21	plate thickness, mm			
22	width of air channel, mm			
23	width of flue-gas channel, mm			
24	air-side rib pitch, mm			
25	flue-gas-side rib pitch, mm			
26	material: plate			
27	rib			
28	frame			
29	air crossover duct: number			
30	bolted/welded			
31	supplied with clips			
32	water wash: yes/no			
33	type (off-line or on-line)			
34	location			
35				
36	III heat pipe:			
37	number of tubes			
38	tubes OD/wall thickness, mm			
39	tube material			
40	tubes per row			
41	number of rows			
42	tube pitch (square/triangular), mm			
43		air side	gas side	
44	fins: type			
45	height × thickness × No. /m			
46	material			
47	effective length, m			
48	heating surface, m^2			
49	maximum allowable soak temperature, °C			
50	sootblower: yes/no			
51	type			
52	location			
53	**Notes:**			
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Fan data sheet	**SI units**		
	rev:	date:	sheet 1 of 2
Purchaser/owner:	**Item No.:**		
Service:	**Location:**		

			rev
1	fan manufacturer:	model/size: Arrangement:	
2	service:	number required:	
3	drive system:	fan rotation from driven end ☐ cw ☐ ccw	
4	gas handled:	molecular mass:	
5	site elevation, m:	fan location:	
6	**Operating conditions:**		

		design	test block	other conditions		rev
7	operating condition/case:					
8	mass flowrate capacity, kg/s					
9	volume flowrate capacity, m^3/s					
10	air density, kg/m^3					
11	temperature, °C					
12	relative humidity, %					
13	static pressure @ inlet, mbar					
14	static pressure @ outlet, mbar					
15	performance:					
16	kW @ temperature (all losses included)					
17	fan speed, r/min					
18	static pressure rise across fan, mbar					
19	inlet damper/vane position					
20	discharge damper position					
21	fan static efficiency, %					
22	steam rate, kg/kW·h (turbine only)					

			rev
23	fan control:	drive:	
24	air supply	make type	
25	fan control, furnished by	rated kW r/min	
26	method: ☐ inlet damper ☐ outlet damper	electrical area classification:	
27	☐ inlet guide vanes ☐ variable speed	class group division	
28	starting method	power volts Ph Hz	
29	**Construction features:**		
30	housing:	bearings:	
31	material thickness, mm	☐ hydrodynamic ☐ anti-friction	
32	split for wheel removal yes no	type	
33	drains, number/size	lubrication	
34	access doors, number/size	mass flowrate coolant required m^3/s water @ °C.	
35	blades:	thermostatically cont. heaters ☐ yes ☐ no	
36	type	temperature detectors ☐ yes ☐ no	
37	number thickness, mm	vibration detectors ☐ yes ☐ no	
38	material		
39	hub:	speed detectors:	
40	☐ shrink fit ☐ keyed	☐ non-contact probe	
41	material	☐ speed switch	
42	shaft:	☐ other	
43	material	couplings:	
44	diameter @ brgs., mm	type	
45	shaft sleeves:	make model	
46	material	service factor	
47	shaft seals:	mount coupling halves	
48	type:	☐ fan	
49		☐ driver	
50	centrifugal force ωr^2, $kg \cdot m^2$	spacer ☐ yes ☐ number length, mm	
51	**Notes:** (all data on per unit basis):		
52			
53			

Fan data sheet	SI units		
	rev:	date:	sheet 2 of 2

Construction features (continued)

No.						rev
1	miscellaneous:					rev
2	common baseplate (fan driver)	silencer (inlet) (outlet)	inlet (screen) (filter)			
3	bearing pedestals/soleplates	evase	housing drain connection			
4	performance curves	vibration isolation	spark-resistant coupling guard			
5	sectional drawing	type	insulation clips			
6	outline drawing	special coatings	inspection access			
7	inlet boxes	control panel	heat shields			
8	noise attenuation:	masses, kg				
9	maximum allowable sound pressure level dB(A) @ m	fan	driver	base		
10	predicted sound pressure level dB(A) @ m	sound trunk				
11	attenuation method	evase				
12	furnished by	total shipping mass				
13	painting:	connections:				
14	manufacturer's standard		size	rating	orientation	
15		inlet				
16	shipment:	outlet				
17	domestic / export / export boxing required	drains				
18						
19	erection:					
20	assembled	tests:				
21	partly assembled	mechanical run-in (no load)				
22	outdoor storage over 6 months	witnessed performance				
23	applicable specifications:	rotor balance				
24		shop inspection				
25		assembly and fit-up check				
26						
27						
28	**Notes:**					
29	Items marked to be included in vendor scope of supply.					
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Sootblower data sheet	**SI units**		
	rev:	date:	sheet 1 of 1
Purchaser/owner:	**Item No.:**		
Service:	**Location:**		

						rev
1	**Operating data:**					rev
2	fuel oil type/relative molecular mass					
3	sulfur, mass fraction, %					
4	vanadium, mg/kg					
5	nickel, mg/kg					
6	ash, mass fraction, %					
7	lane location					
8	flue-gas temperature @ blower, maximum °C					
9	flue-gas pressure @ blower, maximum °C					
10	blowing medium					
11	**Utility data:**					
12						
13	steam ______ kPa @ ______ °C ______ kg/s per blower					
14						
15	air ______ kPa ______ m^3/s (N) per blower					
16						
17	power ______ volts ______ phase ______ Hz					
18						
19	**Layout data:**					
20	tube outside diameter, mm					
21	tube length, m					
22	tube spacing, (stag./in line), mm					
23	bank width, m					
24	no. of intermediate tube sheets					
25	lane dimension (minimum clearance), mm					
26	maximum cleaning radius, m					
27	extended surface type					
28	number of extended surface rows					
29	lining thickness, mm					
30	**Blower data:**					
31	manufacturer					
32	type					
33	model					
34	number required					
35	number of lanes (rows)					
36	number per lane					
37	arrangement					
38	operation					
39	control required					
40	control panel location (local or remote)					
41	driver type (man., pneumatic or electrical motor)					
42	electrical area classification					
43	motor starters classification					
44	motor: kW					
45	enclosure					
46	r/min					
47	lance travel speed					
48	head: material & rating					
49	wall box isolation					
50						
51						
52	**Notes:**					
53						
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Fired heater data sheet		**US Customary units**				
		rev:		date:	sheet 1 of 6	
Purchaser/owner:		**Item No.:**				
Service:		**Location:**				
1	unit:	* number required:				rev
2	manufacturer:	reference:				
3	type of heater:					
4	*total heater absorbed duty, Btu/h:					
5	**Process design conditions**					
6	*operating case					
7	heater section					
8	*service					
9	heat absorption, Btu/h					
10	*fluid					
11	*flowrate, lb/h					
12	*flowrate, b.p.d.					
13	*pressure drop, allowable (clean/fouled), psi					
14	pressure drop, calculated (clean/fouled), psi					
15	*avg. rad. sect. flux density, allow., Btu/h - ft^2					
16	avg. rad. sect. flux density, calc., Btu/h - ft^2					
17	max rad. sect. flux density, Btu/h - ft^2					
18	conv. sect. flux density (bare tube), Btu/h - ft^2					
19	*velocity limitation, ft/s					
20	process fluid mass velocity, lb/s - ft^2					
21	*maximum allow./calc.inside film temperature, °F					
22	*fouling factor, h - ft^2 - °F/Btu					
23	*coking allowance, in					
24	**Inlet conditions:**					
25	*temperature, °F.					
26	*pressure, (psia) (psig)					
27	*liquid flow, lb/h					
28	*vapour flow, lb/h					
29	*liquid gravity, (deg API) (sp. gr. @ 60 °F)					
30	*vapour molecular mass					
31	*viscosity, (liquid/vapour), cP					
32	*specific heat, (liquid/vapour), Btu/lb-°F					
33	*thermal conductivity, (liquid/vapour), Btu/h-ft-°F					
34	**Outlet conditions:**					
35	*temperature, °F.					
36	*pressure, (psia) (psig)					
37	*liquid flow, lb/h					
38	*vapour flow, lb/h					
39	*liquid gravity, (deg API) (sp. gr. @ 60 °F)					
40	*vapour relative molecular mass					
41	*viscosity, (liquid/vapour), cP					
42	*specific heat, (liquid/vapour), Btu/lb - °F					
43	*thermal conductivity, (liquid/vapour), Btu/h - ft -°F					
44	**Remarks and special requirements:**					
45	*distillation data or feed composition:					
46	short term operating conditions:					
47						
48	**NOTES:**					
49						
50						

Fired heater data sheet			US Customary units		
			rev:	date:	sheet 2 of 6

Combustion design conditions

1	operating case					rev
2	*type of fuel					
3	*excess air, percent					
4	calculated heat release (h_L), Btu/h					
5	fuel efficiency calculated, % (h_L)					
6	fuel efficiency guaranteed, % (h_L)					
7	radiation loss, % of heat release (h_L)					
8	flue-gas temperature leaving:	radiant section, °F				
9		convection section, °F				
10		air preheater, °F				
11	flue-gas quantity, lb/h					
12	flue-gas mass vel. through convection section, lb/s - ft^2					
13	draught	at arch, in H_2O				
14		at burners, in H_2O				
15	*ambient air temperature, efficiency calculation, °F					
16	*ambient air temperature, stack design, °F					
17	*altitude above sea level, ft					
18	volumetric heat release, (h_L), Btu/h - ft^3					
19	*emission limits:	ppmv (d) (corrected to 3% O_2)	NO_x:	CO:	SO_x	
20		lb/Btu . (h_L) (h_V)	UHC:	particulates:		

21	**Fuel characteristics:**						
22	*gas type		*liquid type		*other type		
23	*h_L	Btu/(lb) (scf)	*h_L	Btu/lb	*h_L	Btu/(scf) (lb)	
24	* h_V	Btu/(lb) (scf)	* h_V	Btu/lb	* h_V	Btu/(scf) (lb)	
25	*press. @ burner,	psig	*press. @ burner,	psi	*press. @ burner,	psi	
26	*temp. @ burner,	°F	*temp. @ burner,	°F	*temp. @ burner,	°F	
27	*molecular weight		*viscosity @ °F	cSt			
28			*atomizing steam temp.	°F			
29			*pressure,	psi			
30	component	mole %	component	mass fraction	component	%	
31							
32							
33							
34			*vanadium (ppm)				
35			*sodium (ppm)				
36			*sulfur				
37			*ash				

38	**Burner data:**				
39	manufacturer:	size/model No:		number:	
40	type:	location:		orientation:	
41	heat release per burner, Btu/h	design:	normal:	minimum:	
42	pressure drop across burner @ design heat release, in H_2O:				
43	distance burner centreline to tube centreline, horizontal, in:			vertical, in:	
44	distance burner centreline to unshielded refractory, horizontal, in:			vertical, in:	
45	pilot, type:	capacity, (Btu/h):		fuel:	
46	ignition method:				
47	flame detection, type:		number:		
48	**Notes:**				
49					
50					

Fired heater data sheet		US Customary units				
		rev:	date:	sheet 3 of 6		
Mechanical design conditions						
1	*plot limitations:	*stack limitations:				rev
2	*tube limitations:	*noise limitations:				
3	*structural design data: wind velocity:	*wind occurrence:				
4	snow load:	*seismic zone:				
5	*minimum/normal/maximum ambient air temperature, °F:	*relative humidity, %				
6	heater section:					
7	service:					
8	**Coil design:**					
9	*design basis: tube wall thickness (code or spec.)					
10	rupture strength (minimum or average)					
11	*stress-to-rupture basis, h					
12	*design pressure, elastic/rupture, psi					
13	*design fluid temperature, °F					
14	*temperature allowance, °F					
15	corrosion allowance, tubes/fittings, in					
16	hydrostatic test pressure, psi					
17	*post-weld heat treatment (yes or no)					
18	*percent of welds fully radiographed					
19	maximum (clean) tube metal temperature, °F					
20	design tube metal temperature, °F					
21	inside film coefficient, Btu/h ft^2-°F					
22	**Coil arrangement:**					
23	tube orientation: vertical or horizontal					
24	*tube material (specification and grade)					
25	tube outside diameter, in					
26	tube wall thickness, (minimum) (average), in					
27	number of flow passes					
28	number of tubes					
29	number of tubes per row (convection section)					
30	overall tube length, ft					
31	effective tube length, ft					
32	bare tubes: number					
33	total exposed surface, ft^2					
34	extended surface tubes: number					
35	total exposed surface, ft^2					
36	tube layout (in line or staggered)					
37	tube spacing, cent. to cent.: horiz. × diag. (or vert.)					
38	spacing tube cent. to furnace wall (min.), in					
39	corbels (yes or no)					
40	corbel width, in					
41	**Description of extended surface:**					
42	type: (studs) (serrated fins) (solid fins)					
43	material					
44	dimensions (height × diameter/thickness), in					
45	spacing (fins/in) (studs/plane)					
46	maximum tip temperature, (calculated), °F					
47	extension ratio (total area/bare area)					
48	**Plug type headers:**					
49	*type					
50	material (specification and grade)					
51	nominal rating					
52	*location (one or both ends)					
53	welded or rolled joint					
54	**Notes:**					
55						
56						

Fired heater data sheet			US Customary units			
			rev:	date:	sheet 4 of 6	
Mechanical design conditions (continued)						
1	heater section:					rev
2	service:					
3	**Return bends:**					
4	type					
5	material (specification and grade)					
6	nominal rating or schedule					
7	*location (f. b. = fire box, h. b. = header box)					
8	**Terminals and/or manifolds:**					
9	*type (bev. = bevelled, manif. = manifold, flg. = flanged)					
10	inlet: material (specification and grade)					
11	size/schedule or thickness					
12	number of terminals					
13	flange material (specification and grade)					
14	flange size and rating					
15	outlet: material (specification and grade)					
16	size/schedule or thickness					
17	number of terminals					
18	flange material (specification and grade)					
19	flange size and rating					
20	*manifold to tube connection (welded, extruded, etc.)					
21	manifold location (inside or outside header box)					
22	**Crossovers:**					
23	*welded or flanged					
24	*pipe material (specification and grade)					
25	pipe size/schedule or thickness					
26	*flange material					
27	flange size/rating					
28	*location (internal/external)					
29	fluid temperature, °F.					
30	**Tube supports:**					
31	location (ends, top, bottom)					
32	material (specification and grade)					
33	design metal temperature, °F					
34	thickness, in					
35	type and thickness of insulation, in					
36	anchor (material and type)					
37	**Intermediate tube supports:**					
38	material (specification and grade)					
39	design metal temperature, °F					
40	thickness, in					
41	spacing, ft					
42	**Tube guides:**					
43	location:					
44	material:					
45	type/spacing:					
46	**Header boxes:**					
47	location:	hinged door/bolted panel:				
48	casing material:	thickness, in:				
49	lining material:	thickness, in:				
50	anchor (material and type):					
51	**NOTES:**					
52						
53						
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Fired heater data sheet	US Customary units		
	rev:	date:	sheet 5 of 6

Mechanical design conditions (continued)

				rev
1	**Refractory design basis:**			
2	ambient temperature, °F:	wind velocity, mph/fps:	casing temperature, °F:	
3	**Exposed vertical walls:**			
4	lining thickness, in:	hot-face temperature, design/calculated, °F:		
5	wall construction:			
6				
7	anchor (material & type):			
8	casing material:	thickness, in:	temperature, °F:	
9	**Shielded vertical walls:**			
10	lining thickness, in:	hot-face temperature, design/calculated, °F.:		
11	wall construction:			
12				
13	anchor (material & type):			
14	casing material:	thickness, in:	temperature, °F:	
15	**Arch:**			
16	lining thickness, in:	hot-face temperature, design/calculated, °F:		
17	wall construction:			
18				
19	anchor (material and type):			
20	casing material:	thickness, in:	temperature, °F:	
21	**Floor:**			
22	lining thickness, in:	hot-face temperature, design/calculated, °F:		
23	floor construction:			
24				
25	casing material:	thickness, in:	temperature, °F:	
26	minimum floor elevation, ft:	free space below plenum, ft:		
27	**Convection section:**			
28	lining thickness, in:	hot-face temperature, design/calculated, °F:		
29	wall construction:			
30				
31	anchor (material and type):			
32	casing material:	thickness, in:	temperature, °F:	
33	**Internal wall:**			
34	type:	material:		
35	dimension, height/width:			

36	**Ducts:**	**Flue gas:**			**Combustion air:**		
37	location:	breeching					
38	size, ft or net free area, ft^2:						
39	casing material:						
40	casing thickness, in:						
41	lining: internal/external						
42	thickness, in						
43	material						
44	anchor (material and type)						
45	casing temperature, °F						

46	**Plenum chamber (air):**			
47	casing material:	thickness, in:	size, ft:	
48	lining material:		thickness, in:	
49	anchor (material & type):			
50	**Notes:**			
51				
52				

Fired heater data sheet			US Customary units			
			rev:	date:	sheet 6 of 6	

Mechanical design conditions (continued)

1	**Stack or stack stub:**					
2	number:	self-supported or guyed		location:		
3	casing material:	*corrosion allow., in:		minimum thickness, in:		
4	inside metal diameter, ft:	height above grade, ft:		stack length, ft:		
5	lining material:			thickness, in:		
6	anchor (material and type)					
7	extent of lining:	internal or external:				
8	design flue-gas velocity, ft/s:	flue-gas temp., °F:				
9	**Dampers:**					
10	location					
11	type (control, tight shut-off, etc.)					
12	material: blade					
13	material: shaft					
14	multiple/single leaf					
15	provision for operation (man. or auto.)					
16	type of operator (cable or pneumatic)					
17	**Miscellaneous:**					
18	platforms: location	number	width	length/arc	stairs/ladder	access from
19						
20						
21						
22						
23						
24	type of flooring:					
25	doors:		number	location	size	bolted/hinged
26	access					
27						
28	observation					
29						
30	tube removal					
31						
32	instrument connections:			number	size	type
33	flue-gas/combustion air temperature					
34	flue-gas/combustion air pressure					
35	flue-gas sample					
36	snuffing steam/purge					
37	O_2 analyser					
38	CO or NO_x analyser					
39	vents/drains					
40	process fluid temperature					
41	tube skin thermocouples					
42						
43						
44	painting requirements:					
45	internal coating:					
46	galvanizing requirements:					
47	are painters trolley and rail included:					
48	special equipment:	sootblowers:				
49		air preheater:				
50		fan(s):				
51		other:				
52	**Notes:**					
53						
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Burner data sheet		**US Customary units**		
		rev:	date:	sheet 1 of 3
Purchaser/owner:		**Item No.:**		
Service:		**Location:**		
1	**General data**:			rev
2	type of heater			
3	altitude above sea level, ft			
4	air supply:			
5	ambient/preheated air/gas turbine exhaust			
6	temperature, °F (min./max./design)			
7	relative humidity. %			
8	draught type: forced/natural/induced			
9	draught available: across burner, in H_2O			
10	draught available: across plenum, in H_2O			
11	required turndown			
12	burner wall lining thickness, in			
13	heater casing thickness, in			
14	firebox height, ft			
15	tube circle diameter, ft			
16	**Burner data:**			
17	manufacturer			
18	type of burner			
19	model/size			
20	direction of firing			
21	location (roof/floor/sidewall)			
22	number required			
23	minimum distance burner centreline, ft:			
24	to tube centreline (horizontal/vertical)			
25	to adjacent burner centreline (horizontal/vertical)			
26	to unshielded refractory (horizontal/vertical)			
27	burner circle diameter, ft			
28	pilots:			
29	number required			
30	type			
31	ignition method			
32	fuel			
33	fuel pressure, psi.			
34	capacity, Btu/h			
35	**Operating data:**			
36	fuel			
37	heat release per burner, Btu/h (h_L)			
38	design			
39	normal			
40	minimum			
41	excess air @ design heat release, (%)			
42	air temperature, °F			
43	draught (air pressure) loss, in H_2O			
44	design			
45	normal			
46	minimum			
47	fuel pressure required, psig			
48	flame length @ design heat release, ft			
49	flame shape (round, flat, etc.)			
50	atomizing medium/oil ratio, lb/lb			
51	**Notes:**			
52				
53				
54				
55				

Burner data sheet		US Customary units			
		rev:	date:	sheet 2 of 3	
Gas fuel characteristics					
1	fuel type				rev
2	heating value (h_L), (Btu/scf) (Btu/lb)				
3	relative molecular mass (air = 1,0)				
4	molecular mass				
5	fuel temperature @ burner, °F.				
6	fuel pressure: available @ burner, psi.				
7	fuel gas composition (mole %)				
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20	total				
21	**Liquid fuel characteristics**				
22	fuel type				
23	heating value (h_L), Btu/lb.				
24	specific gravity/°API				
25	h/c ratio (by mass)				
26	viscosity, @ °F, cSt				
27	viscosity, @ °F, cSt				
28	vanadium, ppm				
29	potassium, ppm				
30	sodium, ppm				
31	nickel, ppm				
32	fixed nitrogen, ppm				
33	sulfur, % wt.				
34	ash, % wt.				
35	water, % wt.				
36	distillation: ASTM initial boiling point, °F				
37	ASTM mid-point, °F				
38	ASTM end-point, °F				
39	fuel temperature @ burner, °F				
40	fuel pressure available @ burner, psi.				
41	atomizing medium: air/steam/mechanical				
42	temperature, °F				
43	pressure, psi				
44	**Notes:**				
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Burner data sheet			US Customary units		
			rev:	date:	sheet 3 of 3
Miscellaneous					
1	burner plenum:	common/integral			rev
2		material			
3		plate thickness, in			
4		internal insulation			
5	inlet air control:	damper or registers			
6		mode of operation			
7		leakage, %			
8	burner tile:	composition			
9		minimum service termperature, °F			
10	noise specification				
11	attenuation method				
12	painting requirements				
13	ignition port:	size/number			
14	sight port:	size/number			
15	flame detection:	type			
16		number			
17	scanner connection:	size/number			
18	safety interlock system for atomizing medium & oil				
19	performance test required (yes or no)				
20	**Emission limits:**				
21	firebox bridgewall temperature, °F				
22	NO_x	* ppmv (d) or lb/Btu (h_L) (h_H)			
23	CO	* ppmv (d) or lb/Btu (h_L) (h_H)			
24	UHC	* ppmv (d) or lb/Btu (h_L) (h_H)			
25	particulates	* ppmv (d) or lb/Btu (h_L) (h_H)			
26	SO_x	* ppmv (d) or lb/Btu (h_L) (h_H)			
27					
28	*corrected to 3% O_2 (dry basis @ design heat release)				
30	NOTE 1 At design conditions, minimum of 90% of the available draught with air register fully open shall be utilized across the burner. In addition, a minimum of 75% of the air side pressure drop with air registers fully open shall be utilized across burner throat.				
31					
32					
33	NOTE 2 Vendor to guarantee burner flame length.				
34	NOTE 3 Vendor to guarantee excess air, heat release and draught loss across burner.				
35					
36					
37					
38					
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Air preheater data sheet		US Customary units			
		rev:	date:	sheet 1 of 2	
Purchaser/owner:		**Item No.:**			
Service:		**Location:**			
1	manufacturer:				rev
2	model:				
3	number required:				
4	heating surface, ft^2				
5	mass, lb				
6	approximate dimensions: (h x w x l) ft				
7	**Performance data**				
8	operating case				
9					
10	air side: flowrate entering, lb/h				
11	inlet temperature, °F				
12	outlet temperature, °F				
13	pressure drop: allowable, in H_2O				
14	pressure drop: calculated, in H_2O				
15	heat absorbed, Btu/h				
16	flue-gas side: flowrate, lb/h				
17	inlet temperature, °F				
18	outlet temperature, °F				
19	pressure drop: allowable, in H_2O				
20	pressure drop: calculated, in H_2O				
21	heat exchanged, Btu/h				
22	air bypass rate, lb/h				
23	total air flowrate to burners, lb/h				
24	mix air temperature, °F				
25	flue-gas composition, mole % (O_2/N_2/H_2O/CO_2/SO_x)				
26	flue-gas specific heat, Btu/lb - °F				
27	flue-gas acid dew point temperature, °F				
28	minimum metal temperature: allowable, °F				
29	minimum metal temperature: calculated, °F				
30	**Miscellaneous:**				
31	minimum ambient air temperature, °F				
32	site elevation above sea level, ft				
33	relative humidity				
34	external cold air bypass (yes/no)				
35	cold end thermocouples (yes/no) number required				
36	access doors: number/size/location				
37	insulation (internal/external):				
38	cleaning medium: steam or water				
39	pressure, psi				
40	temperature, °F				
41					
42	**Mechanical design:**				
43	design flue-gas temperature, °F				
44	design pressure differential, in H_2O				
45	seismic factor				
46	painting requirements				
47	leak test				
48	structural wind load, psf				
49	air leakage (guaranteed maximum), %				
50					
52	**Notes:** (all data on per unit basis)				
53					
54					

Air preheater data sheet				US Customary units			
				rev:	date:	sheet 2 of 2	
Construction data							
1	I	cast iron:					rev
2		number of passes					
3		number of tubes per block					
4		number of blocks					
5		type of surface					
6		tube material					
7		tube thickness, in					
8		glass block (yes/no)					
9		number of glass tubes					
10		air crossover duct:	number				
11			bolted/welded				
12			supplied with clips				
13		water wash:	yes/no				
14			type (off-line or on-line)				
15			location				
16							
17	II	plate type:					
18		number of passes					
19		number of plates per block					
20		number of blocks					
21		plate thickness, in					
22		width of air channel, in					
23		width of flue-gas channel, in					
24		air-side rib pitch, in					
25		flue-gas-side rib pitch, in					
26		material:	plate				
27			rib				
28			frame				
29		air crossover duct:	number				
30			bolted/welded				
31			supplied with clips				
32		water wash:	yes/no				
33			type (off-line or on-line)				
34			location				
35							
36	III	heat pipe:					
37		number of tubes					
38		tubes OD/wall thickness, in					
39		tube material					
40		tubes per row					
41		number of rows					
42		tube pitch (square/triangular), in					
43				air side	gas side		
44		fins: type					
45		height × thickness × No. /in					
46		material					
47		effective length, ft.					
48		heating surface, ft^2					
49		maximum allowable soak temperature, °F					
50		sootblower:	yes/no				
51			type				
52			location				
53	**Notes:**						
54							
55							
56							
57							

Fan data sheet	US Customary units		
	rev:	date:	sheet 1 of 2
Purchaser/owner:	**Item No.:**		
Service:	**Location:**		

						rev
1	fan manufacturer:	model/size:		arrangement:		
2	service:	number required:				
3	drive system:	fan rotation from driven end		cw	ccw	
4	gas handled:	molecular weight:				
5	site elevation, ft:	fan location:				
6	**Operating Conditions:**					
7	operating condition/case:	design	test block	other conditions		
8	capacity, lb/h					
9	capacity, acfm					
10	density, lb/ft^3					
11	air temperature, °F					
12	relative humidity, %					
13	static pressure @ inlet, inches H_2O					
14	static pressure @ outlet, inches H_2O					
15	performance:					
16	BHP @ temperature (all losses included)					
17	fan speed, r/min					
18	static pressure rise across fan, inches H_2O					
19	inlet damper/vane position					
20	discharge damper position					
21	fan static efficiency, %					
22	steam rate, lb/HP·h (turbine only)					
23	fan control:	drive				
24	air supply	make		type		
25	fan control, furnished by	rated HP		r/min		
26	method: inlet damper / outlet damper	electrical area classification				
27	inlet guide vanes / variable speed	class	group	Division		
28	starting method	power	volts	ph	Hz	
29	**Construction Features:**					
30	housing:	bearings:				
31	material / thickness, in	hydrodynamic		anti-friction		
32	split for wheel removal / yes / no	type				
33	drains, number/size	lubrication				
34	access doors, number/size	coolant required	gpm water @	°F		
35	blades:	thermostatically cont. heaters		yes	no	
36	type	temperature detectors		yes	no	
37	number / thickness, in	vibration detectors		yes	no	
38	material					
39	hub:	speed detectors:				
40	shrink fit / keyed	non-contact probe				
41	material	speed switch				
42	**Notes**: (all data on per unit basis):					
43						
44						

Fan data sheet			US Customary units		
			rev:	date:	sheet 2 of 2

Construction features (continued)

1	shaft:		other	
2	material	couplings:		
3	diameter @ brgs., in	type		
4	shaft sleeves:	make	model	
5	material	service factor		
6	shaft seals:	mount coupling halves		
7	type:		fan	
8			driver	
9	centrifugal force ωr^2, lb-ft^2	spacer	yes / no / length, in	

10	miscellaneous:			rev
11	common baseplate (fan driver)	silencer (inlet) (outlet)	inlet (screen) (filter)	
12	bearing pedestals/soleplates	evase	housing drain connection	
13	performance curves	vibration isolation	spark-resistant coupling guard	
14	sectional drawing	type	insulation clips	
15	outline drawing	special coatings	inspection access	
16	inlet boxes	control panel	heat shields	

17	noise attenuation:			mass, lb.		
18	maximum allowable sound pressure level	dB(A) @	ft	fan / driver / base		
19	predicted sound pressure level	dB(A) @	ft.	sound trunk		
20	attenuation method			evase		
21	furnished by			total shipping mass		
22	painting:			connections:		
14	manufacturers standard			size	rating	orientation
15				inlet		
16	shipment:			outlet		
17	domestic / export / export boxing required			drains		
18						
19	erection:					
20	assembled			tests:		
21	partly assembled			mechanical run-in (no load)		
22	outdoor storage over 6 months			witnessed performance		
23	applicable specifications:			rotor balance		
24				shop inspection		
25				assembly and fit-up check		
26						
27						

28	**Notes:**
29	Items marked to be included in vendor scope of supply.
30	
31	
32	
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Sootblower data sheet		US Customary units		
		rev:	Date:	sheet 1 of 1
Purchaser/owner:		**Item No.:**		
Service:		**Location:**		

			rev
1	**Operating data:**		
2	fuel oil type/specific gravity or °API		
3	sulfur, mass fraction (%)		
4	vanadium, ppm (mass)		
5	nickel, ppm (mass)		
6	ash, mass fraction (%)		
7	lane location		
8	flue-gas temperature @ blower, maximum °F		
9	flue-gas pressure @ blower, maximum °F		
10	blowing medium		
11	**Utility data:**		
12			
13	steam ______ psi @ ______ °F ______ lb/h per blower		
14			
15	air ______ psi ______ scfm per blower		
16			
17	power ______ volts ______ phase ______ Hz		
18			
19	**Layout data:**		
20	tube outside diameter, in		
21	tube length, ft		
22	tube spacing, (stag./in line), in		
23	bank width, ft		
24	number of intermediate tube sheets		
25	lane dimension (minimum clearance), in		
26	maximum cleaning radius, ft		
27	extended surface type		
28	number of extended surface rows		
29	lining thickness, in		
30	**Blower data:**		
31	manufacturer		
32	type		
33	model		
34	number required		
35	number of lanes (rows)		
36	number per lane		
37	arrangement		
38	operation		
39	control required		
40	control panel location (local or remote)		
41	driver type (man., pneumatic or electrical motor)		
42	electrical area classification		
43	motor starters classification		
44	motor: HP		
45	enclosure		
46	r/min		
47	lance travel speed		
48	head: material & rating		
49	wall box isolation		
50			
51			
52	**Notes:**		
53			
54			

Annex B
(informative)

Purchaser's checklist

This checklist may be used to indicate the purchaser's specific requirements where this International Standard provides a choice or specifies that a decision shall be made. These items are indicated by a bullet (●) in this International Standard.

Subclause	Item	Requirement
4.2	Pressure design code:	________ ________ ________
4.3	Applicable local rules and regulations:	________ ________
5.1.4	Number of copies of referenced drawings and data required:	________ ________
5.3.3 h)	Decoking procedures required?	Yes No
5.2 e) 5.4 f)	Noise data sheets provided?	Yes No
5.4 a)	As-built data sheets and drawings required?	Yes No
6.3.2	Space required for future sootblowers, water washing, etc.?	Yes No
6.3.3	Sootblowers to be provided?	Yes No
7.2.1	Acceptable extended surface type: studs solid fins segmented fins	 Yes No Yes No Yes No ________
9.1.4	Inspection openings required? If yes, are terminals flanges acceptable?	Yes No Yes No
9.1.6	Low-point drains required? High-point vents required?	Yes No Yes No
10.3.2	Tube support corrosion protection: 50Cr-50Ni material Refractory coating	 Yes No Yes No
11.3.7	Anchor fixing method	________
11.4.17	Protective coating of casing, ceramic fibre construction	________
11.5.7	Protective coating of casing, back-up insulation	________
12.1.1	Structural design code:	________ ________
12.2.5	Locations for future platforms, ladders and stairways:	________ ________
12.2.7	Fireproofing required?	Yes No

Subclause	Item	Requirement
12.3.1.2	Header box closures: hinged doors bolted panels	 Yes No Yes No
12.3.1.4	Horizontal partitions required in convection-section header boxes?	Yes No
12.4.4	Platform decking requirements: checkered plate open grating	 Yes No Yes No
12.5.1	Acceptable low temperature materials:	________
13.1.2	Codes for stacks, ducts and breeching: or Methods in annex H to be used?	________ Yes No
13.2.2	Bolting permitted for stack assembly?	Yes No
13.5.3 c)	Acceptable aerodynamic devices: helical strakes vertical strakes staggered vertical plates	 Yes No Yes No Yes No
14.1.8	Single burner with multiple guns acceptable?	Yes No
14.1.10 d)	Minimum main fuel rate during cold burner light-off:	________
14.1.17	Required heater capacity during forced-draught outage and continued operation on natural draught.	________ ________
14.1.22	On-stream removal of complete burner parts or assembly is required?	Yes No
14.2.1	Acceptable sootblower type: retractable automatic sequential	 Yes No Yes No Yes No
14.4.5	Location of control dampers Position on failure:	 Open Close
15.1.3.5	Additional flue-gas sampling connections:	________
15.2.1	Crossover thermowell connections required?	Yes No
15.2.2	Outlet thermowell connections required?	Yes No
15.3.2.2	Water washing required? radiant section convection section	 Yes No Yes No
15.4.1	Tube skin themocouples required?	Yes No
16.1.1	Site receiving and handling limitations:	________ ________
16.2.1 f)	Charpy impact test requirements:	________ ________

Subclause	Item	Requirement
16.3.1	Acceptable welding processes for coil fabrication:	________ ________ ________ ________
16.3.3	Acceptable purge gases:	________ ________
16.4.3	Galvanizing of handrails etc.? Bolt protection: galvanizing zinc-coating	Yes No Yes No Yes No
17.1.3	Pre-inspection meetings required prior to the start of fabrication?	Yes No
17.3.1	Positive materials identification (PMI) required?	Yes No
17.3.2 c)	Radiography of critical sections required?	Yes No
17.3.3	Sampling plan for dimensional checks of cast radiant tube supports, hangers and guides:	________ ________
17.3.4 c)	Sampling quantities and degree of coverage for radiography of cast return bends and pressure fittings:	________ ________
17.5.1.2	Is pneumatic pressure testing acceptable instead of hydrostatic?	Yes No
17.5.4.2	PMI requirements:	________ ________
E.2.1.4	Electrical area classification for fired heater equipment/ system:	________ ________
E.2.1.7	Weather and environmental requirements for outdoor installation:	________ ________
E.2.2.1	Corrosion allowance required for fan scroll and housing?	Yes No
E.2.5.2	Blade design	________ ________
E.2.5.8	Corrosion-resistant shaft sleeves required for ID fans?	Yes No
E.2.7.4	Rotor response analysis required? To be confirmed by test-stand data?	Yes No Yes No
E.2.8.3	Mechanical run test required?	Yes No
E.2.11.1.2	Corrosive agents in the flue gas or environment, affecting fan materials selection:	________ ________ ________
E.2.11.3	Alternative notch-toughness requirements for fans:	________ ________ ________

Subclause	Item	Requirement
E.3.1	Accessories to be supplied by fan vendor	__________ __________
E.3.2.1	Fan driver type:	__________ __________
E.3.2.2	Process variations for fan sizing:	__________ __________ __________
E.3.3.1.2	Fan vendor required to review overall control system for compatibility?	Yes No
E.3.4.2.1	Type and source of control signal, its sensitivity and range, and the equipment scope to be furnished by the vendor:	__________ __________ __________ __________ __________ __________
E.3.4.3.1	Damper blades: parallel opposed	 Yes No Yes No
E.3.4.3.2	Fan vendor to state maximum expected leakage through closed dampers and vanes?	Yes No
E.3.6.2.2	Type of insulation and jacketing	__________ __________
E.4.1.6 a)	Shop fit-up and assembly of fan, drivers and other auxiliaries required prior to shipment?	Yes No
E.4.1.6 c)	Hardness testing required?	Yes No
E.4.2.1	Fan testing requirements:	_____ _____ _____ _____
E.4.3.1	Equipment to be specially prepared for six months of outdoor storage?	Yes No
E.4.3.2	Shipping preparation requirements.	__________ __________

Annex C
(informative)

Proposed shop assembly conditions

SHOP ASSEMBLY CONDITIONS

SERVICE	______	EQUIPMENT NO.	______
UNIT	______	PLANT LOCATION	______
TYPE	______	NO. REQUIRED	______
OWNER	______	REFERENCE NO.	______
PURCHASER	______	REFERENCE NO.	______
VENDOR	______	REFERENCE NO.	______
DATE	______	PAGE ___1___OF	______

DEGREE OF ASSEMBLY

Complete Assembly (Number of sections)	Radiant	Convection
Boxes:		
1. Refractory only	______	______
2. With anchors only	______	______
Panels:		
3. With tubes and refractory installed	______	______
4. With refractory only	______	______
5. With anchors only	______	______
Coils:		
6. Number of coil assemblies	______	______
7. Number of hairpins, canes, tubes	______	______
8. Field welds, number/size	______	______

Number of pieces:	Lined	Unlined	
		With anchors	Without anchors
9. Breeching	______	______	______
10. Flue-gas ducts	______	______	______
11. Combustion air ducts	______	______	______
12. Header boxes	______	______	______
13. Plenum chamber	______	______	______
14. Stack	______	______	______

Installation:	Shop-installed	Field-installed
15. Tube supports	______	______
16. Floor refractory	______	______
17. Header boxes	______	______
18. Plenum chambers	______	______
19. Bridgewall	______	______
20. Dampers	______	______
21. Cages to ladders	______	______
22. Platform flooring to framing	______	______
23. Platform support clips to casing	______	______
24. Handrails, midrails and toeplates to posts	______	______
25. Stair treads to stringers	______	______
26. Doors	______	______
27. Tube-skin thermocouples	______	______
28. Internal coatings	______	______
29. Burners	______	______
30. Sootblowers	______	______

SERVICE ____________	EQUIPMENT NO. ____________

DEGREE OF ASSEMBLY (continued)

Air heater:
31. ____________
32. ____________
33. ____________
34. ____________
35. ____________
36. ____________
37. ____________
38. ____________
39. ____________
40. ____________

Fans:
1. ____________
2. ____________
3. ____________

Drivers:
4. ____________
5. ____________
6. ____________

Other:
7. ____________
8. ____________
9. ____________

ESTIMATED SHIPPING MASSES AND DIMENSIONS

10. Total heater mass, tonnes (long tons) ____________
11. Total, ladders, stairs, platform mass, tonnes (long tons) ____________
12. Total stack mass, tonnes (long tons) ____________
13. Maximum radiant section mass, tonnes (long tons) ____________
14. Maximum radiant-section dimensions, length × width × height, m (ft) ____________
15. Maximum convection section mass, tonnes (long tons) ____________
16. Maximum convection section dimensions, length × width × height, m (ft) ____________

Annex D
(normative)

Stress curves for use in the design of tube support elements

D.1 General

This annex provides stress curves that shall be used in the design of tube support elements. The following stress curves are provided:

a) one-third of the ultimate tensile strength;

b) two-thirds of the yield strength (0,2 % offset);

c) 50 % of the average stress required to produce 1 % creep in 10 000 h;

d) 50 % of the average stress required to produce rupture in 10 000 h.

Some of the stresses listed in items a) through d) were not available for carbon steel castings or plate or for 50Cr-50Ni-Nb castings. The stress curves were plotted from data gathered over normal design ranges. All of the materials are suitable for application at lower temperatures.

D.2 Casting factor

For cast materials, the stresses shown in Figures D.1 through D.13 are actual stresses based on published data accepted by the industry. A casting-factor multiplier of 0,8 shall be applied to the allowable stress value in the calculation of the minimum thickness.

D.3 Minimum cross-sections

If good foundry practice or casting methods or tolerances require the use of a cross-section heavier than that based on the calculation specified in D.2 or the stress curves shown in Figures D.1 through D.13, the governing thickness shall be specified.

D.4 Maximum design temperatures

The maximum design temperatures shown in Figures D.1 through D.13 were obtained from Table 8 and are based on resistance to oxidation, except for the maximum design temperatures shown in Figures D.10 and D.12 (Types 309H and 310H plate), which are based on available stress data. The stress curves for some materials extend beyond the maximum design temperature because of the materials' possible use, with high oxidation rates, at higher temperatures.

D.5 Corrosion resistance

ASTM A 560, Grade 50Cr-50Ni-Nb, material is generally selected for its resistance to vanadium attack; however, its resistance diminishes at temperatures above 870 °C (1 600 °F).

D.6 Proprietary alloys

Many low-chromium alloys, alloy cast iron and high-chromium nickel alloys are proprietary. The allowable stresses to be used for the design of castings that would use these materials (that are not included in Table 8) shall therefore be obtained from the supplier and shall be subject to the agreement of the purchaser.

D.7 Stress curves

All the stress curves in Figures D.1 through D.13 are based on published data. Apparent anomalies in the shapes of the curves reflect the actual data points used to construct the curves.

D.8 Data sources

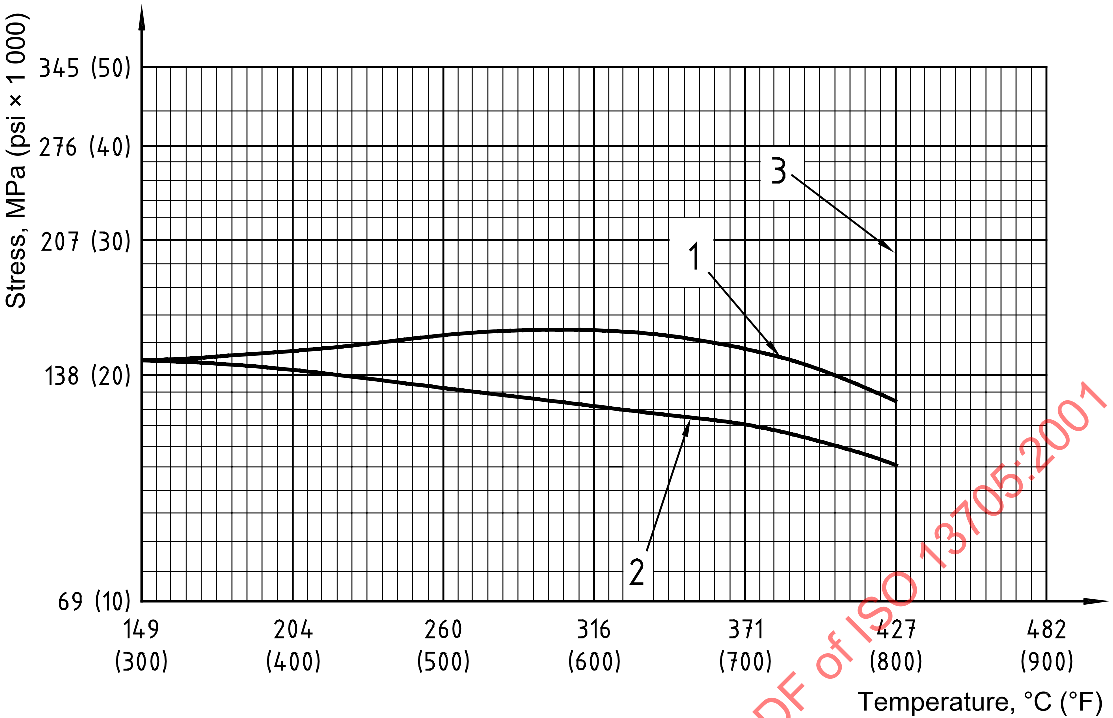
Table D.1 lists the sources of the stress data presented in Figures D.1 through D.13.

Table D.1 — Sources of data presented in Figures D.1 through D.13

Figure	Material	Curve	Data source[a]
D.1	Carbon steel castings	Tensile strength Yield strength	SFSA Steel Castings Handbook SFSA Steel Castings Handbook
D.2	Carbon steel plate	Tensile strength Yield strength	ASTM DS 11S1 ASTM DS 11S1
D.3	2¼Cr-1Mo castings	Tensile strength Yield strength Rupture stress Creep stress	ASTM DS 6 ASTM DS 6S2 ASTM DS 6S2 ASTM DS 6S2
D.4	2¼Cr-1Mo plate	Tensile strength Yield strength Rupture stress Creep stress	ASTM DS 6S2 ASTM DS 6S2 ASTM DS 6S2 ASTM DS 6S2
D.5	5Cr-½Mo castings	Tensile strength Yield strength Rupture stress Creep stress	ASTM DS 6 ASTM DS 58 ASTM DS 58 ASTM DS 58
D.6	5Cr-½Mo plate	Tensile strength Yield strength Rupture stress Creep stress	ASTM DS 58 ASTM DS 58 ASTM DS 58 ASTM DS 58
D.7	19Cr-9Ni castings	Tensile strength Yield strength Rupture stress Creep stress	ASM *Metals Handbook* ASM *Metals Handbook* ASM *Metals Handbook* ASM *Metals Handbook*
D.8	Type 304H plate	Tensile strength Yield strength Rupture stress Creep stress	ASTM DS 5S2 ASTM DS 5S2 ASTM DS 5S2 ASTM DS 5S2
D.9	25Cr-12Ni castings	Tensile strength Yield strength Rupture stress Creep stress	ASM *Metals Handbook* ASM *Metals Handbook* ASM *Metals Handbook* ASM *Metals Handbook*
D.10	Type 309H plate	Tensile strength Yield strength Rupture stress Creep stress	ASTM DS 5 ASTM DS 5 ASTM DS 5 ASTM DS 5
D.11	25Cr-20Ni castings	Tensile strength Yield strength Rupture stress Creep stress	ASM *Metals Handbook* ASM *Metals Handbook* ASM *Metals Handbook* ASM *Metals Handbook*
D.12	Type 310H plate	Tensile strength Yield strength Rupture stress Creep stress	ASTM DS 5 ASTM DS 5 ASTM DS 5 ASTM DS 5
D.13	50Cr-50Ni-Nb castings	Rupture stress Creep stress	IN-657[b] IN-657[b]

a See Bibliography.

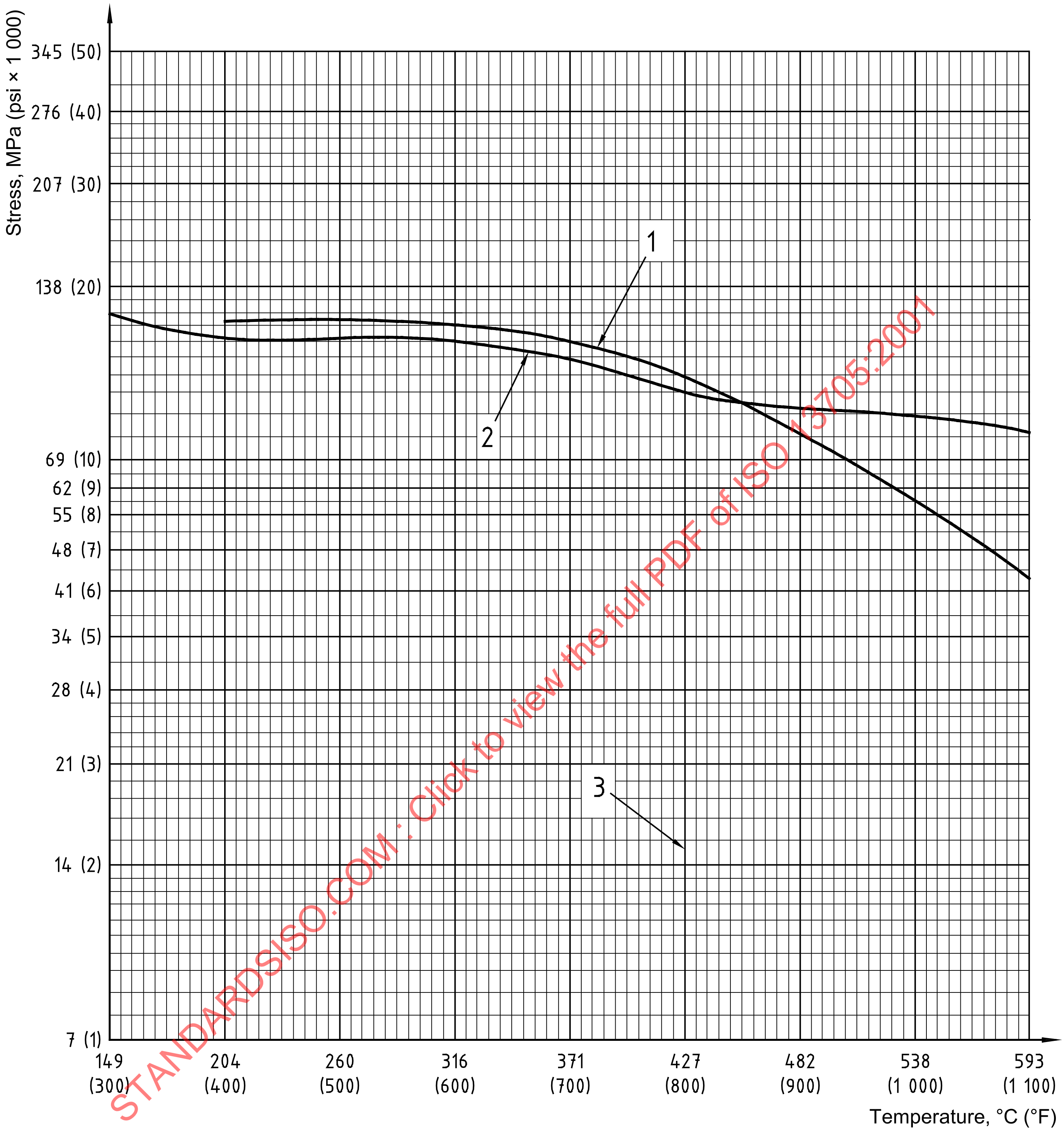
b IN-657, *Cast Nickel-Chromium-Niobium Alloy for Service Against Fuel-Ash Corrosion - Engineering Properties*, Inco Alloy Products Ltd., Wiggin Street, Birmingham B16 0AJ, UK.



Key

1 1/3 tensile strength
2 2/3 yield strength
3 Maximum design temperature

Figure D.1 — Carbon steel castings: ASTM A 216, Grade WCB



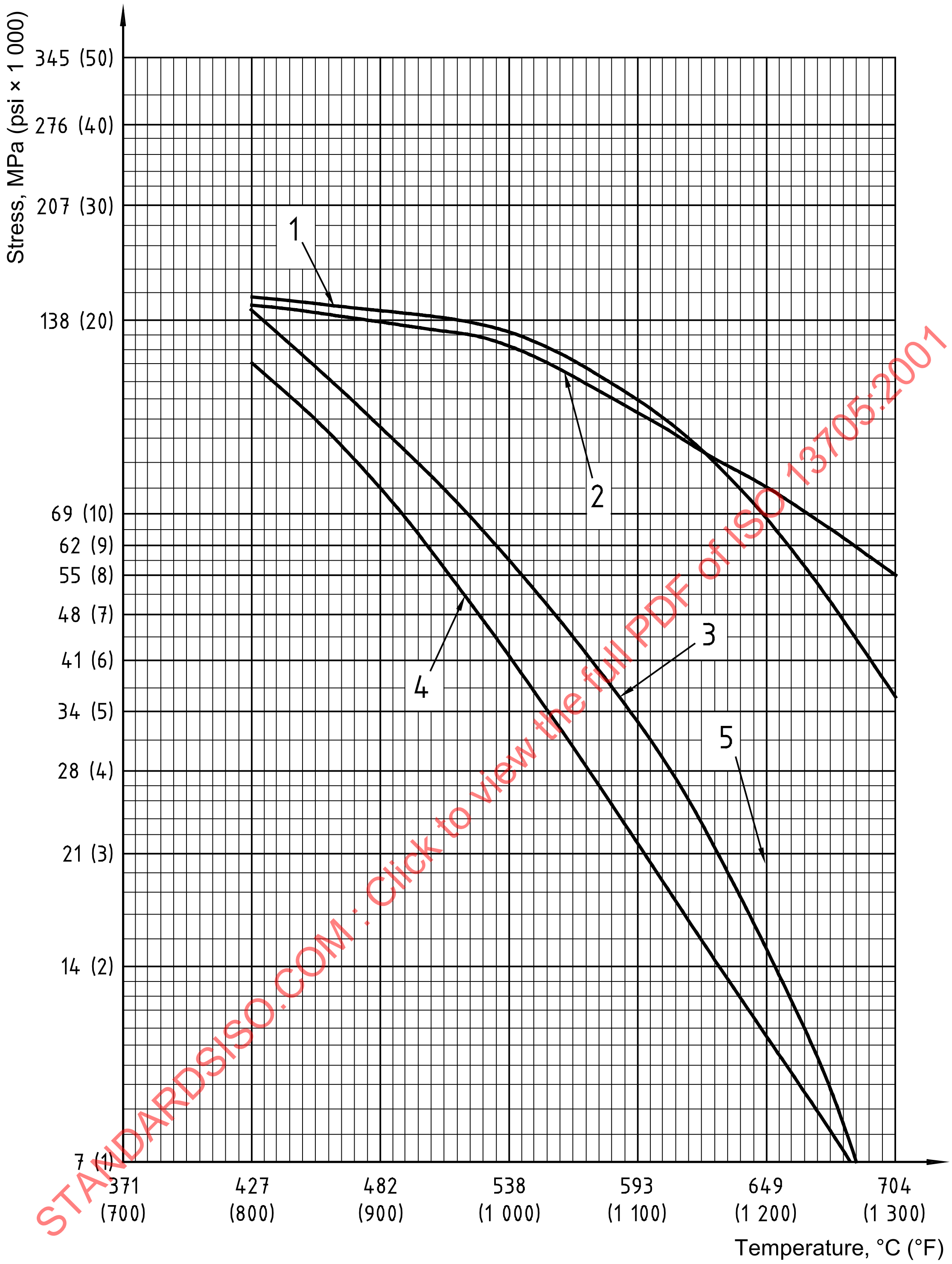
Key

1 1/3 tensile strength

2 2/3 yield strength

3 Maximum design temperature

Figure D.2 — Carbon steel plate: ASTM A 283, Grade C



Key

1 2/3 yield strength

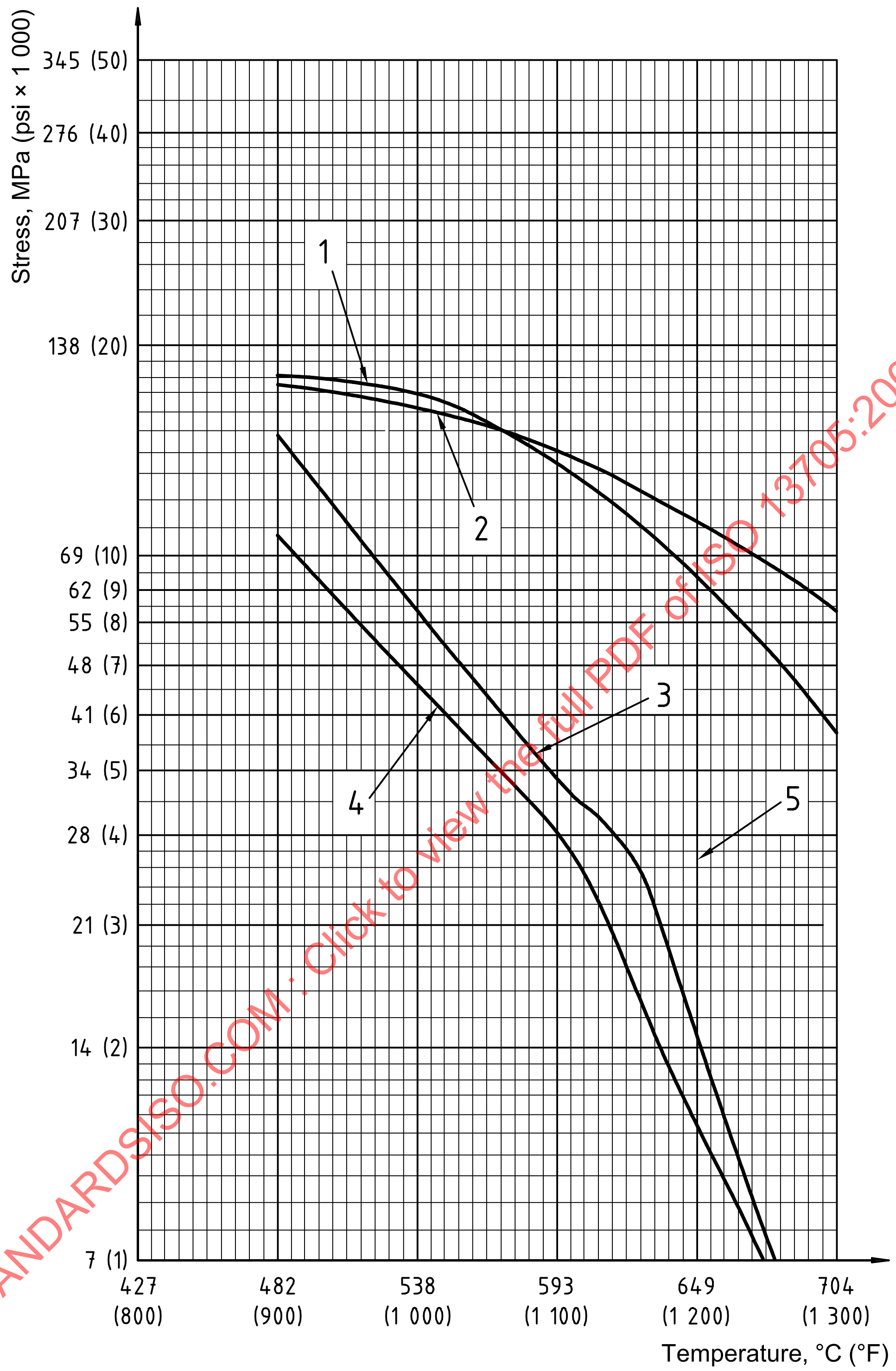
2 1/3 tensile strength

3 50 % of rupture in 10 000 h

4 50 % of 1 % creep in 10 000 h

5 Maximum design temperature

Figure D.3 — 2 1/4 Cr-1Mo castings: ASTM A 217, Grade WC9



Key

1 2/3 yield strength

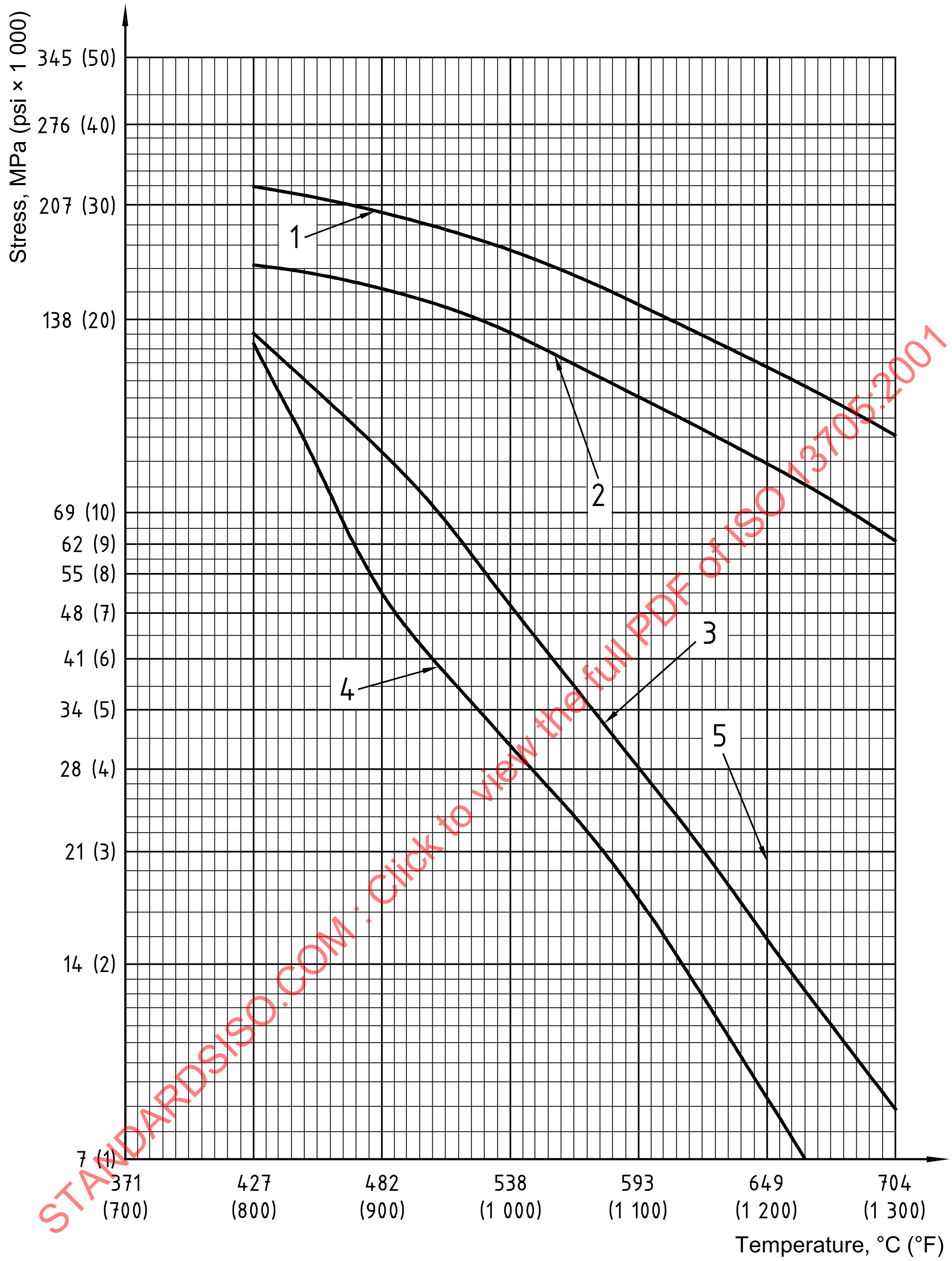
2 1/3 tensile strength

3 50 % of rupture in 10 000 h

4 50 % of 1 % creep in 10 000 h

5 Maximum design temperature

Figure D.4 — 2 1/4 Cr-1Mo plate: ASTM A 387, Grade 22, Class 1



Key

1 2/3 yield strength

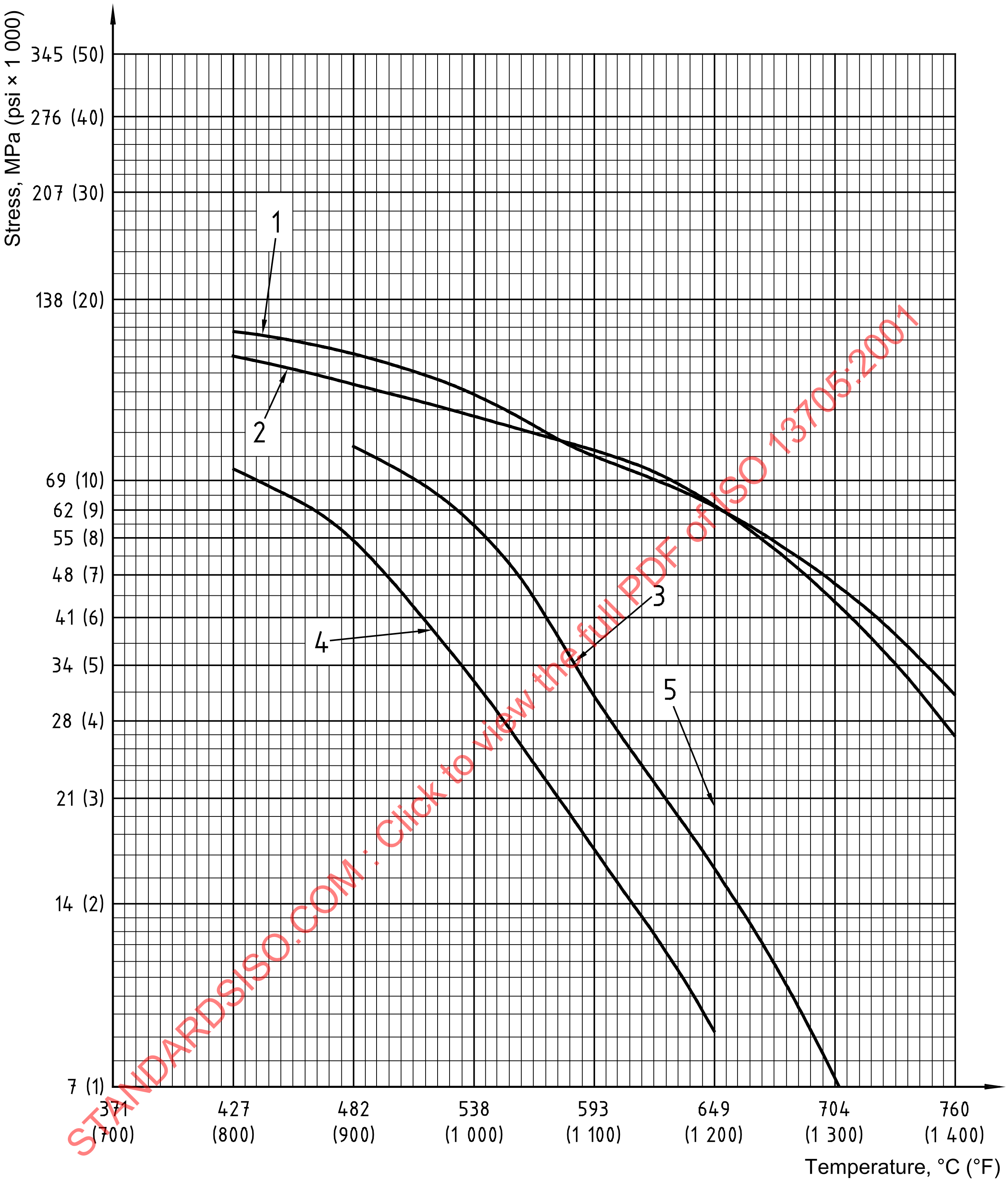
2 1/3 tensile strength

3 50 % of rupture in 10 000 h

4 50 % of 1 % creep in 10 000 h

5 Maximum design temperature

Figure D.5 — 5Cr-1/2Mo castings: ASTM A 217, Grade C5



Key

1 1/3 tensile strength

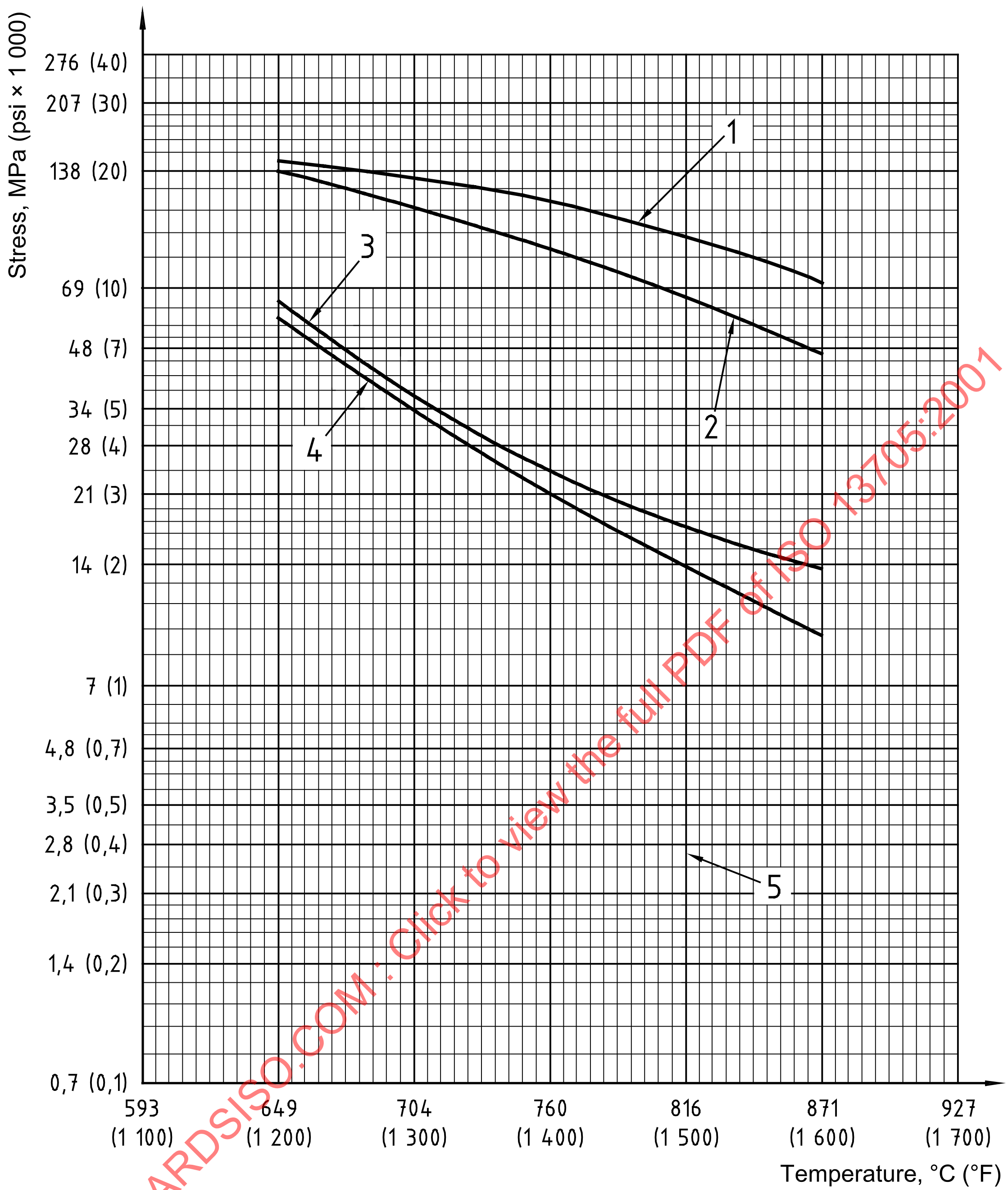
2 2/3 yield strength

3 50 % of rupture in 10 000 h

4 50 % of 1 % creep in 10 000 h

5 Maximum design temperature

Figure D.6 — 5Cr-1/2Mo plate: ASTM A 387, Grade 5, Class 1



Key

1 2/3 yield strength

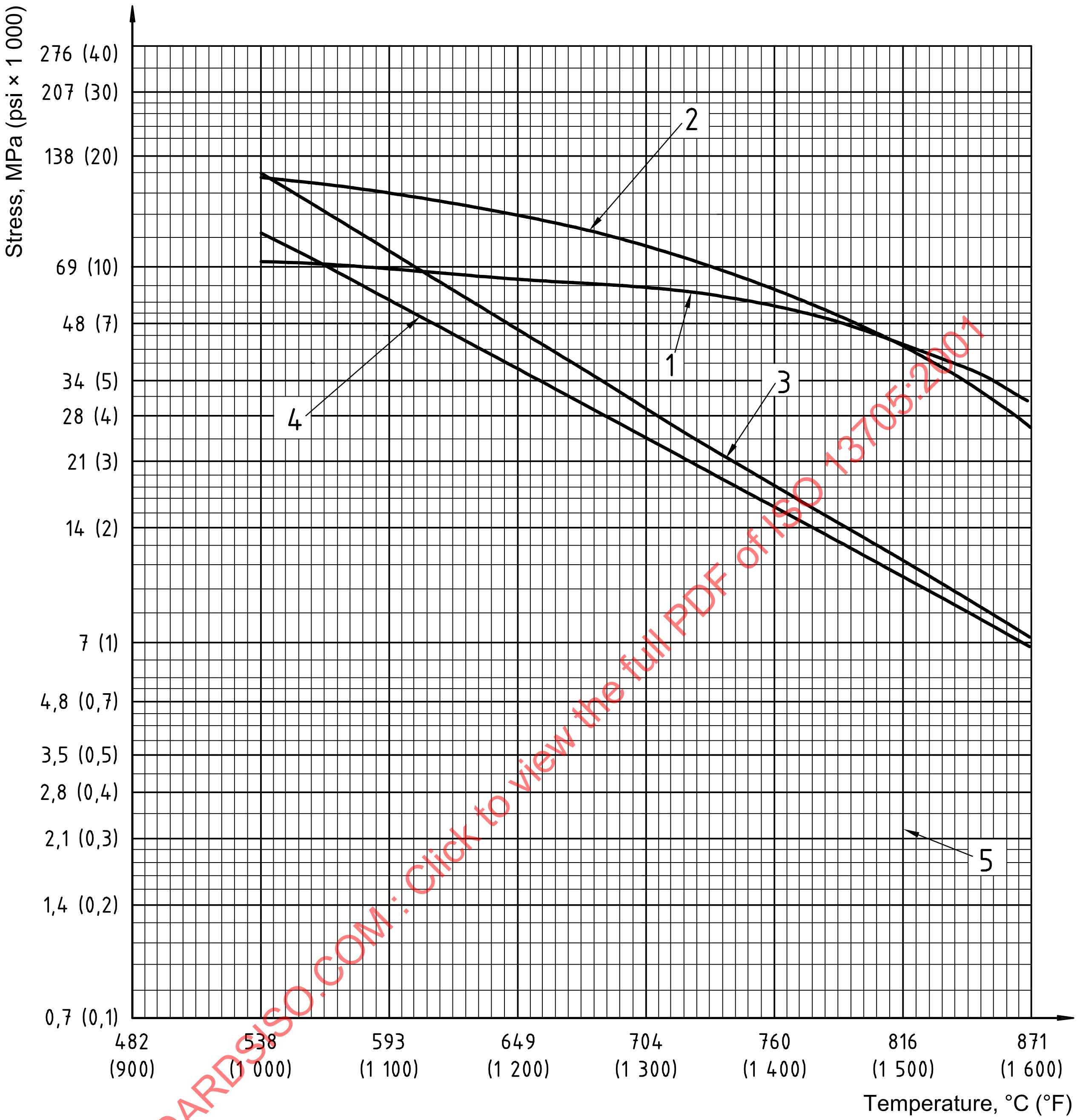
2 1/3 tensile strength

3 50 % of rupture in 10 000 h

4 50 % of 1 % creep in 10 000 h

5 Maximum design temperature

Figure D.7 — 19Cr-9Ni castings: ASTM A 297, Grade HF



Key

1 2/3 yield strength

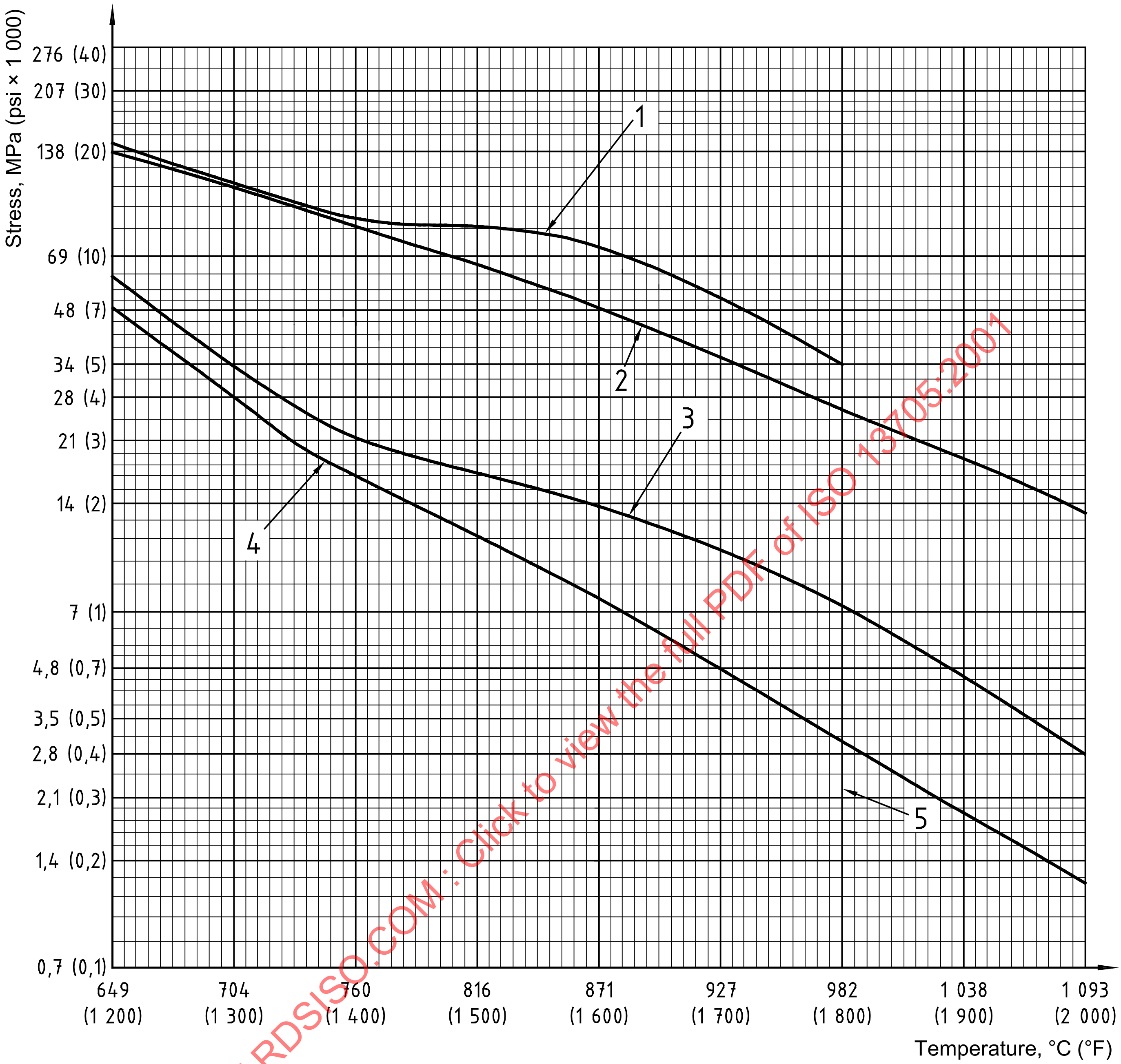
2 1/3 tensile strength

3 50 % of rupture in 10 000 h

4 50 % of 1 % creep in 10 000 h

5 Maximum design temperature

Figure D.8 — Type 304H plate: ASTM A 240, Type 304H



Key

1 2/3 yield strength

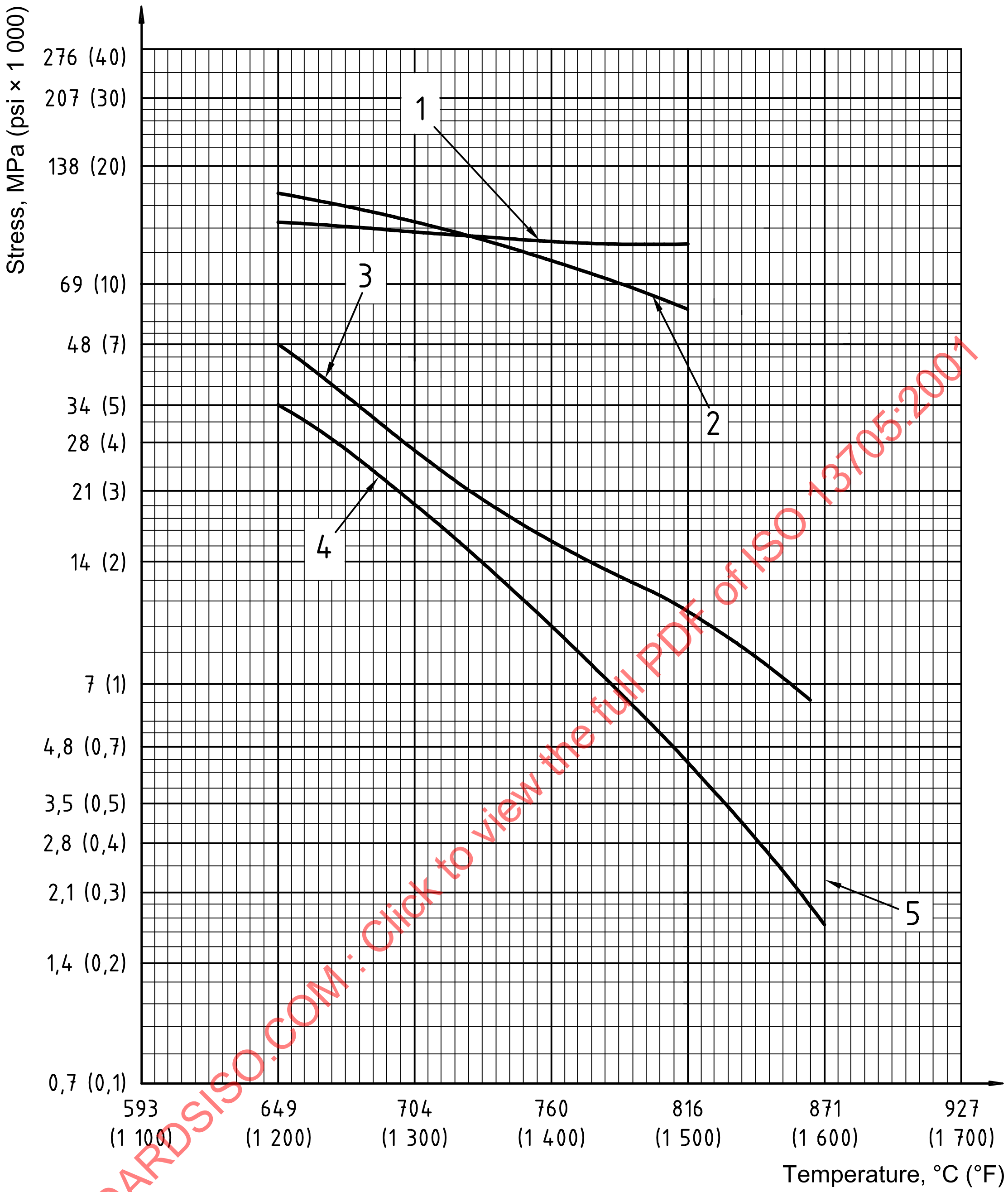
2 1/3 tensile strength

3 50 % of 1 % creep in 10 000 h

4 50 % of rupture in 10 000 h

5 Maximum design temperature

Figure D.9 — 25Cr-12Ni castings: ASTM A 447, Grade HH, Type II



Key

1 2/3 yield strength

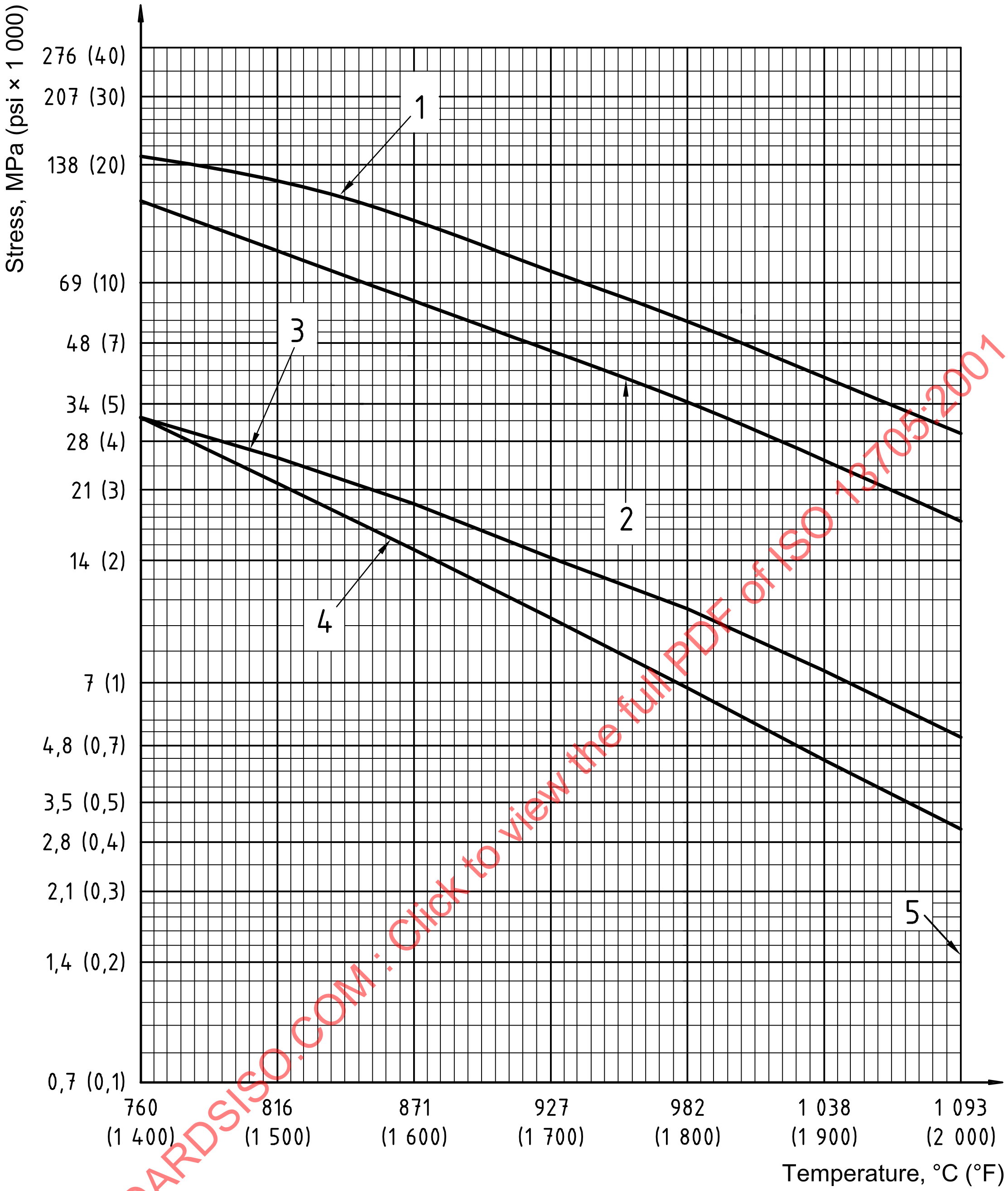
2 1/3 tensile strength

3 50 % of rupture in 10 000 h

4 50 % of 1 % creep in 10 000 h

5 Maximum design temperature

Figure D.10 — Type 309H plate: ASTM A 240, Type 309H



Key

1 2/3 yield strength

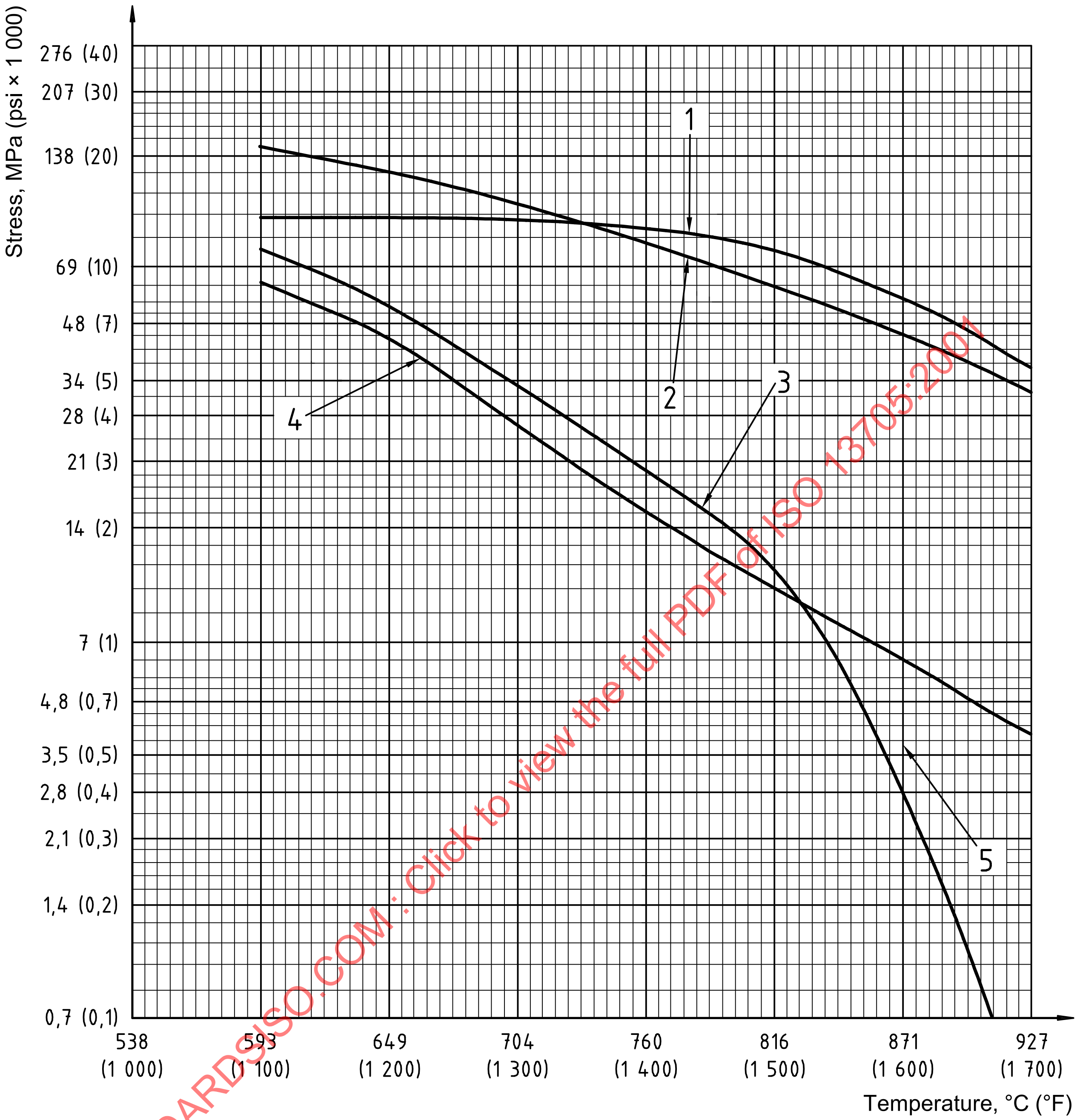
2 1/3 tensile strength

3 50 % of 1 % creep in 10 000 h

4 50 % of rupture in 10 000 h

5 Maximum design temperature

Figure D.11 — 25Cr-20Ni castings: ASTM A 350, Grade HK40



Key

1 2/3 yield strength

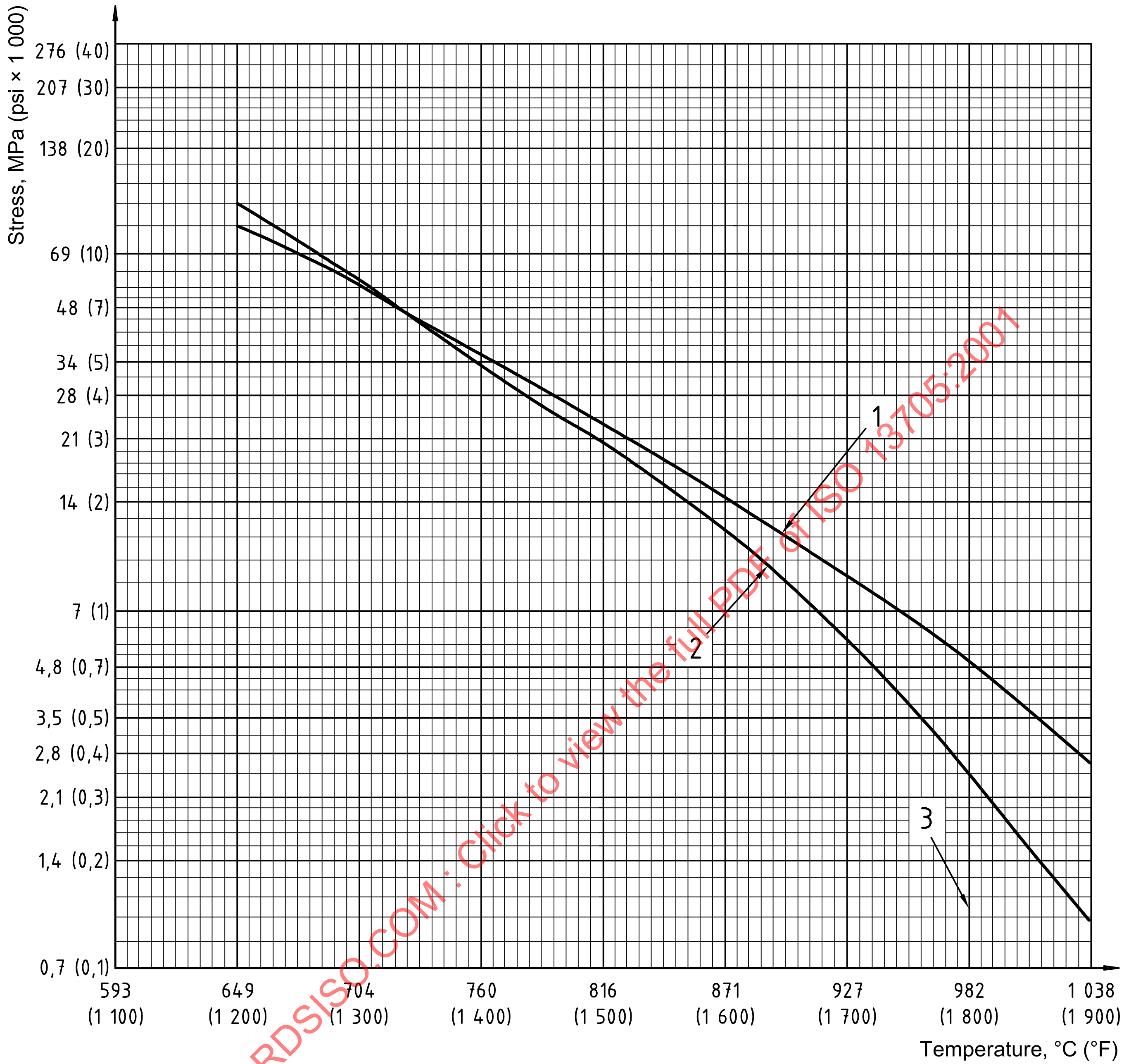
2 1/3 tensile strength

3 50 % of 1 % creep in 10 000 h

4 50 % of rupture in 10 000 h

5 Maximum design temperature

Figure D.12 — Type 310H plate: ASTM A 240, Type 310H



Key

1 50 % of rupture in 10 000 h

2 50 % of 1 % creep in 10 000 h

3 Maximum design temperature

Figure D.13 — 50Cr-50Ni-Nb castings: ASTM A 560, Grade 50Cr-50Ni-Nb

Annex E
(normative)

Centrifugal fans for fired heater systems

E.1 General

This annex specifies requirements and gives recommendations for centrifugal fans intended for continuous duty in fired heater systems. The terms and definitions given below apply specifically to this annex and therefore are not given in clause 3.

E.1.1
fan rated point
⟨fan speed⟩ highest speed necessary to meet any specified operating condition

E.1.2
fan rated point
⟨fan capacity⟩ rated capacity required by fan design to meet all operating points

NOTE This capacity point should be selected so that it encompasses specified operating conditions within the scope of the expected performance curve.

E.1.3
normal operating point
point at which usual operation is expected and optimum efficiency is desired

NOTE This is usually the point at which the vendor certifies that performance is within the tolerances stated in this International Standard

E.1.4
maximum allowable speed
highest speed at which the manufacturer's design permits continuous operation

E.1.5
maximum allowable temperature
maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the specified fluid at the specified pressure

E.1.6
fan total pressure
difference between the total pressure at the fan outlet and the total pressure at the fan inlet

E.1.7
fan velocity pressure
pressure corresponding to the average velocity at the specified fan outlet area

E.1.8
fan static pressure
difference between the fan total pressure and the fan velocity pressure

NOTE This may alternatively be expressed as the difference between the static pressure at the fan outlet and the total pressure at the fan inlet.

E.1.9
static pressure rise
static pressure at the fan outlet minus the static pressure at the fan inlet

E.1.10
inlet velocity pressure
difference between fan static pressure and static pressure rise

E.1.11
actual flowrate
flowrate determined at the conditions of static pressure, temperature, compressibility and gas composition, including moisture, at the fan inlet flange

NOTE It is expressed in cubic metres per minute (cubic feet per minute).

E.1.12
fan vendor
manufacturer of the fan

E.2 Design

E.2.1 General

E.2.1.1 The equipment (including auxiliaries) shall be designed and constructed for a minimum service life of 20 years and at least three years of uninterrupted operation. It is recognized that this is a design criterion.

E.2.1.2 Fans shall be designed to operate satisfactorily at all specified operating conditions. The two operating points of particular concern are the rated point and the normal operating point (see E.1.1, E.1.2 and E.1.3). It shall be the responsibility of the fan purchaser to provide complete required data (such as flowrate, pressure, temperature and inlet gas density) to the fan manufacturer. In developing these data, the fan purchaser shall consider the following.

a) The normal operating point is that point at which it is expected that the furnace will be operated most of the time. It shall be the fan manufacturer's responsibility to optimize the fan's efficiency as close to this point as practical.

b) The fan rated point shall include the flow required to meet the heater maximum design firing rate (including all surpluses for excess air, system leakage and design safety factor). In no case shall the rated point be less than 115% of the normal operating flow. The fan static pressure and temperature required for the rated point shall be specified by the purchaser.

E.2.1.3 The arrangement of the equipment, including ducting and auxiliaries, shall be developed jointly by the purchaser and the vendor. The arrangement shall provide adequate clearance areas and safe access for operation, maintenance and removal.

● **E.2.1.4** Motors, electrical components and electrical installations shall be suitable for the area classification (class, group and division) specified by the purchaser and shall meet the requirements of NFPA 70, Articles 500 and 501, as well as local codes specified and furnished by the purchaser. API RP 500 provides guidance on area classification.

E.2.1.5 All equipment shall be designed to permit rapid and economical maintenance. Major parts such as fan housing, inlet cone, and bearing housings shall be designed (shouldered or dowelled) and manufactured to ensure accurate alignment on reassembly. Field dowelling by others may be required after final alignment.

E.2.1.6 The fan vendor shall formally review and approve or comment on the purchaser's inlet and outlet duct and equipment arrangement drawings. This review shall consider structural aspects, such as loading on fan parts, and configuration details that impact fan performance as described in AMCA 201. Foundation drawing review is not required, unless specified by purchaser.

● **E.2.1.7** Fans shall be suitable for installation outdoors with no roof. The purchaser shall specify the weather and environmental conditions in which the equipment shall operate (including maximum and minimum temperatures and unusual humidity or dust problems). The unit and its auxiliaries shall be suitable for operation under these specified conditions. For the purchaser's guidance, the vendor shall list in the proposal any special protection that the purchaser is required to supply.

E.2.1.8 Spare parts for the machine and all furnished auxiliaries shall meet all the criteria of this International Standard.

E.2.1.9 The selected operating speed of the fan shall not exceed 1 800 r/min, unless otherwise approved by the purchaser.

E.2.1.10 Fan arrangement and bearing support shall be in accordance with AMCA 99-2404-78, arrangement 3 or arrangement 7, with the fan impeller located between bearings, the bearings mounted independently of the fan housing on rigid pedestals and sole plates, and the bearings protected from the air or gas stream if any of the following conditions exist:

a) driver rated power of 112 kW (150 BHP) or greater;

b) speed greater than 1 800 r/min;

c) maximum specified operating temperature greater than 235 °C (455 °F);

d) corrosive or erosive service;

e) service subject to fouling deposits that could cause rotor unbalance.

For services not subject to the above conditions, AMCA arrangements 1, 8 and 9, all with bearings mounted independent of the fan housing, are acceptable if approved by the purchaser.

For fan selection, it should also be considered that

— reduced speed is desirable for erosive service and for units subject to fouling deposits on the rotor;

— belt drives should be limited to no more than 75 kW (100 BHP) rated driver size.

If drivers are rated less than 30 kW (40 BHP) and speeds greater than 1 800 r/min, AMCA arrangements other than 3 and 7 may be specified on the data sheet.

E.2.1.11 Fan performance shall be based on fan static pressure rise, not including discharge velocity pressure. When specifying required performance, the purchaser is responsible for including the effect of inlet velocity pressure. To obtain the static pressure differential, the silencer and inlet losses, including control system losses, shall be added by the fan vendor to the purchaser's specified inlet and outlet static pressures.

E.2.1.12 Unless otherwise specified, fans shall have continuously rising pressure characteristic (pressure versus flowrate plot) from the rated capacity to 70 % or less of rated flow.

Performance curves, corrected for the specified gas at the specified conditions, shall be based on performance tests in accordance with AMCA 210, including, where applicable, evase and inlet box(es).

E.2.1.13 The fan shall be mechanically designed for continuous operation at the following temperatures:

a) 56 °C (100 °F) above the maximum expected inlet temperature to induced-draught fans;

b) 14 °C (25 °F) above maximum specified ambient air temperature to forced-draught fans.

E.2.1.14 Fan, components and accessories shall be designed to withstand all loads and stresses during rapid load changes, such as starting, failure of damper operator or sudden position change of dampers. Considerations for driver sizing and starting operations are covered in E.3.2.1 and E.3.2.5.

E.2.1.15 Fan inlets shall be designed as described below.

a) For forced-draught fans, provision of the inlet equipment and arrangements, including silencer(s) and transition piece(s), shall be coordinated between the purchaser and the fan vendor. (Portions may normally be supplied by each.)

b) Unless otherwise specified, the air intake shall be at least 4,5 m (15 ft) above grade. The purchaser shall evaluate air intake elevation requirements considering the possibility of dust entering the system and causing surface fouling, the area noise limitation requirement and the corresponding need for a silencer, the possibility of a combustible vapour entering the fan, and power penalties for inlet stack and silencer configurations.

c) The fan inlet equipment shall include intake cap or hood, trash screen, ducting and support, inlet damper or guide vanes, inlet boxes and silencer, as required. All components shipped separately shall be flanged for assembly. The inlet equipment assembly shall be designed for the wind load shown on the fan data sheet.

E.2.2 Fan housing

● **E.2.2.1** The fan scroll and housing sides shall be continuously welded plate construction. The minimum plate thickness shall be 5 mm (3/16 in) for forced-draught fans and 6 mm (1/4 in) for induced-draught fans. The purchaser shall specify whether a corrosion allowance is required. Stiffeners shall be provided to form a rigid housing free of structural resonance and to limit vibration and noise. The external stiffeners may be intermittently welded to the fan housing.

For fans in arrangements 3 and 7, the housing and inlet box(es) shall be split at a bolted, flanged and gasketed connection to allow assembled rotor removal and installation without disturbing duct connections. Other arrangements shall be similarly split where impeller diameter exceeds 1 070 mm (42 in).

The inlet cone shall be constructed so that it does not impede rotor removal or installation. The cone shall either be split, separately removed as a whole, or removable in assembly with the rotor.

E.2.2.2 Bolted and gasketed access doors, of largest possible size up to 600 mm × 600 mm (24 in × 24 in), shall be provided in the scroll and inlet box(es) for access to the fan internals for inspection, cleaning, rotor balancing, and to any internal bolting necessary for rotor removal.

E.2.2.3 Adequate flanged sections shall be provided in the fan housing and inlet box(es) so that the rotor can be removed and installed without requiring personnel to enter the inlet box(es).

E.2.3 Fan housing connections

E.2.3.1 Inlet and discharge connections shall be flanged and bolted. Facings, gaskets and bolting of all connections shall prevent leakage.

E.2.3.2 Accessible flanged drain connections, 50 mm (2 in) minimum diameter, shall be provided at the low point(s) of the housing and inlet boxes.

E.2.4 External forces and moments

Fan housings are generally designed for low external forces and moments from the inlet and outlet connections. It shall be the responsibility of the heater designer to specify on the data sheets the expected external loads to be imposed on the fan housing from the ancillary equipment (that is, ducting, sound trunks, silencers, and filters), if this equipment is not supplied by the fan vendor. The vendor shall design the housing to accept the specified loads. The vendor shall provide the following information as required on the fan data sheets:

a) maximum allowable external forces and moments;

b) expansion joint information and recommendations if joints are required for thermal expansion, vibration isolation, or both.

E.2.5 Rotating elements

E.2.5.1 Fan impellers shall have a non-overloading horsepower characteristic and shall be designed for the highest possible efficiency. Backward-curved/backward-inclined blades are permitted in the constructions detailed in E.2.5.1.c). Such configurations are non-overloading.

Design and configurations available as options include

a) hollow airfoil construction of 2,5 mm (0,10 in) minimum skin thickness material designed and constructed to prevent the internal accumulation of condensables, foulants, or corrosion products,

b) solid blades with airfoil shape,

c) non-airfoil shape of minimum single thickness, 6 mm (1/4 in) .

● **E.2.5.2** Induced-draught fan design shall consider operations in a possible dirty gas environment. Blade design shall be specified by the purchaser. Radial and radial-tipped configurations are considered non-fouling designs and have lower inherent efficiencies.

E.2.5.3 The impeller shall be of welded construction. Shrouds, backplates, and center plates shall normally be of one-piece construction. They may be fabricated if the sections are joined by full-penetration butt welds meeting the examination requirements of E.4.1. The vendor shall state whether post-weld heat treatment of the fabricated wheel is required, after consideration of environmental and mechanical (residual stress) effects.

E.2.5.4 Gas temperature-change rates, heating and cooling, in excess of 8 °C (15 °F) per minute may be expected on induced-draught fans. Fan vendors shall specify the maximum allowable rate of change to ensure that an adequate hub-to-shaft interference fit is maintained.

E.2.5.5 Impellers shall have solid hubs, be keyed to the shaft and be secured with an interference fit. Unkeyed fits with appropriate interference are permissible with purchaser's approval. Cast or ductile iron hubs are acceptable below a mechanical design temperature of 150 °C (300 °F). If the impeller is to be bolted to the hub, the manufacturer's design shall preclude relative movement between the impeller and hub.

E.2.5.6 Shafts shall be of one piece, heat-treated, forged steel; shafts 150 mm (6 in) in diameter and smaller may be machined from hot rolled steel. For arrangements three or seven, shaft diameters shall be stepped on both sides of the impeller fit area to facilitate impeller assembly and removal. Fillets shall be provided at all changes in shaft diameters and in keyways. Keyways shall have fillet radii in accordance with ASME B17.1. Welding on the shaft is not permitted.

E.2.5.7 Shafts shall be capable of handling 110 % of rated driver torque from rest to rated speed.

● **E.2.5.8** If specified by the purchaser, induced-draught fans shall be provided with corrosion-resistant shaft sleeves to reduce the effect of dew-point corrosion at shaft seals. Sleeves shall extend 150 mm (6 in) into the fan housing.

E.2.6 Shaft sealing of fans

E.2.6.1 Shaft seals shall be provided to minimize leakage from or into fans over the range of specified operating conditions and during idle periods. Seal operation shall be suitable for variations in inlet conditions that may prevail during startup and shutdown or any special operation specified by the purchaser.

E.2.6.2 Shaft seals shall be replaceable from the outside of the inlet box(es) without disturbing the shaft or bearings.

E.2.7 Critical speeds/resonance

E.2.7.1 Unless otherwise specified, the separation margin of critical speeds from all lateral (including rigid and bending) modes shall be at least 25 % over the maximum continuous speed. The separation margin is intended to prevent the overlapping of the resonance response envelope into the operating speed range.

NOTE The term critical speed used herein considers the factors defined by “design resonant speed” in AMCA 801-92, paragraph 3.2.3.

E.2.7.2 Resonances of support systems within the vendor’s scope of supply shall not occur within the specified operating speed range or the specified separation margins, unless the resonances are critically damped.

E.2.7.3 Bearing housing resonance shall not occur within the specified operating speed range or specified separation margins.

● **E.2.7.4** If specified by the purchaser, critical speeds shall be determined analytically by means of a damped unbalanced rotor response analysis and, if specified by the purchaser, this shall be confirmed by test-stand data.

E.2.7.5 The vendor who has unit responsibility shall determine that the drive-train critical speeds are compatible with the critical speeds of the machinery being supplied, and that the combination is suitable for the specified range of operating speed. A list of all undesirable speeds, from zero to trip, shall be submitted to the purchaser for his review and included in the instruction manual for his guidance.

E.2.8 Vibration and balancing

E.2.8.1 Each rotating assembly shall be dynamically balanced.

E.2.8.2 Prior to rotor assembly, the shaft shall be inspected for mechanical runout and concentricity at the impeller mounting surface seat and bearing journals. Runout shall not exceed the total indicator reading specified in Table E.1.

Table E.1 — Maximum shaft runout indicator readings

Dimensions in millimetres (inches)

Shaft diameter	Total indicator reading	
	Bearing journal area	Wheel mounting area
<150 (<6)	0,025 (0,001)	0,050 (0,002)
150 (6) to 355 (14)	0,038 (0,0015)	0,075 (0,003)
>355 (>14)	0,050 (0,002)	0,100 (0,004)

● **E.2.8.3** If specified by the purchaser, a mechanical running test shall be performed at the fan vendor’s shop (see E.4.2.2). During the shop test of the assembled machine operating at maximum continuous speed or at any other speed within the specified operating range, the maximum allowable unfiltered peak vibration velocity, measured on the bearing housing in any radial plane, shall not exceed 5 mm/s (0,2 in/s) or 2,5 mm/s (0,1 in/s) at running frequency. At the trip speed of the driver, the vibration shall not exceed 6 mm/s (0,25 in/s) unfiltered velocity.

E.2.9 Bearings and bearing housings

E.2.9.1 Bearing types shall be either antifriction or hydrodynamic (sleeve). Unless otherwise specified, fans rated at 112 kW (150 BHP) or greater shall have horizontally split, self-aligning hydrodynamic bearings.

E.2.9.2 Antifriction bearings shall be self-aligning and the selection shall be based on the following ratings:

a) DN factor less than 200 000. (The DN factor is the product of bearing bore, expressed in millimetres, and the rated speed, expressed in revolutions per minute.)

b) L-10 life factor (as defined in AFBMA Standard 9) of 100 000 h or greater. (The rating life is the number of hours at rated bearing load and speed that 90 % of the group of identical bearings will complete or exceed before the first evidence of failure).

c) Load factor less than 2 013 400. (Load factor is the product of rated power, expressed in kilowatts, and rated speed, expressed in revolutions per minute).

“Maximum load” (filling slot) antifriction bearings shall not be used for any service, including drivers (motors, turbines, and gears).

E.2.9.3 Thrust bearings shall be sized for continuous operation under all specified conditions, including double-inlet fans operating with one inlet cone 100 % blocked. As a guide, thrust bearings shall be applied at no more than 50 % of the bearing manufacturer’s ultimate load rating.

E.2.9.4 Shaft bearings shall be accessible without dismantling ductwork or fan casing. Overhung impeller designs shall have provisions for supporting the rotor during bearing maintenance.

E.2.9.5 All induced-draught fans shall be supplied with a heat slinger (with safety guards), located between the fan housing and/or inlet box(es) and the adjacent bearing(s).

E.2.9.6 Sufficient cooling, including an allowance for fouling, shall be provided to maintain the oil temperature below 70 °C (160 °F) for pressurized systems and below 82 °C (180 °F) for ring-oiled or splash systems, based on the specified operating conditions and an ambient temperature of 43 °C (110 °F). Where water cooling is required, water jackets shall have only external connections between the upper and lower housing jackets and shall have neither gasketed nor threaded connection joints, which may allow water to leak into the oil reservoir. If cooling coils (including fittings) are used, they shall be of nonferrous material and shall have no internal pressure joints or fittings. Coils shall have a thickness of at least 1,07 mm (19 BWG or 0,042 in) and shall be at least 12,5 mm (0,50 in) in diameter.

E.2.9.7 Bearing housings shall be drilled with pilot holes for use in final dowelling.

E.2.10 Lubrication

E.2.10.1 Unless otherwise specified, bearings and bearing housings shall be arranged for hydrocarbon oil lubrication in accordance with the bearing manufacturer’s recommendations. Grease-packed antifriction bearings shall not be provided without purchaser’s approval.

E.2.10.2 On dampers and variable inlet vanes, all linkage, shaft fittings and bearings shall be permanently lubricated. Components requiring periodic lubrication shall be furnished with lubrication fittings which are accessible while the fan is in operation.

E.2.10.3 If a forced-feed oil system is required, the scope shall be agreed between the purchaser and the vendor.

E.2.11 Materials

E.2.11.1 General

E.2.11.1.1 Construction materials shall be the manufacturer’s standard for the specified operating conditions, except as required by the purchaser.

● **E.2.11.1.2** The purchaser shall specify if there are any corrosive agents present in the flue gas and in the environment, including constituents that may cause stress-corrosion cracking. The fan vendor shall recommend materials that are suitable for mechanical design and fabrication (see E.2.5.3).

E.2.11.1.3 Where mating parts such as studs and nuts of AISI Standard Type 300 stainless steel or materials with similar galling tendencies are used, they shall be lubricated with an antiseizure compound rated for the specified temperatures.

E.2.11.1.4 Low-carbon steels can be notch-sensitive and susceptible to brittle fracture at ambient or low temperatures. Therefore only fully killed, normalized steels made to fine-grain practice are acceptable. ASTM A 515 steel shall not be used.

E.2.11.1.5 Internal bolting shall be at least equivalent to the fan construction material.

E.2.11.2 Welding

E.2.11.2.1 All welding, including weld repairs, shall be performed by operators and procedures qualified in accordance with AWS D14.6-96 for rotor welds and AWS D1.1 for housings and inlet boxes.

E.2.11.2.2 The vendor shall be responsible for the review of all welding, including weld repair, to ensure that the quality requirements of AWS D14.6, Section 7, have been satisfied.

E.2.11.2.3 All rotor-component butt welds shall be continuous full-penetration welds.

E.2.11.2.4 Intermittent welds, stitch welds or tack welds are not permitted on any part of the fan or accessories furnished by the vendor, except as noted in E.2.2.1 and E.3.4.3.5. Such welds used for parts positioning during assembly shall be removed.

E.2.11.3 Low temperature

● For operating temperatures below – 29 °C (– 20 °F) or, if specified by the purchaser, for other low ambient temperatures, steels shall have, at the lowest specified temperature, an impact strength sufficient to qualify under the minimum Charpy V-notch impact energy requirements of ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, UG-84. For materials and thicknesses not covered by the Code, the purchaser shall specify the requirements on the data sheet.

E.2.12 Nameplates and rotation arrows

E.2.12.1 A nameplate shall be securely attached at an easily accessible point on the equipment and on any other major piece of auxiliary equipment.

E.2.12.2 The rated conditions and other data shall be clearly stamped on the nameplate and shall include, but are not limited to, the following:

a) vendor;

b) model number;

c) serial number;

d) size;

e) type;

f) purchaser's equipment item number (may be listed on separate nameplate if space is insufficient);

g) actual flowrate, in cubic metres per minute (cubic feet per minute);

h) static pressure differential, in mmH_2O (in H_2O);

i) temperature, inlet, in °C (°F);

j) revolutions per minute, rated;

k) revolutions per minute, maximum allowable (at maximum allowable temperature);

l) first critical speed;

m) kilowatts (BHP) (rated);

n) centrifugal force, ωr^2, rated;

o) rotor mass, in kilograms (pounds);

p) design operating altitude, in metres (feet) above sea level.

The contract or data sheets shall specify SI, US Customary or other units.

E.2.12.3 Rotation arrows shall be cast in or attached to each major item of rotating equipment.

E.2.12.4 Nameplates and rotation arrows (if attached) shall be of AISI Type 300 stainless steel or of nickel-copper alloy (Monel or its equivalent). Attachment pins shall be of the same material. Welding is not permitted.

E.3 Accessories

E.3.1 General

● The purchaser shall specify those accessories to be supplied by the fan vendor.

E.3.2 Drivers

● **E.3.2.1** The type of driver shall be specified by the purchaser. The driver shall be sized to meet the fan rated point conditions, including external gear and/or coupling losses, and shall be in accordance with applicable specifications, as stated in the enquiry and order. The driver shall be sized and designed for satisfactory operation under the utility and site conditions specified by the purchaser.

● **E.3.2.2** Anticipated process variations that can affect the sizing of the driver (such as changes in the pressure, temperature or properties of the fluid handled, as well as special plant startup conditions) shall be specified by the purchaser.

E.3.2.3 Forced-draught fan driver sizing shall consider fan performance at minimum ambient temperature.

E.3.2.4 Induced-draught fan driver sizing shall consider possible variations in operating temperature and gas density (for example, a cold start).

Provisions for flow control, through dampering or speed variation, will allow for startup and operation to be at less than normal process operating temperature. With these features, the need for greater driver size to handle low temperatures can be avoided. Operating instructions shall cover the use of dampers or speed control for such cases, particularly at startup.

E.3.2.5 The starting conditions for the driven equipment shall be specified by the purchaser, and the starting method shall be mutually agreed upon by the purchaser and the fan vendor. The driver's starting-torque capabilities shall exceed the speed-torque requirements of the driven equipment. The fan vendor shall verify that the starting characteristics of the fan and driver are compatible.

E.3.2.6 Unless otherwise specified, motor-driven fans shall be direct-connected.

E.3.2.7 For motor-driven units, the motor nameplate rating (exclusive of the service factor) shall be at least 110 % of the greatest power required (including gear and coupling losses) for any of the specified operating conditions.

E.3.2.8 Full load and starting current, system centrifugal force, and curves showing motor speed-torque, speed-current and speed-power factor shall be provided for each fan drive.

E.3.2.9 Motor drivers shall be capable of starting the fan, with the control damper in the minimum position, with 80 % of the design voltage applied.

E.3.3 Couplings and guards

E.3.3.1 Flexible couplings and guards between drivers and fans shall be supplied by the fan vendor, unless otherwise specified on the data sheets.

E.3.3.2 Unless otherwise specified, all couplings shall be spacers with the spacer length sufficient to allow removal of the coupling hubs and allow maintenance of adjacent bearings and seals without removal of the shaft or disturbing the equipment alignment.

E.3.3.3 Each coupling shall have a coupling guard that sufficiently encloses the coupling and shafts to prevent any personnel access to the danger zone during operation of the equipment train. The guard shall be readily removable for inspection and maintenance of the coupling without disturbing the coupled machines.

E.3.4 Controls and instrumentation

E.3.4.1 General

E.3.3.1.1 Unless otherwise specified, controls and instrumentation shall be designed for outdoor installation.

- **E.3.3.1.2** The fan vendor shall provide fan performance data (in accordance with E.5) to enable the purchaser to properly design a control system for startup and for all specified operating conditions. If specified by the purchaser, the fan vendor shall review the purchaser's overall fan control system for compatibility with fan vendor-furnished control equipment (see E.3.2.5).

E.3.4.2 Control systems

- **E.3.4.2.1** The fan may be controlled on the basis of inlet pressure, discharge pressure, flowrate, or some combination of these parameters. This may be accomplished by suction or discharge throttling, or speed variation. The purchaser shall specify the type and source of the control signal, its sensitivity and range, and the equipment scope to be furnished by the vendor.

E.3.4.2.2 For constant-speed drive, the control signal shall actuate an operator which positions the inlet or outlet damper.

E.3.4.2.3 For a variable-speed drive, the control signal shall act to adjust the set point of the driver's speed-control system. Unless otherwise specified, the control range shall be from the maximum continuous speed to 95 % of the minimum speed required for any specified operating case, or 70 % of the maximum continuous speed, whichever is lower.

E.3.4.2.4 The full range of the purchaser's specified control signal shall correspond to the required operating range of the driven equipment. Unless otherwise specified, the maximum control signal shall correspond to the maximum continuous speed or the maximum flowrate.

E.3.4.2.5 Unless otherwise specified, facilities shall be provided to automatically open or close (as specified) the dampers or variable-inlet vanes on loss of control signal and to automatically lock or brake the dampers or vanes in their last position on loss of motive force (such as air supply or electric power). This is a specific system consideration, and the associated controls shall be arranged to avoid creating hazardous or other undesirable conditions.

E.3.4.2.6 Unless otherwise specified, the fan vendor shall furnish and locate the operators, actuator linkages and operating shafts for remote control of the dampers or variable-inlet vanes. Operator output shall be adequate for the complete range of damper or variable-inlet vane positions. The proposed location of operator linkages and shafts shall be reviewed with the purchaser for consideration of maintenance access and safety.

E.3.4.2.7 External position-indicators shall be provided for all dampers or variable-inlet vanes.

E.3.4.2.8 Unless otherwise specified, pneumatic activators shall be mechanically suitable for an air gauge pressure of 860 kPa (125 psi) and shall provide the required output with an air gauge pressure as low as 410 kPa (60 psi).

E.3.4.3 Dampers or variable-inlet vanes

● **E.3.4.3.1** Frames for inlet dampers (unless integral with the inlet box) and outlet dampers shall be flanged and drilled airtight steel frames for tight-fitting bolting to the fan or ductwork. Dampers shall have either parallel or opposed blades, as specified by the purchaser for the required control. Damper blades shall be supported continuously by the shafts. No stub shafts are allowed. Damper shafts shall be sealed or packed to limit leakage, except for atmospheric air inlet dampers.

● **E.3.4.3.2** If specified by the purchaser, the fan vendor shall state the maximum expected leakage through the closed damper or vanes, at the operating temperature and pressure specified by the purchaser. The stated leakage shall correspond to pressure and temperature differentials expected with the fan operating.

E.3.4.3.3 Unless otherwise specified, the damper or variable-inlet vane mechanisms shall be interconnected to a single operator. The operating mechanism shall be designed so that the dampers or variable-inlet vanes can be manually secured in any position.

E.3.4.3.4 Variable-inlet vane-operating mechanisms shall be located outside the flowing gas stream. The mechanism shall be readily accessible for in-place inspection and maintenance, and be of bolted attachment construction to permit removal if necessary. Provision shall be furnished for lubrication of the mechanism during operation.

E.3.4.3.5 Variable-inlet vanes shall be continuously welded to the spindle or intermittently welded on the back side of the blade with full slot welds along the full length of the front side.

E.3.5 Piping and appurtenances

E.3.5.1 Inlet trash screens

Inlet trash screen(s) to prevent entry of debris shall be provided for forced-draught fans handling atmospheric air. This screen shall be fabricated from wire of minimum diameter 3 mm (1/8 in), with a mesh of 38 mm (1,5 in) nominal opening. The screen shall be suitably supported by cross-members. Rain hood(s) shall be provided on vertical inlets. Screen supports and rain hoods shall be of galvanized carbon steel or coated in accordance with E.3.6.1.1. Trash screen shall be of 300 series stainless steel.

E.3.5.2 Silencers and inlet ducts

E.3.5.2.1 The differential pressure across each inlet or exhaust silencer shall not exceed 20 mm (0,8 in) water column.

E.3.5.2.2 Silencers shall be designed to prevent internal damage from acoustic or mechanical resonances.

E.3.5.2.3 Mineral-wool fibre insulation shall not be used in silencer construction.

E.3.5.2.4 Carbon steel construction shall be of 5 mm (3/16 in) minimum thickness plate. Corrosion allowance and alternative material, if required, shall be specified by the purchaser.

E.3.5.2.5 Main-inlet duct and silencer connections shall be flanged.

E.3.6 Coatings, insulations and jacketing

E.3.6.1 Coatings

E.3.6.1.1 Unless otherwise specified, if constructed of carbon steel, low-alloy steel or cast iron, the following areas shall be cleaned in accordance with ISO 8501-1 and then painted with a 75 µm (0,003 in) dry film thickness of inorganic zinc:

a) internal surfaces of forced-draught fan intake ducts and accessories, fan housing and internals;

b) internal surfaces of induced-draught fan housing, inlet box(es), discharge connection and accessories;

c) external nonmachined surfaces of all bearing pedestals and bearing housings, fan housings, inlet and discharge connections and accessories on both insulated and uninsulated units. Apply after all external shop weldments are complete.

E.3.6.1.2 Coatings shall be selected to resist deterioration and fume generation at the maximum specified inlet gas temperature.

E.3.6.2 Insulation and jacketing

E.3.6.2.1 Insulation clips or studs shall be shop-welded on all fan housings, inlet boxes- and discharge connections where normal operating temperature is 83 °C (180 °F) or higher, or if acoustic insulation of fans is required. Unless otherwise specified, the clips or studs shall be designed and installed for a minimum insulation thickness of 50 mm (2 in).

● **E.3.6.2.2** The insulation shall maintain a maximum jacket-surface temperature of 83 °C (180 °F) at zero wind and 27 °C (80 °F) ambient conditions. The purchaser shall specify the type of insulation and jacketing. This material may be supplied and field-installed by other than the fan vendor, unless otherwise specified.

E.4 Examination, testing and preparation for shipment

E.4.1 Examination

E.4.1.1 Material examination

● If radiographic, ultrasonic, magnetic-particle or liquid-penetrant examination of welds, cast steel and wrought materials is specified by the purchaser, the criteria in E.4.1.2 through E.4.1.5 shall apply, unless other criteria are specified by the purchaser. Cast iron may be inspected in accordance with E.4.1.4 and E.4.1.5. Refer to E.2.11.1.2.

E.4.1.2 Radiography

The method and acceptance criteria for radiography shall be in accordance with the pressure design code.

E.4.1.3 Ultrasonic examination

The method and acceptance criteria for radiography shall be in accordance with the pressure design code.

E.4.1.4 Magnetic particle examination

The method and acceptance criteria for radiography shall be in accordance with the pressure design code.

E.4.1.5 Liquid-penetrant examination

The method and acceptance criteria for radiography shall be in accordance with the pressure design code.

E.4.1.6 Mechanical inspection

- a) If specified by the purchaser, centrifugal fans shall be shop-assembled prior to shipment. Drivers (if provided) and other auxiliaries shall be included in the shop assembly as specified. The purchaser shall be notified prior to completion of shop assembly to permit inspection prior to disassembly (if required) and shipment. If disassembly is required for shipment, all mating parts shall be suitably match-marked and tagged for field assembly. All equipment shall be furnished completely assembled to the maximum extent, limited only by the requirements of shipping.

b) During assembly of the system and before testing, each component (including cast-in passages of these components) and all piping and appurtenances shall be cleaned to remove foreign materials, corrosion products and mill scale.

- c) If specified by the purchaser, the hardness of parts and heat-affected zones shall be verified as being within the allowable values by testing. The method, extent, documentation and witnessing of the testing shall be mutually agreed upon by the purchaser and the vendor.

E.4.2 Testing

E.4.2.1 General

- If specified by the purchaser, the centrifugal fan equipment shall be tested; the minimum test requirements shall be as listed in E.4.2.2. Additional requirements for a shop or field test shall be provided by the purchaser. AMCA 210, AMCA 203, AMCA 802 and AMCA 803 may be used as the basis for testing.

Many fan manufacturers do not have the capability to perform shop mechanical-run tests except on the smaller units. The need for a shop test, along with the capability of vendors to perform the test, should be carefully considered before imposing such a requirement. At least six weeks before the first scheduled test, the fan vendor shall submit to the purchaser, for his review and comment, detailed procedures for all running tests, including acceptance criteria for all monitored parameters. The fan vendor shall notify the purchaser not less than five working days before the date the equipment will be ready for testing. Equipment for specified tests shall be provided by the fan vendor. Acceptance of shop tests does not constitute a waiver of requirements to meet field performance, under specified operating conditions, nor does inspection relieve the vendor of any required responsibilities.

E.4.2.2 Mechanical running test

If other test details are not specified, the testing shall include the following as a minimum.

a) The fan shall be operated from 0 % to 115 % of design speed for turbine drives and at 100 % or rated speed for other drives. Operation shall be for an uninterrupted period of 2 h, with stabilized bearing temperatures, to check bearing performance and vibration.

b) Operation and function of fan instrumentation and controls shall be demonstrated to the extent practical.

c) The vendor shall maintain a record of all final tests, including vibration and bearing-oil temperature data. Vibration measurements shall be recorded throughout the specified speed range.

d) Bearings shall be removed, inspected and, if required, reassembled in the fan after completion of a satisfactory mechanical run test.

e) All oil pressures, viscosities and temperatures shall be within the range of operating values recommended in the vendor's operating instructions for the specified unit being tested. Oil flowrates for each bearing housing shall be determined.

All bearings shall be pre-lubricated.

E.4.2.3 Analysis of rotor response

If specified by the purchaser, the rotor response analysis defined in E.2.7.4 shall be confirmed on the test stand.

E.4.3 Preparation for shipment

● **E.4.3.1** Equipment shall be suitably prepared for the type of shipment specified, including blocking of the rotor if necessary. If specified by the purchaser, the equipment shall be prepared so that it is suitable for six months of outdoor storage from the time of shipment. If storage for a longer period is contemplated, the vendor shall provide recommended protection procedures.

● **E.4.3.2** Preparation for shipment shall be made after all testing and inspection of the equipment has been accomplished and the equipment has been approved by the purchaser. The shipping preparations shall be specified by the purchaser.

E.5 Vendor's data

E.5.1 Data required with proposals

The following data are required with the vendor's proposals:

a) copies of the purchaser's data sheets with vendor's complete fan information entered thereon;

b) utility requirements, including lubricant:

c) net and maximum operating and erection masses and maximum normal maintenance masses, with item identification;

d) typical drawings and literature to fully describe offering details;

e) preliminary performance curves as described in E.5.2.1.

E.5.2 Data required after contract

E.5.2.1 The fan vendor shall provide complete performance curves to encompass the map of operations, with any limitations indicated thereon. The fan vendor shall provide, as a minimum, fan static pressure/capacity and horsepower/capacity curves for 100 %, 80 %, 60 %, 40 % and 20 % damper position settings; and fan static efficiency/capacity curves. Where gas temperature variations are specified, separate curves shall be provided for maximum, minimum and normal operating temperatures.

E.5.2.2 For variable-speed fan systems, the performance curves shall illustrate the degree of speed control necessary to attain rated, normal and 50 % of normal flowrates. If additional turndown is specified, an illustrative curve shall be provided.

E.5.2.3 The curves for dampered and variable-speed systems shall contain a system resistance curve to illustrate the degree of control necessary to attain each operating point, and shall correspond to the geometry of equipment as installed.

E.5.2.4 Fan static efficiency versus speed curves for variable-speed fan systems (including fan and drivers), within the vendor's scope of supply, shall be provided.

E.5.2.5 Unless otherwise specified, the fan vendor shall provide fan and drive centrifugal force. For each motor-driven fan under full-voltage across-the-line starting conditions, the fan vendor shall provide

a) full load and starting currents,

b) curves for motor speed versus torque, versus current, and versus power factor,

c) allowable number of cold starts, hot restarts, or both, per hour, and any at-rest period required,

d) curve of system acceleration time versus current,

e) the recommended acceleration or deceleration rate for the variable-frequency controller for each motor-driven fan under controlled-frequency starting conditions,.

f) preliminary outline and arrangement drawings and schematic diagrams,

g) startup, shutdown or operating restrictions recommended to protect equipment,

h) spare parts recommendations, including drawings, part numbers and materials,

i) list of special tools included or required,

j) shaft seal details,

k) certified drawings, including outline and arrangement drawings and schematic diagrams,

l) shaft coupling details,

m) data on cold-alignment setting and expected thermal growth.

n) details of damper linkages and control systems, including torque or power requirements,

o) completed as-built data sheets,

p) parts lists for all equipment supplied,

q) instruction manuals covering installation, final tests and checks, startup, shutdown, operating limits and recommended operating and maintenance procedures.

Annex F
(informative)

Air preheat systems for fired process heaters

F.1 General

This annex provides guidelines for the selection or evaluation of air preheat systems applied to fired process heaters. Details of fired heater design are considered only where they interact with the air preheat system design. This annex does not provide rules for design but indicates areas that need attention and offers calculation methods to check the suitability of systems or equipment.

The systems discussed in detail are those currently in common use in the industry and it is not intended to imply that other systems are not recommended. Many of the individual features dealt with in these guidelines will be applicable to any type of air preheat system.

Standards and publications referenced in this informative annex are listed in the Bibliography. The applicability of changes to these documents that occur after the enquiry shall be mutually agreed upon by the purchaser and the vendor.

F.2 General factors in selecting an air preheat system

F.2.1 Factors affecting system applications

A number of general factors should be considered in selecting an air preheat system. Those general factors are discussed here. F.4 covers specific factors for selecting particular types and features of air preheat systems.

Combustion air is usually preheated to increase fired-heater efficiency, and the effectiveness of such air preheating should be compared with providing additional convection-section surface. Air preheating becomes more attractive with increased fired-heater process inlet temperature or duty. An air preheat system allows recovery of heat that would otherwise be lost with the stack gases.

In some cases, air preheating may allow an increase in fired-heater capacity or duty. For example, if fired-heater operation is limited by a large flame envelope or poor flame shape (flame impingement on tubes) or by inadequate draught (flue-gas removal limitations), the addition of an air preheat system can increase heater capacity. The air preheat system equipment can overcome these limitations; however, mechanical and process factors should be carefully considered as a result of the increase in radiant heat flux. These factors include higher tube and firebox hardware temperatures and higher process film temperatures, possibly leading to unacceptable degradation or coking.

An economic analysis is generally required to justify an air preheat system, but consideration should also be given to the effect of adding air preheat on operating conditions. The economic analysis should compare the installed cost, the cost of required power, and maintenance costs with the value of expected fuel savings and/or increased capacity. In the case of a retrofit, the installed cost should include the cost of downtime of the heater for the installation to take place.

Preheating of combustion air may provide the following advantages:

— improved control of combustion air flow;

— reduced oil burner fouling;

- better flame pattern control;
- more complete combustion of difficult fuels.

Preheating of combustion air has the following disadvantages:

- increased potential for corrosion of components in the flue stream due to sulfur trioxide (SO_3) attack;
- formation of acid mists, resulting in stack plume, if sulfur content of fuel is high;
- increased maintenance requirements for mechanical equipment;
- increased concentration of nitrogen oxide in the flue gas;
- reduced stack effluent velocity and thermal rise of flue gases, if the existing stack is utilized in a retrofit.

F.2.2 Types of air preheat systems

F.2.2.1 General

Many types of air preheat systems and designs are available, including both direct and indirect. The regenerative and recuperative designs are examples of direct air preheat systems where heat transfer takes place from the existing flue gas to the incoming combustion air. Indirect systems use an intermediate fluid to absorb heat from the exiting flue gas and then to release it to the incoming combustion air. One other system uses an external source to heat the combustion air without cooling the flue gas.

Air preheat equipment always imposes a resistance to air flow and usually to the flue-gas flow. It is normally necessary to use mechanical equipment, such as fans or blowers, to overcome these resistances. Forced-draught (FD) fans are used to supply the combustion air and, where required, induced-draught (ID) fans are used to remove the flue gas.

Some types of air preheaters are available as proprietary systems or designs that often provide specific arrangements that may be advantageous in certain processes.

F.2.2.2 Direct air preheaters

F.2.2.2.1 Regenerative air preheater

A regenerative air preheater contains a matrix of metal or refractory elements, which may be stationary or moving. For fired process heater applications, the commonly used regenerative air preheater has the elements housed in a rotating wheel. The elements are alternately heated in the exiting flue gas and cooled by the incoming combustion air. Figure 4 shows flows and arrangements for a typical system.

F.2.2.2.2 Recuperative air preheater

A recuperative air preheater has separate passages for the flue gas and the air, and heat flows from one to the other through the walls of these passages. The configuration is typically in the form of a tubular or plate heat exchanger in which the passages are formed of tubes, plates, or a combination of tubes and plates clamped together in a casing. The system shown in Figure 4 is also typical of a recuperative preheater.

F.2.2.2.3 Heat-pipe air preheater

A heat-pipe air preheater involves a number of banks of sealed heat pipes in which a heat-transfer fluid vaporizes in the parts of the tubes in the flue gas and condenses in the parts of the tubes in the air. Figure 4 shows the system diagram for a heat-pipe unit.

F.2.2.3 Indirect air preheaters

An indirect system typically has separate tube banks in the flue-gas and combustion air streams, and pipes carrying a heat-transfer fluid join one to the other. The heat-transfer fluid absorbs heat from the flue gas, flows to the tubes in the air stream, and releases heat to the combustion air there. The heat-transfer fluid is contained in a closed system and moves naturally or is moved by pumps. A forced circulation (or pumped) system is shown in Figure 5.

F.2.2.4 External heat-source air preheater

An external heat-source air preheater design uses a “once-through” flow of utility or process fluid in a tubular coil located in the air stream. Figure 6 illustrates such a system.

F.2.3 Factors affecting air preheat system choice

Some of the factors, other than cost and efficiency, that should be considered when selecting the most appropriate type of air preheat system include

a) available plot area for the ducts, fans, and heat transfer device or devices,

b) ability to service the air preheat system with minimum impact on the operating schedule of the fired heater,

c) design features that minimize fouling or its effects or that provide on-stream cleaning capability,

d) air leakage into the flue gas as it affects corrosion of downstream equipment, consumption of power, and provision of adequate air for design combustion conditions,

e) leakage of heat-transfer fluid as it affects the safety of fired heater operation,

f) limitations on maximum exposure temperatures,

g) burner location and arrangement,

h) possible need for alternate natural-draught operation and the heater duty required in the natural-draught mode,

i) ease of switching safely to an alternative operating condition in the event of a component failure,

j) potential severity of cold-end corrosion and the methods available to reduce the impact of corrosion,

k) feasibility of enlarging the air preheat system capacity to handle future increases in process requirements,

l) effect of terminal temperatures on the available system efficiency,

m) effect of burner type (forced versus natural draught).

F.3 Interaction of air preheat system with fired heater

F.3.1 Process design

The interaction of the air preheater with the fired heater, in process terms, is particularly important in the case of a retrofit, but the same considerations apply in the case of a new installation. If an existing heater with unaltered heat-transfer surface is to be retrofitted with an air preheat system and yet perform the same duty, the average flux in the radiant section will be increased as will the bridgewall temperature. A process check should be carried out to ascertain what the new conditions will be, and a revised data sheet should be prepared that reflects the new design conditions.

In re-examining the data sheets and checking the process design, the excess air and radiation loss values should be reviewed. The excess air can be reduced by taking advantage of the better control afforded by forced-draught combustion air supply. If effective insulation is employed, it may be more realistic to reduce the radiation loss value. If the additional surface area in the form of ductwork increases the heat loss, it may be more realistic to increase the radiation loss value. The process check involves an iterative procedure since the hot-air temperature will depend on the flue-gas exit temperature and vice versa. As a result of these interactive features, it is clear that one cannot simply decide to preheat some air.

F.3.2 Burners

Even in the case of a retrofit, it is usually necessary to replace the burners. This selection should be used as an opportunity to achieve other objectives as well, for example greater flexibility in fuel use, noise reduction, better control, and nitrogen oxides (NO_x) reduction.

If natural-draught operation is required (and at what level) upon equipment failure, the type of burner is selected and sized on this basis; then combustion air pressure should be established for the preheat condition. If natural-draught operation is not a requirement, then there is a greater flexibility in the choice of bumers.

If the air preheater will have to function at high air temperatures, burners may need to be constructed of exotic alloys. In addition, difficulties may arise with the damper or burner register operation, unless special arrangements are made. If a limitation on NO_x emissions applies, air preheat temperature may have to be limited.

F.3.3 Draught

Most air preheat systems employ forced/induced-draught (balanced-draught) operation. For both operational and safety reasons, some alternative means of providing draught must be available upon loss of operation of the fans or the air preheater. The natural-draught alternative for the combustion air supply has already been mentioned, but there are other techniques that do not place so great a restriction on burner selection. These include the provision of standby drivers, standby fans and shutdown systems.

In the case of induced-draught removal of the exhaust gases, a damper system that bypasses the air preheater and induced-draught fan and allows the exhaust gases to escape directly is normally provided. The stack height should be selected to maintain a negative firebox pressure at a specified percentage of design load.

F.3.4 Linings and heat loss

Since air preheat is generally justified on fuel savings, sources of heat loss should be identified. The addition of ducts, fans and the air preheater increases the surface from which heat loss can occur. The linings should be checked and possibly renewed, since reducing heat loss also improves efficiency and reduces costs.

F.3.5 Convection section

In some cases, the efficiency of an existing heater is so low that other problems can arise. These problems may be solved by adding convection surface area. Additional convection surface area may be justified if

a) air temperature must be limited to control NO_x emissions, to handle high radiant flux, or for mechanical considerations,

b) the air preheater selected cannot tolerate high flue-gas temperature leaving the heater. Additional convection surface may be added to reduce this temperature to acceptable levels.

In either of these two cases, the process design considerations are similar to those for a new heater, and freedom can be exercised in choosing flue-gas temperature. This flexibility in the choice of hot-air temperature arises because the final exit flue-gas temperature can be selected without the preheated-air temperature becoming a limiting factor.

F.3.6 Mechanical design

In the case of a retrofit, checks should be carried out on the mechanical components of the heater to

a) determine if mechanical components are suitable for the new conditions,

b) determine if significant deterioration has taken place,

c) consider changes in design codes that may have taken place since the original heater was designed and installed.

Components that may be affected by these checks include tube supports and guides.

F.4 Selecting an air preheat system

F.4.1 Regenerative air preheat system

F.4.1.1 Plot area

The required plot area is comparatively large because of the need to connect air and flue-gas ducting to the air preheater and to the forced and induced-draught fans. If air flow measurements are to be made, air ducting length may have to be increased to improve accuracy. The air preheater and fans should be mounted independently of the fired heater structure; that is, integration is generally impractical.

Means to reduce the plot area and ductwork at grade include

a) stacking fans,

b) using a vertical-shaft air preheater,

c) using duct-over-duct or side-by-side air preheater arrangements,

d) providing axial-flow fans.

F.4.1.2 Serviceability

The air preheater is mounted independently of the fired heater; therefore, the system is easily designed so that maintenance of the preheater has little impact on heater operation if natural-draught capability is provided. The heat-transfer surface can readily be reversed or replaced. Access should be provided at all four duct connections for service and maintenance.

F.4.1.3 Fouling and cleanability

Heat-transfer surface designs that minimize fouling are available. If fuels other than clean gas are fired, sootblowing and water-washing facilities can be provided. Regular on-line sootblowing is recommended whenever liquid fuels are fired.

Fouling of the heat-transfer surface affects thermal performance, and results in an increase in pressure drop across the unit.

F.4.1.4 Effects of air leakage into the flue gas

Air leakage into the flue gas is an inherent problem in the regenerative air preheater. Predicted leakage data at the design conditions should be provided by the air preheater manufacturer. The reduction in flue-gas temperature resulting from this leakage should be considered when evaluating means to handle potential for low-temperature corrosion downstream of the air preheater and the air preheat system.

F.4.1.5 Limitations on maximum exposure temperature

The manufacturer should provide recommended service temperature limits. The limits are generally set by metallurgical considerations.

F.4.1.6 Cold-end corrosion of the air preheater

Cold-end seal corrosion may result in increased air leakage. Other effects can include a change in pressure drop and a small reduction in heat recovery. To overcome these effects, the cold-end heat-transfer surface can be reversed or replaced on a scheduled basis.

Techniques to reduce cold-end corrosion include

a) cold-air bypassing,

b) cold-air preheating ahead of the air preheater,

c) hot-air recirculation,

d) use of low alloy corrosion-resistant steel,

e) use of ceramic-coated heat-transfer surfaces.

As with all air preheat systems that recover heat from flue gas, the protection of the downstream equipment from corrosion should be considered. Failure of the heat-transfer elements, whether due to cold-end corrosion or other causes, has little impact on the operability of the fired heater. The increase of combustion-air leakage to the flue-gas stream, unless significant, should not be sufficient to force firing reductions on the fired heater.

F.4.1.7 Burner location and arrangement

Systems using ducts to transport combustion air from the air preheater to the burners are most attractive if the burners are grouped and can be arranged in one or two adjacent plenums. Widely separated burner groups require extensive ductwork.

F.4.1.8 Effects of terminal temperature

If air preheater elements corrode and foul, the reduction in air preheater performance, generally, will not be as much as in other systems. Fired heater capacity usually will not be affected. Normal regenerative air preheater design includes an allowance for leaking air flows, and the additional leakage caused by leaking of the seals is readily handled by the fans without having an impact on the fired heater duty.

F.4.1.9 Increasing air preheater capacity

If an increase in the fired heater capacity or a fuel change is anticipated in the future, the following options should be considered:

a) providing a regenerative air preheater that has additional rotor depth capacity suitable for future operations;

b) using variable-speed drivers on the fans to conserve horsepower during initial operation. The fan operating curves should be satisfactory for all cases;

c) designing ducts for future flow, temperature and pressure requirements.

F.4.1.10 Operation without fans

If natural-draught burners with low draught loss are provided, it is possible and practical to achieve the design fired-heater duty without the fans in service. Flue gas and air will need to bypass the air preheater. The stack height and cross-sectional area should be adequate to provide the necessary draught for the natural-draught case.

F.4.1.11 Burners

The pressure differential across the air preheater causes air to leak into the flue gas. Thus additional fan capacity and horsepower are required. The use of forced-draught burners with high pressure drop increases that pressure differential and the rate of air leakage.

F.4.2 Recuperative air preheat system

F.4.2.1 Plot area

The required plot area is comparatively large because of the need to connect air and flue-gas ducting to the air preheater and to the forced and induced-draught fans. If air flowrate measurements are to be made, air-ducting length may need to be increased to improve accuracy.

Means to reduce the plot area and ductwork at grade include

a) stacking fans,

b) locating the recuperative air preheater with the fired-heater convection section,

c) using top connections on grade-located recuperative air preheaters to minimize ductwork at grade.

F.4.2.2 Serviceability

If the air preheater is mounted independently of the fired heater, the system is easily designed so that maintenance has little impact on the fired heater operation if natural-draught capability is provided.

Access should be provided at all four duct connections for service and maintenance. There are no motors, moving parts, seals or elements to be maintained.

If the air preheater is located with the fired-heater convection section, maintenance cannot be performed during fired-heater operation.

F.4.2.3 Fouling and cleanability

The combustion air and flue gas are completely separated, so fouling is usually limited to the flue-gas side. An ample flow path is required to minimize loss of draught or air flow should fouling occur. Cleaning and water-washing facilities can be provided. The manufacturer should be consulted on the advisability of on-line cleaning.

Fouling of the heat-transfer surfaces reduces thermal performance and may increase the pressure drop across the unit. Access for off-line cleaning should be considered in the duct design.

F.4.2.4 Effects of air leakage into the flue gas

Recuperative air preheat systems are usually designed for no air leakage. If substantial leakage does occur, the loss of air to the burners will reduce the fired-heater capacity and the temperature of flue gas to the stack.

F.4.2.5 Limitations on maximum exposure temperature

The manufacturer should provide recommended service temperature limits. The limits are generally set by metallurgical and thermal expansion considerations.

F.4.2.6 Cold-end corrosion of the air preheater

Metal temperatures at the coldest point need to be maintained above the acid dew point to prevent corrosion; alternatively, corrosion-resistant materials may be used.

Severe corrosion of the heat-transfer surface can result in a change in pressure drop, a reduction in heat recovery, and a loss of fired-heater capacity.

Techniques to reduce cold-end corrosion include

a) cold-air bypassing,

b) cold-air preheating ahead of the air preheater,

c) hot-air recirculation,

d) use of ceramic-coated or glass cold-end heat-transfer surface,

e) increasing the ratio of total surface on the flue-gas side to that on the air side.

As with all air preheating systems that recover heat from flue gas, the protection of the downstream equipment from corrosion should be considered.

F.4.2.7 Burner location and arrangement

Systems using ducts to transport combustion air from the air preheater to the burners are most attractive if the burners are grouped and can be arranged in one or two adjacent plenums. Widely separated burner groups require extensive ductwork.

F.4.2.8 Effect of terminal temperatures

If elements corrode and foul as a result of low flue-gas temperature, air preheater capacity is reduced. Fired heater capacity may also be reduced.

F.4.2.9 Increasing air preheater capacity

If an increase in the fired-heater capacity or a fuel change is anticipated in the future, the following options should be considered:

a) selecting a recuperative air preheater that can have elements added. Provision for adding elements usually has to be included in the original air preheater design;

b) using variable-speed drivers on the fans to conserve horsepower during initial operation. The fan operating curves will need to satisfy all cases;

c) designing ducts for future flowrate, temperature and pressure requirements.

F.4.2.10 Operation without fans

If natural-draught burners with low draught loss are provided, it is possible and practical to achieve the design fired-heater duty without the fans in service. Air needs to bypass the air preheater and be induced by the heater-stack draught. If the air preheater is located below the heater flue-gas outlet, flue gas needs to bypass the air preheater and be exhausted by the available stack draught. If the air preheater is located with the convection section, operation without the air to cool the air preheater may not be possible. Alternatively, higher draught loss may limit operation to a reduced capacity.

F.4.3 Heat-pipe air preheat system

F.4.3.1 Plot area

The required plot area is comparatively large as a result of the need to connect air and flue-gas ducting to the air preheater and to the forced and induced-draught fans. If air flowrate measurements are to be made, the air-ducting length will usually need to be increased to improve accuracy.

Means to reduce the plot area and ductwork at grade include

a) stacking fans,

b) locating the heat-pipe air preheater with the fired-heater convection section,

c) providing a geometry that accommodates different duct arrangements,

d) using axial-flow fans.

F.4.3.2 Serviceability

If the air preheater is mounted independently of the fired heater, the system is easily designed so that maintenance has little impact on fired-heater operation if natural-draught capability is provided.

Access should be provided at all four duct connections for service and maintenance.

There are no motors, moving parts, seals or elements to be maintained.

If the air preheater is located with the fired-heater convection section, maintenance cannot be conducted during fired-heater operation.

F.4.3.3 Fouling and cleanability

The combustion air and flue gas are completely separated, so that fouling is limited to the flue-gas side. An ample flow path is required to minimize loss of draught or air flow should fouling occur.

Sootblowing lanes should be provided and sootblowers installed whenever they are also installed in the convection coil of the fired-heater. On-line cleaning of the air preheater should be carried out whenever the convection coil is cleaned.

Fouling of the heat-transfer surfaces reduces the thermal performance and may increase the pressure loss across the unit.

Access for off-line cleaning should be considered in the duct design.

F.4.3.4 Effects of air leakage into the flue gas

Heat-pipe air preheat systems are usually designed for no air leakage. If substantial leakage does occur, the loss of air to the burners reduces the fired-heater capacity and the temperature of flue gas to the stack.

F.4.3.5 Limitations on maximum exposure temperature

The manufacturer should provide recommended service temperature limits. The limits are generally set by metallurgical and thermal expansion considerations. Additionally, for the heat pipe, the temperature of the working fluid should be limited to avoid degradation and/or overpressure.

F.4.3.6 Cold-end corrosion of the air preheater

Metal temperatures at the coldest point should be maintained above the acid dew-point to prevent corrosion.

Severe corrosion of the heat-transfer surface can result in a change in pressure drop, a reduction in heat recovery, heat-transfer fluid leaks and a loss of fired-heater capacity. If a leak of working fluid occurs, a safety hazard may result.

Techniques to reduce cold-end corrosion include

a) cold-air bypassing,

b) cold-air preheating ahead of the air preheater,

c) hot-air recirculation,

d) increasing the ratio of total surface on the flue-gas side to that on the air side.

As with all air preheat systems that recover heat from the flue gas, the protection of the downstream equipment from corrosion should be considered.

F.4.3.7 Burner location and arrangement

Systems using ducts to transport combustion air from the air preheater to the burners are most attractive if burners are grouped and can be arranged in one or two adjacent plenums. Widely separated burner groups require extensive ductwork.

F.4.3.8 Effect of terminal temperatures

If elements corrode and foul as a result of low flue-gas temperature, there will be a reduction of air preheater capacity and possibly a reduction of fired-heater capacity.

F.4.3.9 Increasing air preheat capacity

If an increase in the fired-heater capacity or a fuel change is anticipated in the future, the following options should be considered:

a) selecting a heat-pipe air preheater that can have elements added. Provision for adding elements usually has to be included in the original air preheater design;

b) using variable-speed drivers on the fans to conserve horsepower during initial operation. The fan operating curves should satisfy all cases;

c) designing ducts for future flowrate, temperature and pressure requirements.

F.4.3.10 Operation without fans

If natural-draught burners with low draught loss are provided, it is possible and practical to achieve design fired-heater duty without the fans in service. Air needs to bypass the air preheater and be induced by the heater-stack draught. If the air preheater is located below the heater flue-gas outlet, the flue gas must bypass the air preheater and be exhausted by the available stack draught. If the air preheater is located with the convection section, it may not be possible to operate without the air to cool the air preheater and the working fluid. Alternatively, draught losses may make it possible to operate only at a reduced capacity.

F.4.4 Indirect closed-circulation air preheat system

F.4.4.1 Plot area

The overall area is smaller than most other systems if the reheat coil is integrated with the convection section. As a minimum, plot area is required for the circulation system (surge tank, pumps and piping) and, possibly, fans.

Means to reduce the plot area include

a) mounting the induced-draught fan on top of the convection section,

b) locating the forced-draught fan, if required, close to the burner group. Two small fans located at widely separated burner groups could replace one large fan and extensive ducting,

c) locating the reheat coil in the convection section.

F.4.4.2 Serviceability

Maintenance cannot be performed on the reheat coil during fired-heater operation unless it is located outside the fired heater, in which case an induced-draught fan is usually required. If an induced-draught fan is located on the convection section, it is less accessible for inspection and maintenance. There are no motors or moving parts in the air preheater, but those on the circulation system require maintenance.

F.4.4.3 Fouling and cleanability

The combustion air and flue gas are completely separated, so fouling is usually limited to the reheat coil.

Cleaning of the reheat coil can be handled in the same manner as the convection coil; that is, by the provision of sootblowing lanes and the use of sootblowers.

Fouling of the heat-transfer surfaces reduces the thermal performance and may increase the pressure loss across the unit.

F.4.4.4 Effects of air leakage into the flue gas

There is no leakage of air into the flue-gas stream.

F.4.4.5 Limitation of maximum exposure temperature

The heat-transfer medium and the coil arrangement should be chosen so that service temperatures do not exceed the coking or degradation limits.

F.4.4.6 Cold-end corrosion of the air preheat system

Metal temperatures at the coldest point in the reheat coil need to be maintained above the acid dew-point to prevent corrosion and possible leakage. Heat-transfer fluid can be bypassed around the air coil or coils to maintain a higher fluid temperature and hence a higher reheat-coil skin temperature.

Severe corrosion of heat-transfer coils can result in a reduction of heat recovery and a loss of heat-transfer fluid.

F.4.4.7 Burner location and arrangement

Widely separated burner groups do not have to have extensive ductwork to transport combustion air from the air preheater to the burners. Separate air-heating coils can be used at each widely separated burner group since piping, rather than ductwork, is used to transport the heating medium.

F.4.4.8 Effect of terminal temperatures

If elements corrode and foul as a result of low flue-gas temperature, air preheater capacity may be reduced, and a reduction of fired-heater capacity is possible.

F.4.4.9 Increasing air preheat capacity

If an increase in fired-heater capacity or a fuel change is anticipated in the future, the following options should be considered:

a) leaving space for additional tubes in the reheat and air heating coils;

b) designing the circulation system (surge tank, pumps and piping) for the anticipated future conditions;

c) using variable-speed drivers on the fans to conserve horsepower during initial operation. The fan operating curves should satisfy all cases;

d) designing ducts for future flowrate, temperature and pressure requirements.

F.4.4.10 Operation without fans

If natural-draught burners with low draught loss are provided, it is possible to operate at design fired heater duty. In some configurations, air needs to bypass the air-heating coil. Systems with the reheat coil in the convection sections may have limited duty depending on the available draught. Degradation of the working fluid may occur, unless the reheat coil is drained.

F.4.4.11 Effect of working fluid leakage

If a leak of working fluid occurs, there may be a safety hazard.

F.4.5 External heat-source preheat system

F.4.5.1 Plot area

The plot area required is less than that required for the other systems. An air-heating coil, ductwork and, in some designs, a forced-draught fan are used.

F.4.5.2 Serviceability

Maintenance has little impact on fired-heater operation if natural-draught capability is provided.

F.4.5.3 Fouling and cleanability

The air-heating coils can be fouled by airborne dust, pollen and so forth unless a filter is fitted. This type of fouling is not usually significant.

F.4.5.4 Effect of air leakage into the flue gas

There is no such leakage.

F.4.5.5 Limitation on maximum exposure temperature

Generally, there is no problem.

F.4.5.6 Cold-end corrosion of the air preheater

Since flue gas is not involved, there is no problem.

F.4.5.7 Burner location and arrangement

Widely separated burner groups do not have to have extensive ductwork to transport combustion air from the air preheater to the burners. Separate air-heating coils can be used at each widely separated burner group, since piping rather than ductwork is used to transport the heating medium.

F.4.5.8 Effect of terminal temperatures

Fluid stream properties should be considered.

F.4.5.9 Increasing air preheat capacity

If an increase in fired-heater capacity or a fuel change is anticipated in the future, the following options should be considered:

a) leaving space for additional tubes in the air heating coil or coils or for an additional exchanger;

b) using variable speed drivers on a forced-draught fan to conserve horsepower during initial operation. The fan operating curves should satisfy both cases;

c) designing ducts for future flowrate, temperature and pressure requirements.

F.4.5.10 Operation without fans

If natural-draught burners with low draught loss are provided, it is possible to operate at design fired-heater duty without the fan in service. In some configurations, the air needs to bypass the air-heating coil or coils.

F.4.5.11 Effect of working fluid leak

If a leak of working fluid occurs, there may be a safety hazard.

F.5 Safety, operability and maintenance

F.5.1 Safety

Air preheat system components that may be entered for maintenance while the fired heater is in operation should be isolated from the fired heater. Isolation may be by means of slide gates, guillotine blinds or specially designed dampers. Consideration should be given to the tightness of closure required and to means of locking the actuator. Personnel exposure, the effects of leakage on fired-heater operation, and the accessibility for actuation should be evaluated.

If more than one process heater is connected to a common air-preheat system, it is important to monitor the flue-gas conditions at each heater to ensure that each has adequate air supply.

Emergency air inlets should be arranged so that a hot air blast will not harm personnel if the doors open when the forced-draught fan is operating. Automatically operated air doors should be located so that they do not contact personnel when activated.

Thermal rise and effluent velocity should be evaluated, so that personnel on adjacent structures will not come into contact with stack flue gas.

Periodic operational checks of the emergency air inlets, the stack damper, the spare fan or fans and other pieces of equipment are recommended.

Temperature-measuring points should be provided in the ducts to and from the air preheater to indicate overheating or possible presence of fire resulting from a tube rupture in the air preheater.

F.5.2 Operability

The flow element for measuring combustion air flowrate should be located so that only combustion air to the burners is measured. No leakage air should be included in the measurement.

If the fired heater is to be fired over a wide operating range, the use of a variable-speed or multispeed fan driver should be considered. These drivers can provide improved control, reduce noise and conserve power.

If forced-draught burners are installed, operation on natural draught may not be possible. Operations personnel should be alerted to this fact.

Cleaning facilities should be provided at the air preheater if liquid fuels are fired. On-line cleaning of the induced-draught fan may also be desirable.

F.5.3 Accessibility for maintenance

The most desirable location for duct blinds and dampers is near grade, to limit work on or over an operating fired heater.

When locating the fans and the air preheater, accessibility for maintenance should be considered.

F.5.4 Performance checks

Temperature- and pressure-measuring points in all flue-gas and air streams entering and leaving air preheater elements should be provided to monitor performance and fouling.

Pressure-measuring points upstream and downstream of the fans should be provided to assist in monitoring performance.

Air preheater performance may be adversely affected by maldistribution of air or flue-gas flows. Provision of ports to allow Pitot tube checks of entering air and flue-gas flow profiles should be considered.

Where continuous flue-gas analysis is required, properly sized and oriented analyser mounting ports need to be provided.

F.5.5 Air preheat system equipment failure

The preheat system and auxiliary equipment selected along with the required operational reliability of the fired heater should indicate the proper action in the event of equipment failure. Choices include

a) changing to natural draught,

b) bypassing the air preheater,

c) activating a spare fan or fans,

d) shutting down the fired heater.

It should be remembered that not only the means to change the operation should be provided, but also the means to check that such change has been safely and successfully executed.

F.6 Selecting system temperatures

F.6.1 Introduction

The design objective common to most air preheat systems is to obtain the maximum economic heat recovery consistent with availability and reasonable initial and maintenance costs. To achieve this objective, it is important to select cold-end design temperatures that limit fouling and corrosion and to provide a means for controlling cold-end temperatures at or above acceptable values.

The temperature at which corrosion and fouling become excessive is affected by

a) content of fuel sulfur or other contaminant,

b) fuel or flue-gas additives,

c) flue-gas oxygen content,

d) flue-gas moisture content,

e) combustion temperature,

f) furnace cleanliness,

g) burner design,

h) air preheater design,

i) ash from heavy residual oils.

It is important to provide means for controlling cold-end temperatures in an air preheat system design because

— ambient conditions change daily and seasonally,

— combustion conditions change with regard to furnace cleanliness, excess air and duty,

— fuel conditions may change,

— the temperature at which excessive corrosion and fouling occur is difficult to predict with precision.

The system designer is responsible for assessing the factors that affect cold-end corrosion and fouling for specific applications. The designer should

— select design temperatures that provide a maximum economic level of heat recovery for the normal operating conditions,

— provide a system of cold-end temperature control that minimizes levels of corrosion and fouling for all anticipated operating conditions.

In general, the selection of hot-end temperatures requires knowledge of equipment and material temperature limitations and an evaluation of equipment costs and alternative equipment arrangements.

F.6.2 Selecting cold-end temperatures

F.6.2.1 Corrosion and fouling

Corrosion of air preheater cold-end surfaces is generally caused by the condensation of sulfuric acid vapour formed from the combustion products of fuel containing sulfur. The acid deposit also provides a moist surface that is ideal for collecting particles that foul the air preheater heat-transfer surface. Consequently, it is desirable to operate air preheaters at temperatures above the acid dew-point level.

F.12 includes a summary of some of the significant test work reported in the literature (see also references [18] to [26] in the Bibliography).

F.6.2.2 Cold-end temperature control

F.6.2.2.1 General

The control of the metal temperature in the cold-end of the air preheater should accommodate changes in entering-air temperature or increases in sulfur trioxide concentration resulting from a change in fuel or combustion conditions. Three methods of cold-end temperature control for use with regenerative, recuperative and heat-pipe air preheat systems are discussed in F.6.2.2.2 through F.6.2.2.4. The fourth method, reheat of fluid inlet temperature control, is only applicable to indirect air preheat systems and is covered in F.6.2.2.5.

F.6.2.2.2 Cold-air bypass

The simplest type of cold-end temperature control is the cold-air bypass, in which a portion of the combustion air is bypassed around the air preheater. The reduction of combustion air flowrate through the air preheater results in a reduction in the cooling of the flue gas. This allows the flue-gas exit temperature to be maintained at one level while other conditions vary, or to be raised, if necessary to avoid too low a metal temperature. Control of the flue-gas exit temperature can be used to compensate for low entering-air temperature or for increased sulfur trioxide concentration. Note that if the control results in a flue-gas exit temperature higher than the design temperature, control is achieved at the expense of furnace efficiency.

F.6.2.2.3 External preheat of cold air

In this system, the desired cold-end metal temperature is maintained by heating the combustion air, before it enters the air preheater, with low-pressure steam or some other source of low-level heat. Consideration should be given to preventing fouling and plugging of the low-level heat unit with atmospheric dust that may be entrained in the combustion air and to preventing freeze-up of the coil in cold weather.

F.6.2.2.4 Recirculation of hot air

In this approach, hot combustion air is recirculated to the cold end of the exchanger through the forced-draught fan. This system increases the size and power consumption of the forced-draught fan.

F.6.2.2.5 Reheat-fluid inlet temperature control

In the circulating fluid or once through air preheat systems, the temperature of the heat-transfer surfaces exposed to the flue gases is regulated by controlling the inlet temperature of the fluid being reheated. Depending on the system design and configuration, reheat-fluid temperature is increased either by bypassing a portion of the fluid around the air-heating coil or by decreasing the reheat-fluid flowrate.

F.6.2.3 Stack temperature control

In most applications, the primary emphasis of cold-end temperature control is directed to the temperature of the heat-transfer surfaces in the flue gas stream. These surfaces are generally lower in temperature than the surfaces of downstream equipment such as the draught fan and stack. Attention should, however, be given to conditions such as cold-air leakage, insulation failures, stack downdraughts resulting from low exit-gas velocities, and gusty wind conditions that may result in lower metal temperatures and lead to corrosion. A recommended minimum metal temperature curve for surfaces exposed to flue gas is provided in Figure F.1. Any of the four methods to control cold-end temperatures (see F.6.2.2.2 through F.6.2.2.5) may also be used to control the stack temperature.

F.6.2.4 Flue-gas dew-point monitoring

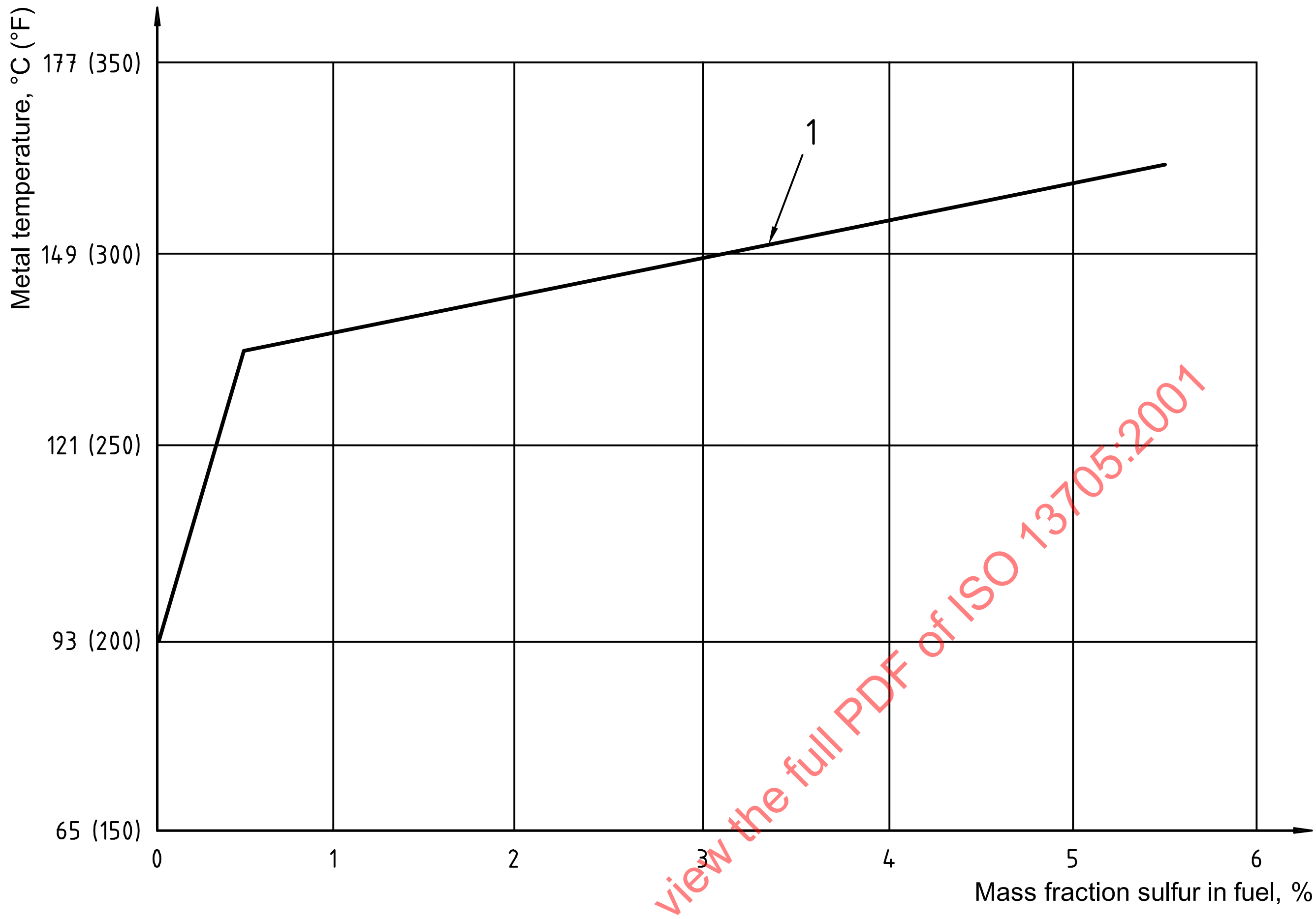
For air preheat systems with the capacity for reducing the stack temperatures below the design temperature, a program of local, periodic flue-gas dew-point testing may offer considerable economic advantages. Dew-point determinations can be used as a guide for varying the cold-end temperatures. The cold-end metal temperature is substantially lower than the exit-gas temperature, so care should be exercised if exit-gas temperature measurement is the only measurement used to indicate cold-end conditions.

F.6.2.5 Design and materials options

F.6.2.5.1 Regenerative air preheaters

The cold-end heat-transfer surfaces of a regenerative air preheater are not required to serve as pressure parts confining a fluid, they are designed to accommodate moderate corrosion and should be replaced periodically. As a result, regenerative air preheaters may operate at lower metal temperatures than most other types of air preheater. However, consideration should be given to effects on downstream equipment of the inherent air leakage and the periodic removal of acidic soot particles during sootblowing.

Regenerative air preheaters are commercially available in standard combinations of carbon steel, low-alloy steel, and corrosion-resistant enameled steel construction. The manufacturer should be consulted for recommended cold-end temperature limits.



Key

1 Recommended minimum metal temperature for convection coils, fans, and duct steel exposed to flue gas.

Figure F.1 — Recommended minimum metal temperature

F.6.2.5.2 Recuperative air preheaters

Recuperative air preheaters are commercially available with carbon steel, cast iron and glass elements. The finning normally provided in the cast iron construction may be modified on the air side of the cold-end elements to increase the metal temperatures.

Units equipped with glass elements will accommodate moderate acid condensation and fouling, but consideration should be given to requirements for the removal of deposits by sootblowing and for water washing without adversely affecting downstream equipment. In addition, the risk of breakage of glass elements, particularly during cleaning operations, should be considered. The manufacturer should be consulted for minimum recommended cold-end temperatures and materials of construction for specific applications.

F.6.2.5.3 Indirect systems

The heat-transfer surfaces exposed to the fired heater flue gas in indirect systems are generally similar in construction to and located in the fired heater convection section. The service and construction of these coils make corrosion and fouling very undesirable.

Cold-end temperatures should be selected so that coils always operate with metal temperatures above the flue gas dew point. A recommended minimum metal temperature curve is shown in Figure F.1.

F.6.3 Selecting hot-end temperature

F.6.3.1 Regenerative air preheaters

Regenerative air preheaters are generally suitable for maximum inlet flue-gas temperatures up to 540 °C (1 000 °F). By using special materials and constructions, these air preheaters can be designed for maximum flue-gas temperatures up to 675 °C (1 250 °F). The manufacturer should be consulted for specific recommendations.

F.6.3.2 Recuperative air preheaters

The standard cast-iron recuperative air preheater is generally suitable for maximum inlet flue-gas temperatures up to 540 °C (1 000 °F). By using special materials and constructions, these air preheaters can be designed for maximum flue-gas temperatures up to 980 °C (1 800 °F). The manufacturer should be consulted for specific recommendations.

F.6.3.3 Indirect systems

The coils of fluid systems, whether heat pipes or circulating, should be designed to avoid degradation of the contained fluid. For heat-transfer fluids, the manufacturer's recommendation for the maximum film temperature should be followed. In the case of the heat pipe, the manufacturer should be consulted for specific recommendations.

F.6.4 Combustion considerations

F.6.4.1 Radiant-section heat flux

In fired-heater coil configurations in which both a radiant and a convection surface are present, the preheating of the combustion air will increase the average radiant-section flux and reduce the convection-section flux for the same overall absorbed duty. Excessive tube-wall temperatures may result.

F.6.4.2 NO_x formation

If all other factors, such as burner configuration and excess air values, are held constant, the preheating of combustion air will increase the concentration of NO_x in the flue gas. It is important to select the combustion air temperatures that, together with the fuels, burners and combustion conditions, will result in acceptable levels of NO_x formation.

F.6.4.3 Burner design

The burner design should be appropriate for maximum design combustion-air temperatures, minimum start-up or air preheater bypass operation temperature, and natural-draught operation, if required.

F.7 Combustion air and flue-gas quantities

F.7.1 Introduction

An important consideration in improving fired-heater efficiency is the control of quantities of combustion air to the lowest level while maintaining complete combustion, stable flames and stable heater operation. (The addition of an air preheat system to improve fired-heater efficiency may employ a forced and/or induced-draught fan or fans.)

The discussion in this clause is limited to establishing minimum quantities of combustion air and flue-gas for new and existing installations equipped with air preheat systems.

F.7.2 New installations

F.7.2.1 Combustion-air design requirements

F.7.2.1.1 General

To establish design combustion-air requirements, the type of burner system can usually be classified into two categories:

a) natural/forced draught burner — Burners suitable for specified operation with and without the forced-draught fan;

b) forced-draught or high intensity burner — Burner heat release can only be achieved with the fan in service. (It is generally recommended that this type of burner not be operated if the forced-draught fan is not in service.)

The use of forced-draught/high intensity burners usually permits fired-heater operation at lower excess air than natural-draught burners and improves fired-heater operation, capacity and efficiency without sacrificing combustion and flame stability characteristics.

F.7.2.1.2 Excess air

The following minimum design burner excess-air quantities are recommended for negative-pressure fired heaters.

a) Natural-draught burners designed to operate with forced-draught hot/cold air and/or natural-draught ambient air:

1) fuel-gas fired: 10 %,

2) fuel-oil fired: 15 %.

b) Forced-draught/high intensity burners:

1) fuel-gas fired: 5 %,

2) fuel-oil fired: 10 %.

Note that these are minimum suggested values. Fired-heater operation at lower excess air is not recommended without special control instrumentation or design features. Where operating experience dictates, fired heaters may be designed to operate at higher excess-air values. Design efficiencies of fired heaters should be at excess-air quantities stated in 6.2.3.

F.7.2.1.3 Minimum air flow for forced-draught fans

If the air preheater is not airtight, the amount of leakage should be specified by the manufacturer and added directly to the design (100 %) flow quantity to determine overall flow requirements. The fan selection shall be made for the calculated quantity of air for design (100 %) operation (including any defined leakage from the preheater and other system losses) at design excess air, all multiplied by a factor of 1,15, a safety margin.

The range of ambient air conditions shall be specified by the purchaser. The forced-draught fan shall be sized using maximum ambient-air temperature and humidity at site elevation. Provision shall be made to allow the forced-draught fan to be started and operated at minimum ambient-air temperature and humidity.

F.7.2.2 Flue-gas design requirements for induced-draught fans

If the air preheater is not airtight, the amount of leakage should be specified by the manufacturer and added directly to the design (100 %) flow quantity to determine overall flowrate requirements. The fan selection shall be made for the calculated quantity of flue gas for the design (100 %) operation (including any defined leakage from the preheater and other units in a multiheater system) at design excess air, all multiplied by a factor of 1,15, a safety margin.

To allow for variation in heater operation from the design condition, an allowance for an increase in flue-gas temperature should be considered. Provision shall be made to allow the induced-draught fan to be started and run when the gas temperature is low, even as low as ambient. These are minimum requirements, and the system should be designed to meet the purchaser's specified requirements.

F.7.2.3 Fan sizing

The design condition (100 %) for the fired heater often includes allowances for safety, future process increases or a general surplus dictated by experience. As a consequence, the resulting air system may be much larger than that required for normal operation, and the heater operation at turndown may be difficult. When preparing specifications, the designer should consider the range of operation required to obtain an optimum arrangement.

F.7.3 Retrofits

Where air preheat systems are added to existing fired-heater installations, flexibility in designing the most economical system is usually limited. The system designer should work closely with the purchaser to achieve optimum results. To compensate for the possibility of greater leakage in an existing fired heater, increases in minimum design flow requirements should be considered.

Preheater air leakage may contribute to combustion requirements, but leaking air does not pass through the air side of the preheater. If this fact is not taken into consideration, incorrect calculations of the exiting gas and air temperatures may result.

F.8 Duct design and damper selection

F.8.1 Introduction

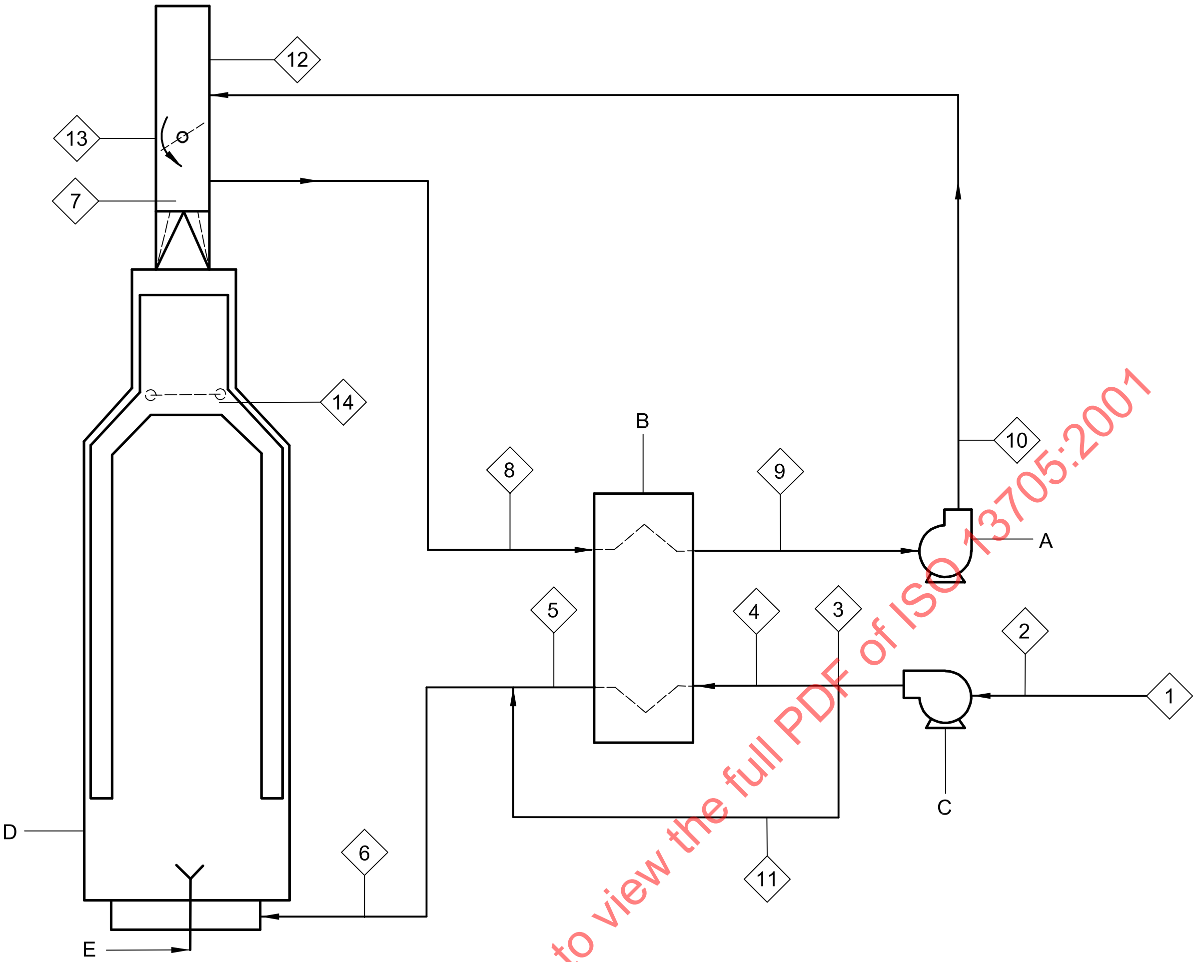
Clause F.8 is intended to provide engineering procedures for the design and analysis of complex air preheat systems with regard to pressure drops and pressure profiles. It has been developed and based on commonly used correlations and procedures. While the calculation procedures are relatively simple, their application to duct systems common to fired air preheaters can be confusing. Comments on some specific applications have been included to provide guidance.

The basic assumption of this clause is that all of the pertinent design data such as flowrates, temperatures and pressure drops for equipment are available from the fired-heater and air preheater designers. These data should be compiled in a usable form (see Figure F.2 as an example). In addition, the spatial relationships between the basic pieces of equipment should be known or laid out in the process of duct design.

F.8.2 Pressure drop calculation

F.8.2.1 General

The following equations and figures are a distillation of a mass of available literature on the subject of fluid flow. This material has been used successfully in the design of duct systems and it is thought to be particularly useful in that type of calculation. Two forms are presented, linear velocity and mass flowrate. Use of either form remains the choice of the designer.



Key

A Induced-draught fan
B Exchanger
C Forced-draught fan
D Furnace
E Fuel

Point number	**Flowrate** kg/h (lb/h)	**Temperature** °C (°F)	**Pressure** mmH_2O (inH_2O)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			

Figure F.2 — Sample flow sheet for duct design and damper selection

F.8.2.2 Calculating pressure drop in a straight duct

In SI units:

$$\Delta p/100 = 5{,}098 \times 10^3 \left(f \cdot \rho \cdot v^2 / d \right) \quad \text{(F.1)}$$

or

$$\Delta p/100 = 5{,}098 \times 10^3 \left(f \cdot q_{m,A}{}^2 / d \cdot \rho \right) \quad \text{(F.2)}$$

where

$\Delta p/100$ is the pressure drop per 100 m, expressed in millimetres of water column (mmH_2O);

f is Moody's friction factor;

ρ is the flow density, in kilograms per cubic metre (kg/m^3);

v is the linear velocity, in metres per second;

$q_{m,A}$ is the areic mass flowrate, in kilograms per square metre per second ($kg/m^2/s$);

d is the duct inside diameter, in millimetres.

In US Customary units:

$$\Delta p/100 = 3{,}587 \left(f \cdot \rho \cdot v^2 / d \right) \quad \text{(F.3)}$$

or

$$\Delta p/100 = 3{,}587 \left(f \cdot q_{m,A}{}^2 / d \cdot \rho \right) \quad \text{(F.4)}$$

where

$\Delta p/100$ is the pressure drop per 100 ft, expressed in inches of water column (inH_2O);

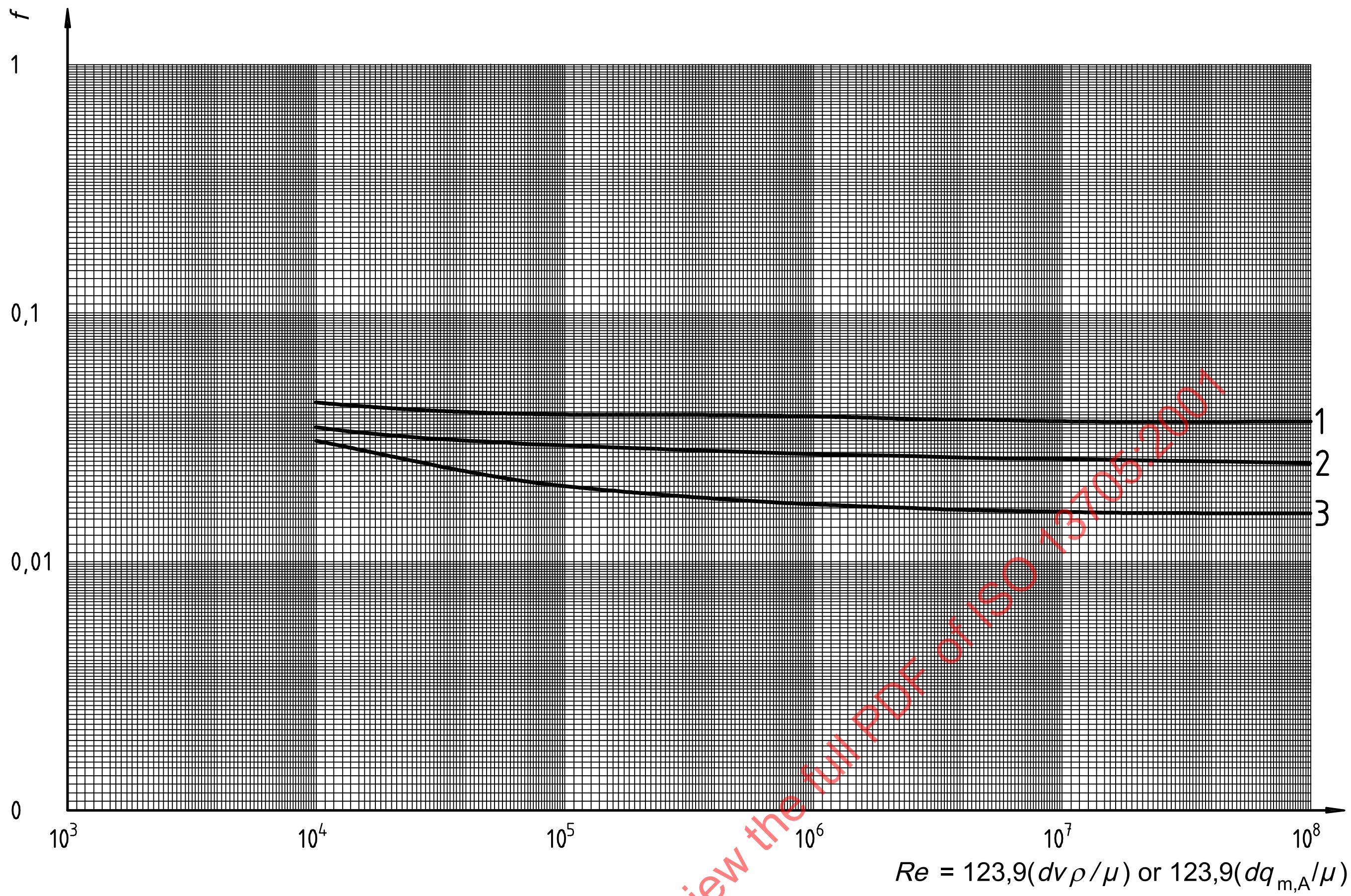
f is Moody's friction factor [see curve 1 on Figure F.3 and equation (F.5)];

ρ is the flow density, in pounds per cubic foot (lb/ft^3);

v is the linear velocity, in feet per second (ft/s);

$q_{m,A}$ is the areic mass flowrate, in pounds per square foot per second ($lb/ft^2/s$);

d is the duct inside diameter, in inches.



Key

1 Very rough lined ducts: E = 0,01
2 Medium rough lined ducts: E = 0,003
3 Smooth unlined ducts: E = 0,000 5

Figure F.3 — Moody's friction factor

F.8.2.2.1 Calculating Reynolds number Re

In SI units:

$$Re = 1{,}0\ d \cdot v \cdot \rho / \mu \qquad \text{(F.5)}$$

or

$$Re = 1{,}0\ d \cdot q_{m,A} / \mu \qquad \text{(F.6)}$$

where

μ is the viscosity, in millipascals per second (mPa·s);

other symbols as above.

In US Customary units:

$$Re = 123{,}9\ d \cdot v \cdot \rho / \mu \qquad \text{(F.7)}$$

or

$$Re = 123{,}9\ d \cdot q_{m,A} / \mu \qquad \text{(F.8)}$$

where

μ is the viscosity, in centipoise (cP);

other symbols as above.

The following generalized equation may be used for viscosities for both air and flue gas without introducing any significant error into the pressure drop calculations.

$$\text{Viscosity} = 0{,}016\ 2\ (T/255{,}6)^{0{,}691} \qquad \text{(F.9)}$$

where T is the temperature, in kelvin (K).

In US Customary units:

$$\text{Viscosity} = 0{,}016\ 2\ (T/460)^{0{,}691} \qquad \text{(F.10)}$$

where T is the temperature, in degrees Rankine (°R).

F.8.2.2.2 Calculating hydraulic mean diameter

Equations (F.1) through (F.8) employ a diameter dimension (d) and hence are for round ducts. To use these equations for rectangular ducts, an equivalent circular duct diameter, referred to as the hydraulic mean diameter, should be calculated. A useful correlation for the hydraulic mean diameter is:

$$d_e = 2ab/(a + b) \qquad \text{(F.11)}$$

where

d_e is the hydraulic mean diameter;

a is the length of one side of rectangle;

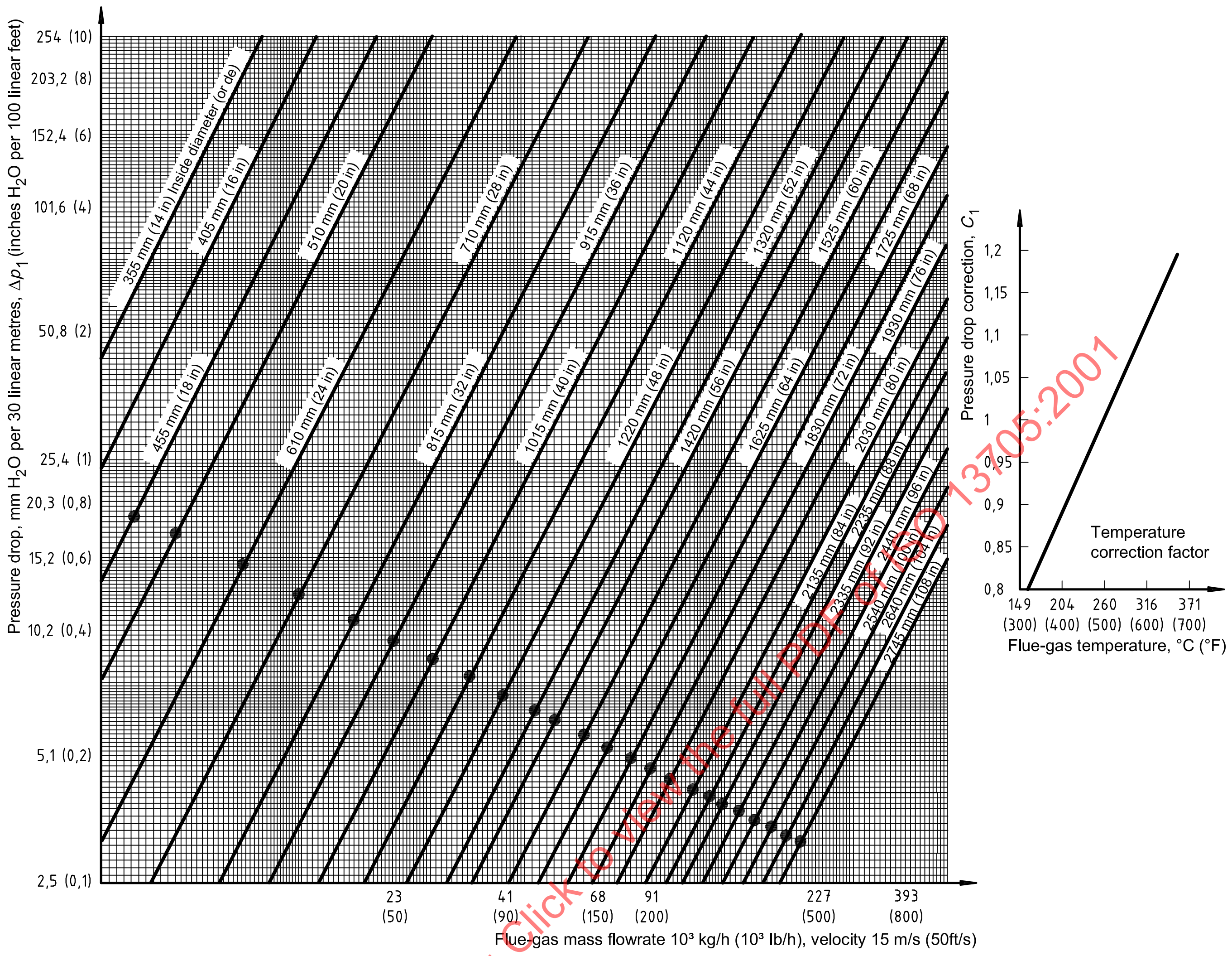
b is the length of adjacent side of rectangle.

When using d calculated from equation (F.11), use the actual velocity calculated for the rectangular duct.

F.8.2.2.3 Approximate solution of pressure drop in straight duct

By making several assumptions, the calculation of pressure drop in straight ducts can be reduced to a simplifying chart, presented for convenience in Figure F.4. Any error introduced is not significant for most cases.

When using a hydraulic mean diameter in Figure F.4, use the correlation shown on the curve rather than the one in equation (F.11).



NOTE 1

$$\Delta p\left[\frac{\text{inH}_2\text{O}}{100\text{ ft}}\right] = \Delta p_1 (C_1)(C_2)$$

Roughness correction, C_2:

a) Very rough (for example, brick) – 1,0

b) Medium rough (for example, castable refractory) – 0,68

c) Smooth (for example, unlined steel) – 0,45

NOTE 2 For rectangular ducts:

$$d_e = 1{,}3 \times 0{,}25(a+b) / 0{,}65(a \cdot b)$$

Figure F.4 — Pressure drop for flue gases (MW = 28) in ducts at 100 kPa (1 bar) (ga) [approx. 134,6 mmH$_2$O (5,3 inH$_2$O)]

F.8.2.3 Calculating pressure drop in fittings and cross-section changes

In SI units:

$$\Delta p = C\left(5{,}1 \times 10^{-2}\right)\rho \cdot v^2 \quad \text{(F.12)}$$

or

$$\Delta p = C\left(5{,}1 \times 10^{-2}\right)q_{m,A}{}^2/\rho \quad \text{(F.13)}$$

where

Δp is the pressure drop in fittings, expressed in millimetres of water column (mmH_2O);

C is the fitting loss coefficient from Table F.1;

ρ is the flow density, in kilograms per cubic metre (kg/m^3);

v is the linear velocity, in metres per second;

$q_{m,A}$ is the areic mass flowrate, in kilograms per square metre per second ($kg/m^2/s$);

In US Customary units:

$$\Delta p = C\left(2{,}989 \times 10^{-3}\right)\rho \cdot v^2 \quad \text{(F.14)}$$

or

$$\Delta p = C\left(2{,}989 \times 10^{-3}\right)q_{m,A}{}^2/\rho \quad \text{(F.15)}$$

where

Δp is the pressure drop in fittings, expressed in inches of water column (inH_2O);

C is the fitting loss coefficient from Table F.1;

ρ is the flow density, in pounds per cubic foot (lb/ft^3);

v is the linear velocity, in feet per second (ft/s);

$q_{m,A}$ is the areic mass flowrate, in pounds per square foot per second ($lb/ft^2/s$);

Consideration should be given to the use of turning or splitter vanes to improve the characteristics of high pressure drop fittings.

Table F.1 — Fittings

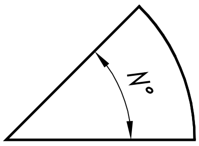
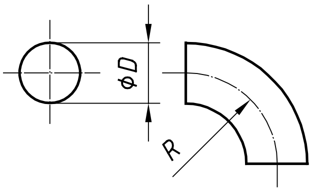
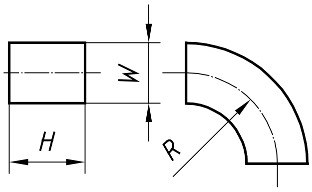
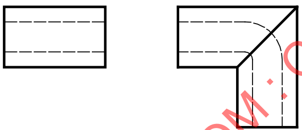
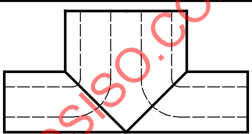
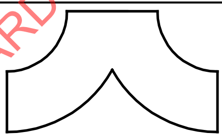
Fitting type	Fitting illustration	Dimensional condition	Loss coefficient	L/D or L/W
Elbow of N° degree turn (rectangular or round)		No vanes	N/90 times the value for a similar 90° elbow	
90° round section elbow		Mitre [a] R/D = 0,5 R/D = 1,0 R/D = 1,5 R/D = 2,0	1,30 0,90 0,33 0,24 0,19	65 45 17 12 10
90° rectangular section elbow		Mitre, H/W = 0,25 R/W = 0,5 R/W = 1,0 R/W = 1,5 Mitre H/W = 0,5 R/W = 0,5 R/W = 1,0 R/W = 1,5 Mitre H/W = 1,0 R/W = 0,5 R/W = 1,0 R/W = 1,5 Mitre H/W = 4,0 R/W = 0,5 R/W = 1,0 R/W = 1,5	1,25 1,25 0,37 0,19 1,47 1,10 0,28 0,13 1,50 1,00 0,22 0,09 1,35 0,96 0,19 0,07	25 25 7 4 49 40 9 4 75 50 11 4,5 110 85 17 6
90° mitre elbow with vanes			C = 0,1 to 0,25	
Mitred tee with vanes		Equal to an equivalent elbow (90°) (base loss on the entering velocity)		
Formed tee		Equal to an equivalent elbow (90°) (base loss on the entering velocity)		

Table F.1 (*continued*)

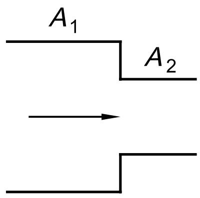
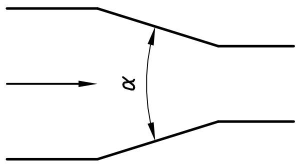
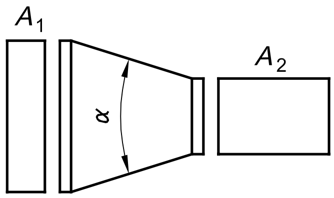
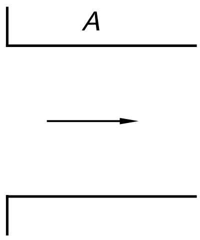
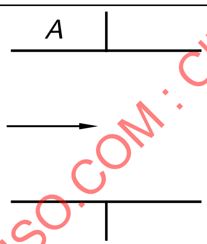
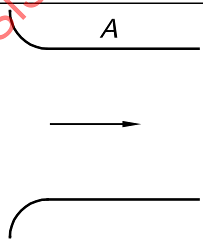
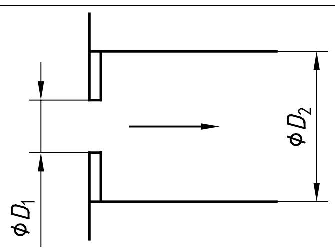
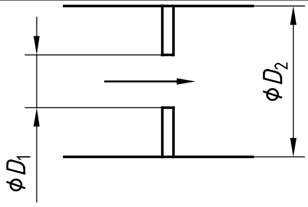
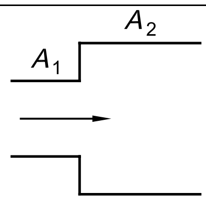
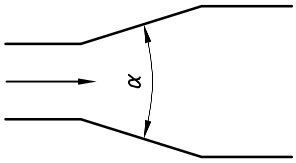
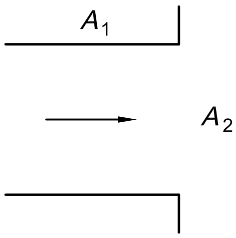
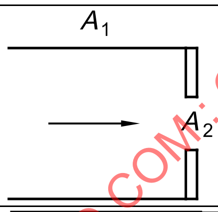
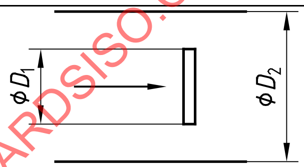
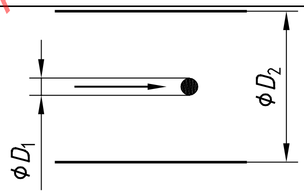
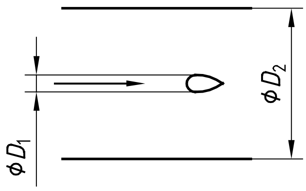
Fitting type	Fitting illustration [c]	Dimensional condition	Loss coefficient based on velocity in smaller area
Sudden contraction		A_2/A_1 = 0,2 A_2/A_1 = 0,4 A_2/A_1 = 0,6 A_2/A_1 = 0,8	0,32 0,25 0,16 0,06
Gradual contraction		α = 30° α = 45° α = 60°	0,02 0,04 0,07
Slight contraction, change of axis		$A_1 \cong A_2$ $\alpha \leqslant 14°$	0,15
Flanged entrance			0,34
Entrance to larger duct			0,85
Bell or formed entrance			0,03
Square-edged orifice at entrance		D_1/D_2 = 0,2 D_1/D_2 = 0,4 D_1/D_2 = 0,6 D_1/D_2 = 0,8	1,90 1,39 0,96 0,61

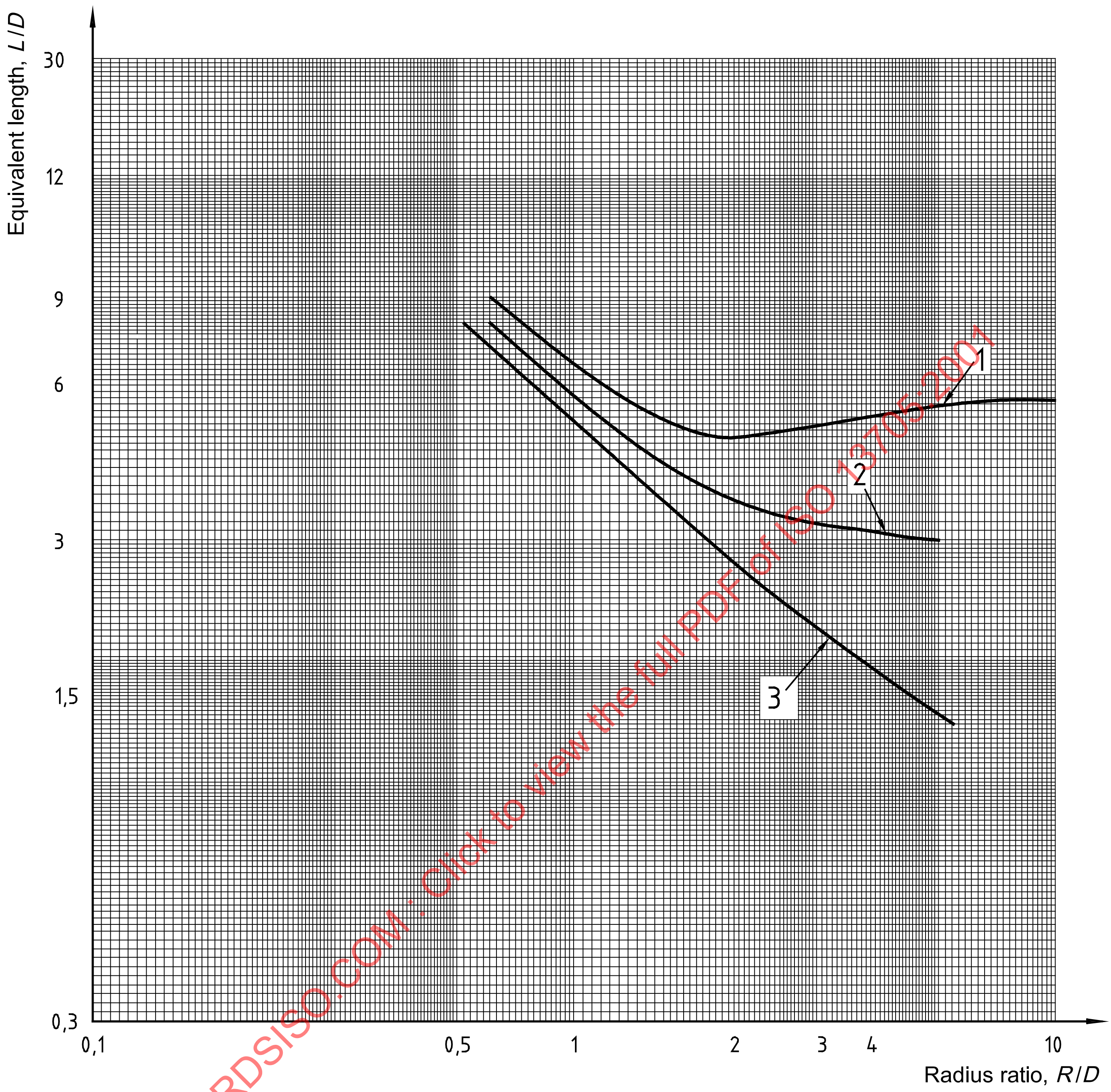
Table F.1 (*continued*)

Fitting type	Fitting illustration [c]	Dimensional condition	Loss coefficient based on velocity in smaller area
Square-edged orifice in duct [b]		D_1/D_2 = 0,2 D_1/D_2 = 0,4 D_1/D_2 = 0,6 D_1/D_2 = 0,8	1,86 1,21 0,64 0,20
Sudden enlargement		A_1/A_2 = 0,1 A_1/A_2 = 0,3 A_1/A_2 = 0,6 A_1/A_2 = 0,9	0,81 0,49 0,16 0,01
Gradual enlargement		α = 5° α = 10° α = 20° α = 30° α = 40°	0,17 0,28 0,45 0,59 0,73
Sudden exit		$A_1/A_2 \cong 0$	1,0
Square-edged orifice at exit		A_2/A_1 = 0,2 A_2/A_1 = 0,4 A_2/A_1 = 0,6 A_2/A_1 = 0,8	2,44 2,26 1,96 1,54
Bar in duct		D_1/D_2 = 0,10 D_1/D_2 = 0,25 D_1/D_2 = 0,50	0,7 1,4 4,0
Pipe or rod in duct		D_1/D_2 = 0,10 D_1/D_2 = 0,25 D_1/D_2 = 0,50	0,2 0,55 2,0
Streamlined object in duct		D_1/D_2 = 0,10 D_1/D_2 = 0,25 D_1/D_2 = 0,50	0,07 0,23 0,90

[a] This value is for a two-piece mitre. For three-, four- or five-piece mitres, see Figure F.5.

[b] For permanent loss in Venturis, use a loss coefficient of 0,05 based on throat area.

[c] A and D represent respectively the cross-sectional area and diameter of the relevant section of the fitting.



Key

1 3-piece elbow
2 4-piece elbow
3 5-(or more) piece elbow

Figure F.5 — Equivalent lengths (*L/D*) for multiple-piece mitre elbows of round cross-section

F.8.2.4 Calculating pressure drop in branch connections as in header ducts

In SI units:

$$H_{\text{v}} = \left(5{,}1 \times 10^{-2}\right) \rho \cdot v^2 \tag{F.16}$$

or

$$H_{\text{v}} = \left(5{,}1 \times 10^{-2}\right) q_{\text{m}}^{\ 2} / \rho \tag{F.17}$$

where

H_v is the velocity head, millimetres water gauge.

In US Customary units:

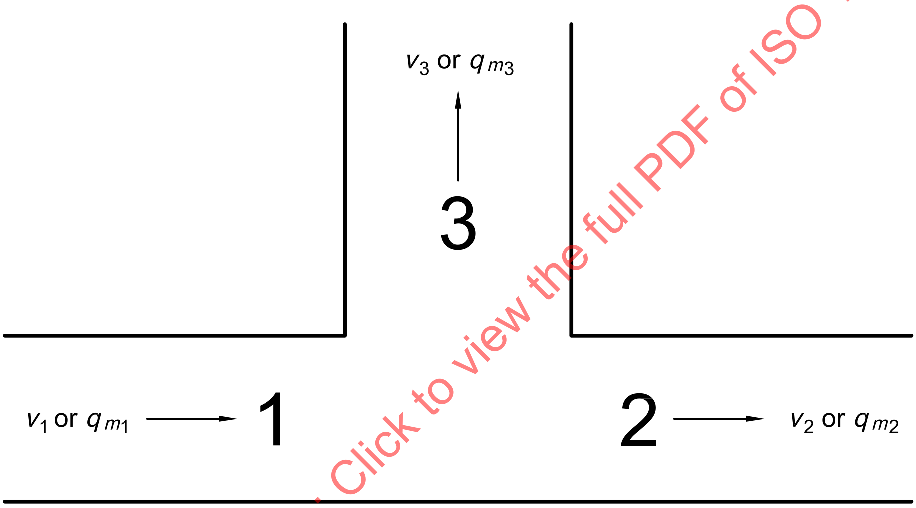
$$H_v = (2{,}989 \times 10^{-3}) \rho \cdot v^2 \tag{F.18}$$

or

$$H_v = (2{,}989 \times 10^{-3}) q_m{}^2 / \rho \tag{F.19}$$

where

H_v is the velocity head, inches water gauge.



$$\Delta p \text{ Point 1 to Point 2} = 0{,}5\ (H_{v1} - H_{v2}) \tag{F.20}$$

NOTE Loss coefficient of 0,5 is the net of loss and regain. It may be a lower value for a well-designed branch.

$$\Delta p \text{ Point 1 to Point 3} = H_{v1}\ (C_b - 1) + H_{v3} \tag{F.21}$$

where

C_b is the branch loss coefficient (see Figure F.6);

v_3 or q_{m3} is the branch velocity;

v_2 or q_{m2} is the downstream velocity;

v_1 or q_{m1} is the upstream velocity;

v_x is the linear velocity;

$q_{m,Ax}$ is the areic mass flowrate;

H_{vx} is the velocity head;

Δp is the pressure drop.

F.8.2.5 Calculating differential pressure resulting from differential temperature (draught)

In SI units:

$$\Delta p_D = 0{,}203(p_A)\left[(29/T_{a,a}) - (MW/T_G)\right](l_2 - l_1) \quad \text{(F.22)}$$

where

- Δp_D is the draught, in millimetres water gauge;
- p_A is the atmospheric pressure at site grade, in kilopascals;
- $T_{a,a}$ is the temperature of ambient air, in kelvin;
- T_G is the temperature of flue gas or air in duct, in kelvin;
- MW is the molecular mass of flue gas;
- l_1 is the elevation of Point 1 above grade, in metres;
- l_2 is the elevation of Point 2 above grade, in metres.

In US Customary units:

$$\Delta p_D = 0{,}179(p_A)\left[(29/T_{a,a}) - (MW/T_G)\right](l_2 - l_1) \quad \text{(F.23)}$$

where

- Δp_D is the draught, in inches water gauge;
- p_A is the atmospheric pressure at site grade, in pounds per square inch (absolute);
- $T_{a,a}$ is the temperature of ambient air, in degrees Rankine;
- T_G is the temperature of flue gas or air in the duct, in degrees Rankine;
- MW is the molecular mass of flue gas;
- l_1 is the elevation of Point 1 above grade, in feet;
- l_2 is the elevation of Point 2 above grade, in feet.

F.8.3 Zone concept

F.8.3.1 General

Regardless of which type of air preheat system is used, one or more of the duct zones shown in Figure F.7 will probably be involved. Knowledge of the basic flowrates, temperatures and pressure drops for equipment pointed out in F.8.1, as well as knowledge of the basic spatial relationships of the components of the system, are mandatory to begin meaningful calculations.

F.8.3.2 Forced-air zone

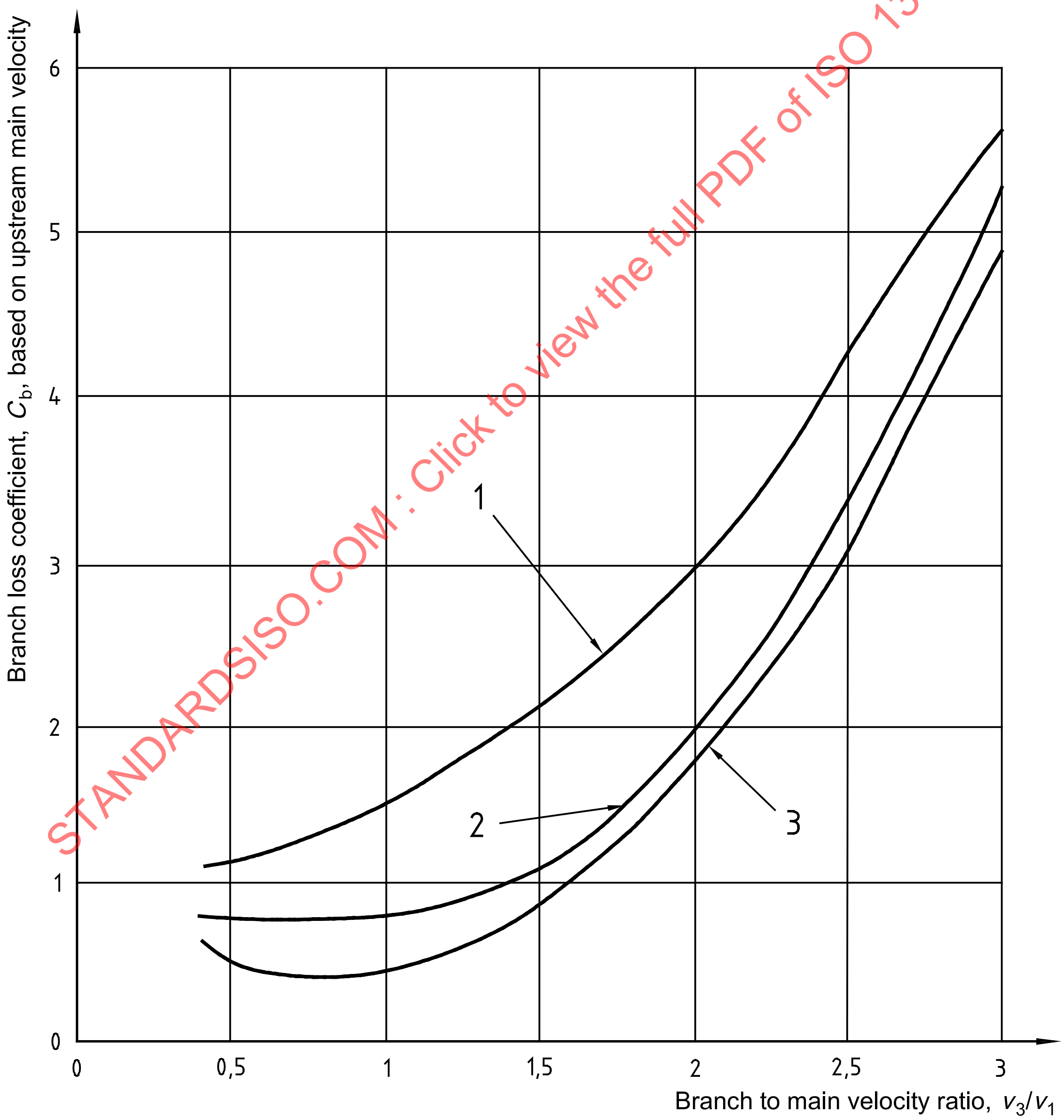
The basic elements in this zone are the fired-heater burners and plenum or heater duct, the air preheater, the forced-draught fan and the inlet trunk or silencer. The nature of this zone requires that the calculations commence at the downstream terminus or burner exit.

The pressure at the burner location inside the fired heater is the starting point. The pressure drop across the burner should be added to this pressure (whether it be negative or positive) to obtain the plenum or burner duct pressure. This may be negative, positive or zero, depending on the combination of heater pressures and burner pressure drop.

At this point, some form of branch connection or header duct calculation may be necessary, depending on the configuration of the burners and the ductwork. Some allowance should be made for any dampers or flow measurement devices between the fired heater and the air preheater.

The air preheater air-side pressure drop should be known from the performance data provided by the manufacturer. Any air leakage should also be known, since this needs to be added to the burner air flow to determine the flowrate between the air preheater and the forced-draught fan.

Clearly, the sum of the heater plenum or header duct pressure, the duct pressure drop including dampers and flow devices, and the preheater air-side pressure drop determines the forced-draught fan discharge pressure. Equally clear is that the forced-draught fan suction pressure will be atmospheric pressure minus the inlet trunk or silencer pressure drop. The value of this pressure drop is normally available from the manufacturer.



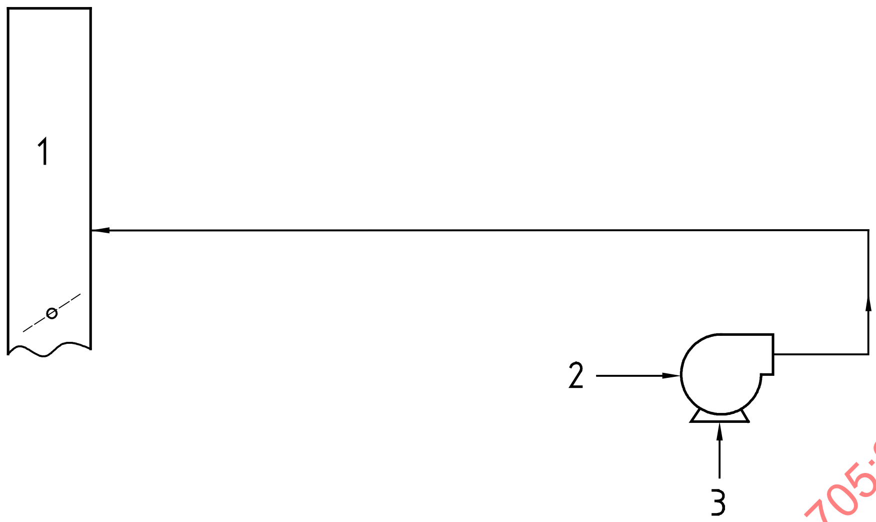
Key

1 90° take-off

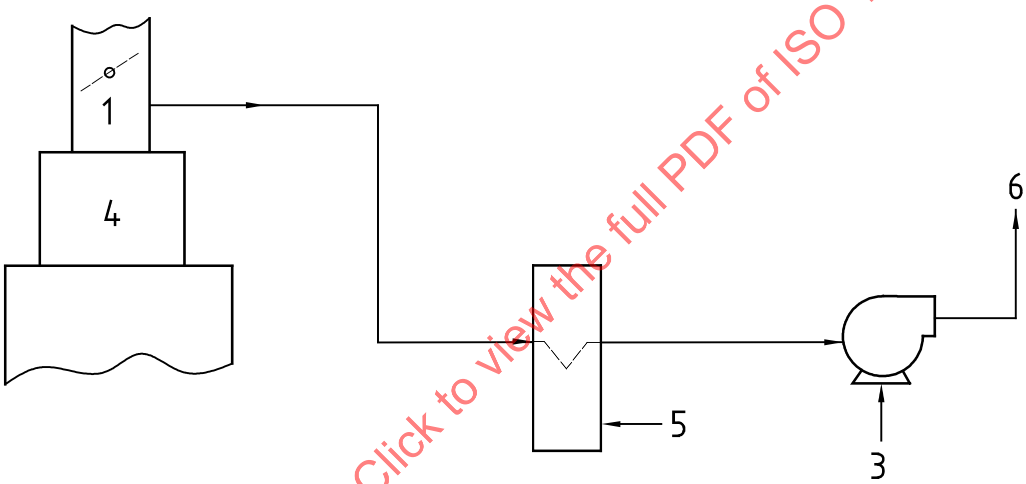
2 60° take-off

3 45° take-off

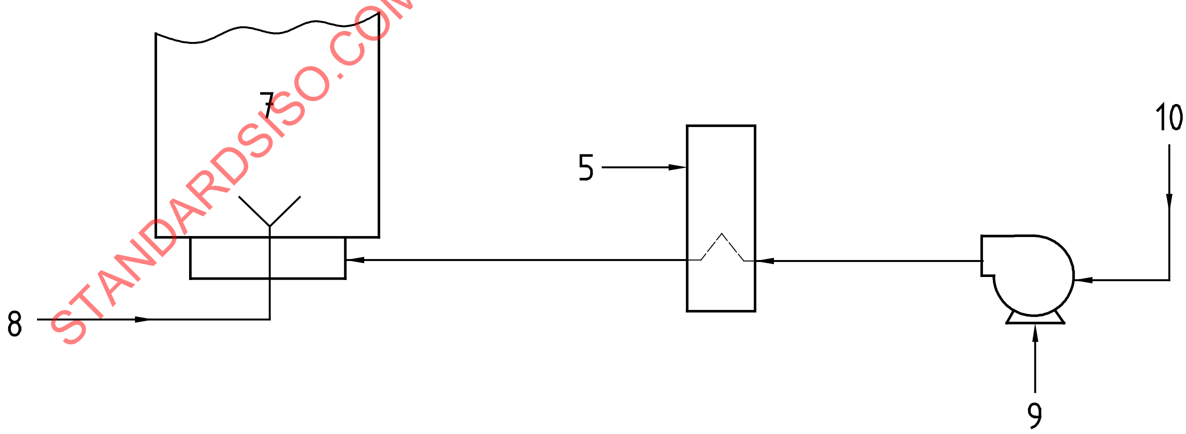
Figure F.6 — Branch loss coefficients



a) Typical induced-draught zone: induced-draught blower to top of stack



b) Typical induced-draught zone: furnace to induced-draught blower



c) Typical forced-air zone

Key

1 Stack with damper
2 From air preheater
3 Induced-draught blower
4 Furnace convection section
5 Air preheater
6 To stack
7 Furnace plenum
8 Fuel
9 Forced-draught fan
10 Inlet trunk or silencer

Figure F.7 — Duct zones

F.8.3.3 Induced-draught zone (furnace to induced-draught fan)

The elements in this zone normally consist of the fired-heater convection section, the stack breeching and lower stack section, the isolation damper, the air preheater and the induced-draught fan. For the normal negative-pressure heater setting, it is desirable to maintain the pressure immediately below the convection section at some predetermined slightly negative value. For this reason, the calculation for this zone should start at that point.

The pressure drop through the convection section should be available from the heater manufacturer. The convection-section pressure drop taken in the direction of flow is a negative value, and should be numerically added to the starting pressure. All pressures leading to the induced-draught fan will be increasingly negative. The pressure at the exit from the convection section is determined; the pressure drops from this point on are for ducts (including lower stack section and breeching) and the flue-gas side of the preheater.

Some pressure differential exists across the isolation damper, and assuming that no bypassing is permitted, some recycle leakage may occur. That is, some cooled flue gas in the stack above the isolation damper may leak through and flow along with the hot flue gas to the air preheater and induced-draught fan and simply be recycled. Such recycle reduces the effectiveness of the air preheater, and if the amount is large, can overload the fan. Unless positive steps are taken to avoid this, some allowance should be made in the flowrate and temperature of the flue gas going to the air preheater and the induced-draught fan.

The pressure drop across the flue-gas side of the air preheater should be known from the manufacturer. If there is any air leakage across the air preheater, it should be added at this point to determine the flowrate to the induced-draught fan.

In summary, the numerical sum of the pressure required at the entry to the convection section, the convection-section pressure drop, and the pressure drops in the breaching, lower stack, ductwork including any dampers, and the preheater-gas side, gives the negative suction pressure for the induced-draught fan. (Corrections for draught effects are required. A discussion of this follows the zone comments.)

NOTE Pressure drops are sometimes referred to as draught losses.

F.8.3.4 Induced-draught zone (induced-draught fan to top of stack)

The elements in this zone consist of the induced-draught fan, the ductwork and the top of the stack. It should be noted that a separate stack can be utilized so that the flue gas is not returned to the original stack.

Zone calculation commences from the downstream exit or the atmosphere at the top of the stack. It is useful to treat the stack as simply an extension of the ductwork, so that the calculation is reduced to a series of duct-pressure drops. The sum of these pressure drops, when corrected for draught effects, gives the induced-draught fan discharge pressure. Any comments made about leakages (see F.8.3.2) should be considered in this zone.

F.8.4 Draught effects

All duct calculations should account for differential pressure resulting from thermal differences, commonly known as the draught effect. This effect can produce either positive or negative pressure, depending on location and conditions. It should be accounted for in determining net pressure losses or gains in any system. It is often only referred to for the calculation involving the stack, but draught effects are present for any situation involving air or gas having a temperature different from the ambient temperature.

F.8.5 Dual-draught system

In systems with burners intended to be operated on natural draught as well as in the forced- or induced-draught mode, ensure in sizing and arranging of ducts, plenums and air-door components to accommodate both types of operation. The draught on the heater side of the burners should be adequate to overcome the friction loss of the system between the burner and the atmosphere. To facilitate swift conversion to natural draught, it is common practice to operate the burner plenum at zero or slightly negative pressure when in the forced- or induced-draught mode. This should be accounted for in the basic design of the system.

F.8.6 Velocity guidelines

In the absence of specific values, the designer may consider the following as a guideline to recommended velocities in ducts:

a) straight duct — recommended velocity 15 m/s (50 ft/s);

b) turns or tees — recommended velocity 15 m/s (50 ft/s) — a lower velocity may be justified by lower energy costs;

c) burner air supply ducts — recommended velocity 7,5 m/s (25 ft/s) to 10,5 m/s (35 ft/s). (An alternative approach is to set the velocity head in these ducts equal to 10 % of the burner pressure drop.)

F.8.7 Damper considerations and selection

F.8.7.1 General

In any attempt at duct system design, consider the placement and selection of dampers for control and isolation of various elements of the system. When selecting a damper, consider the operating differential pressure and the temperature across it. Some situations require a much sturdier design than others.

If balancing dampers are deemed necessary in the air supply system, they should operate manually and should lock positively in the chosen position. Consider what measurements will be made or criteria set for selecting the damper position before judging that a damper is required.

Guillotine blinds or slide gates may be used to isolate equipment, either after a change to natural draught or when isolating one of several heaters served by a common preheat system. Consider exposure of personnel, the effects of leakage on heater operation, the tightness of damper shutoff, and the location of the damper (close to or remote from the affected heater).

Multiple-louvred, opposed-blade dampers are preferred for control applications, as they provide better control characteristics. Parallel-blade or single-blade dampers should not be applied where the flow-directing feature inherent in their design may impair fan performance or provide an unbalanced flow distribution in the preheater.

Actuation linkage systems for dampers used for control or tight shutoff should have a minimum number of parallel or series arms. The potential for asymmetrical blade movement and leakage increases with linkage complexity.

If natural-draught air inlets are required, they should be located where they will not restrict the flow of air to the burners.

The expected leakage or the leakage to be tolerated should be stated in specifying damper requirements. With the exception of isolation damper designs, the amount of leakage varies with type and operating conditions.

F.8.7.2 Damper function and selection

Table F.2 provides a listing of equipment by function and recommended damper type that can be used for damper selection.

F.8.8 Duct stratification

Duct configurations in the vicinity of the fans, air preheater and burners should not allow significant stratification of air or flue gas. Stratification can affect performance adversely. In addition, measurement point locations in these areas should be carefully selected to avoid errors resulting from stratification. A measurement point for traversing should be included.

Table F.2 — Recommended damper types

Equipment	Function	Recommended damper type
Forced draught		
Inlet	Control	Radial vane damper, blade louvre or inlet box damper
Outlet	Isolation for personnel safety	Zero leakage slide gate or guillotine blind
Outlet	Control	Multi-blade louvre
Induced draught		
Inlet	Control	Radial vane damper, multi-blade louvre or inlet box damper
Inlet	Isolation for personnel safety	Zero leakage slide gate or guillotine blind
Outlet	Isolation for personnel safety	Zero leakage slide gate or guillotine blind
Stack	Quick response, isolation and control	Multi-blade louvre or butterfly damper
Combustion-air bypass	Quick response, isolation and control	Multi-blade louvre or butterfly damper
Emergency natural draught/air inlet	Quick response and isolation	Low leakage damper or door
Fired heater	Burner control	Multi-blade or butterfly damper
	Isolation	Zero leakage slide gate or guillotine blind

F.9 Guidelines for specifying equipment

F.9.1 Introduction

This clause covers the requirements for the design and fabrication of the various connecting components of an air preheat system. The preferred choice of materials where applicable is also included.

This annex primarily covers external interconnecting components between the fired process heater and the air preheater. For considerations concerning the fired heater or components internal to the fired heater, refer to clauses 1 through 17.

F.9.2 Ductwork and stack

F.9.2.1 General

The difference between this annex and clauses 1 through 17 lies in the design of ductwork. The ductwork requirements for air preheat systems can be separated into two categories: flue-gas ductwork and air ductwork. Generally, the mechanical and structural design principles are the same for both. The flue-gas ductwork is normally subjected to the corrosive stream (that is, flue gas). Cold-end temperatures can cause dew-point corrosion, so it is important to select proper liners or ductwork material envelopes. The choice of round or rectangular duct, and internal insulation/refractory as opposed to external insulation is an economic decision that should be considered early in the design. Where space permits, round sections of ducts are recommended. Ducts shall be gastight and of flange-and-gasket or seal-welded construction.

Ductwork should be designed to permit replacement of components, such as dampers, blowers, heat exchangers and expansion joints, within the duct system.

Air and flue-gas ducts are required to provide uniform fluid-flow distribution to the air preheater heat-transfer surface. Failure to achieve uniform flow may cause a reduction in performance of the air heating device. Internal duct bracing, if used, should not be installed within three diameters of equipment since disruption or restriction of the flow may occur. Use of turning vanes or air straighteners should be considered to ensure uniform distribution.

F.9.2.2 Cross-section

Round ductwork is structurally simpler to design than rectangular ductwork and requires less material to contain the duct flow area. It can be reinforced with simple stiffening rings and generally requires less material for structural support. It can be designed for maximum flow area per unit of duct mass.

Rectangular ducts need to be reinforced in a manner that will keep the deflections and stresses within acceptable limits. Also, the designer should avoid having the flat side of ducts coincidently resonant with blower or fan speeds. Designing for possible buckling of flat walls may require additional bracing for stiffness.

F.9.2.3 Plenums or wind box

The plenum design and layout shall be such that there is a clearance around and under the plenum to permit withdrawal of burner parts without dismantling the plenum. The plenum shall not enclose the structural supports of the fired process heater without providing for structural integrity. Plenum design should be such that the process heater floor structure does not fail in the event of a fire in the plenum.

In retrofit situations, the design of floor support beams in the existing process heater shall be verified during the design for the effects of preheated air on structural integrity. Separate insulated plenum boxes may be required. The use of air spaces between main structural supports and preheated air plenums should be considered during the design.

F.9.2.4 External or internal duct linings

Internal insulation or refractory should be considered for flue-gas ducts to reduce the metal temperature of the duct envelope, thereby reducing the duct thermal expansion. Consider internal coating for corrosion protection. In the event of a fire in the duct system, internal linings are desirable. Internal refractory can break loose from the duct wall and result in clogged ductwork, plugged air preheaters, and possible damage to fans. Loss of internal linings also exposes ductwork to corrosive attack and temperatures higher than design.

External insulation of ductwork may be desirable to maintain metal temperature and to prevent dew-point corrosion. Such ductwork develops greater thermal expansion however, since the metal temperature is higher. External insulation can be applied after the ductwork has been set in place; it is not subject to shipping damage that may occur when insulation or refractory has been shop-applied.

F.9.2.5 Mechanical considerations

All ductwork subject to thermal expansion shall be analysed for thermal stresses encountered at the design pressure and design metal temperature. All ductwork subject to thermal expansion shall have supports designed to freely accommodate the expected movement resulting from thermal effects or to accept the forces and stresses. The use of rollers, graphite slides or polytetrafluoroethylene slide plates may be required to prevent binding of support shoes.

Ductwork shall be structurally designed for the maximum expected shut-in pressure of the blower or the differential pressure [that is, the outside atmospheric pressure minus the internal maximum operating pressure, in absolute units of not less than 3,4 kPa (0,5 psi or 13,85 in water gauge)], whichever is greater. If the design defaults to 3,4 kPa (0,5 psi) minimum design differential pressure, it shall be assumed that the fluid pressure is positive within the duct. Flat surfaces on the rectangular ductwork, if operating at less than atmospheric pressure inside the duct, shall be designed for the expected vacuum. All flat surfaces of ductwork shall be reinforced, whether under positive or negative pressure. Additional reinforcement may be required for transient conditions or resonant fan conditions.

Duct and supports should be designed to accommodate all thermal and mechanical loads that may be imposed, including erection (including the mass of wet refractory during startup, operation, or shutdown of the system). Where duct sections are removed for maintenance activities, the effect of existing loads and new forces results in changes of deflection or stress; the entire system design shall again be mechanically verified in accordance with codes or procedures agreed to by the purchaser and the vendor.

Where flue-gas ducts tie into a stack mounted on a heater, provide a structural anchor on the duct at a point close to the outside perimeter of the heater stack. Provide an expansion joint between the fixed point (anchors) and the stack to control the significant bending moment resulting from duct thermal expansion forces reacting into the stack.

If multiple furnaces are serviced by a single air preheater, a single flue-gas exhaust stack from the air preheater is recommended.

In multi-cell furnace design cases, or where widely spaced burners are provided that require multiple air ducts to a single furnace, consider manually adjustable and lockable dampers in each duct. These dampers allow for balancing the flow and compensating for differences in duct hydraulic losses.

All duct sections shall be equipped with low-point drain connections. These connections shall not be less than DN 40 (1 1/2 NPS).

The load and thermal effects of cold weather design conditions (that is, snow and ice) during shutdowns shall be considered in the analysis of ductwork.

Manways shall be sized to a minimum of 460 mm × 460 mm (18 in × 18 in) and so located in ductwork (if size permits) to provide for internal access to the entire duct system.

Vertical, self-supporting cylindrical ducts shall be treated as stacks. They shall be designed to safely withstand wind loads and wind-induced (vortex shedding) vibrations in accordance with 13.5.

Structural force shall not be imposed on expansion joints.

Duct system expansion characteristics for lined ducts shall be based on a calculated shell temperature plus 55 °C (100 °F).

F.9.3 Expansion joints

All ductwork subject to thermal expansion shall be furnished with metallic bellows or flexible-fabric bellows expansion joints suitable for gas temperatures expected in the ductwork, and shall be resistant to any corrosion products in the gas stream. Internal sleeve liners to protect the bellows of the expansion joint should be considered. Stiffening rings may be installed on either end of expansion joints in the ductwork to prevent ovalling or other distortion of the ductwork in the event of replacement of the expansion joint.

Flexible-fabric joints of materials suitable for the temperature of the flowing gas in the ductwork may be used to avoid deforming and stressing of adjoining equipment. These expansion joints are generally of layered construction and can be insulated to withstand the flowing gas temperature.

If soft (fabric) expansion joints are used adjacent to components requiring steam cleaning or water washing, the use of internal sleeves is recommended to prevent water damage to the fabric joint.

All ducts having expansion joints at both ends shall be suitably anchored or restrained between the joints to ensure absorption of ductwork thermal growth in the expansion joints in the desired manner.

If duct thermal expansion is deliberately controlled to cause lateral deflection in the expansion joint, the expansion joint shall be specified to absorb lateral deflection or angulation without overstressing the bellows material at design temperature. Expansion joints subject to lateral deflection only shall be provided with tie rods across the bellows. The tie-rod connections to the ductwork shall be gimbaled to allow lateral displacement in the expansion joint without bending or shearing the tie rods or tie-rod connections.

Do not use a tied expansion joint to absorb both axial and lateral deflections. Only internal pressure thrusts are contained by tie rods.

Packed slip expansion joints may be considered for negative-pressure applications and shall be designed to provide positive retention of the packing to permit packing replacement from the outside while the duct is in service. These joints should be between solid anchor points in hot ductwork. They are subject to binding because of dirt, paint or corrosion. Avoid using slip-type joints adjacent to blower/fan inlet or outlet flanges. Slide bars or guide pins shall be provided to prevent angulation or cocking in the gland if stress or friction within the gland is not consistent around the circumference. Packed expansion joints can be designed to take horizontal movements if used as two-hinged joints.

F.9.4 Dampers

F.9.4.1 General

Dampers may be classified into four types based upon the amount of internal leakage across the closed damper at operating pressures:

a) tight shutoff: low leakage;

b) isolation or guillotine (slide gate): no leakage;

c) flow control or distribution: medium to high leakage;

d) natural-draught air-inlet doors: low leakage to fully open.

Tight shutoff dampers may be of single-blade or multi-blade construction. Leakage rates of 0,5 % or less of flow at operating conditions are expected.

Isolation or guillotine (slide gate) dampers are designed to have no internal leakage when closed and may include double-gate with air purge or double-block-and-bleed designs consisting of one or more dampers in series with an air purge between. Internal leakage rates of 0 % are expected with this type of damper. Dampers may have insulated blades to allow personnel to safely enter ductwork (downstream of the damper) during operation of connected equipment.

Natural-draught air-inlet doors shall be designed as fail-open devices in the event of loss of mechanical draught furnished by combustion air fan.

F.9.4.2 Design and construction

Damper frames shall be channels using either rolled structural steel or formed plate. Material and weight of the frames shall be determined on the basis of any combined stress or individual stress, whichever is the maximum resulting from the following loads:

a) seismic;

b) wind;

c) shipping or erection loads;

d) actuator loading;

e) system failure or thermal or deadweight load;

f) corroded-condition load.

Dampers shall be considered structural members and as such shall meet all structural design criteria of fired heater structural members outlined in clause 12.

Damper-blade deflections shall be less than 1/360 of the blade span. The stress of each blade assembly component, based on maximum system static pressure, temperature and seismic loading and the moment of inertia through the cross-section of the blade assembly, shall not exceed those levels specified in AISC Specification for Design, Fabrication, and Erection of Structural Steel for Buildings. The torsional and bending stress shall be considered if the gas stream temperature is equal to or greater than 400 °C (750 °F). Allowable bending stress should be limited to 60 % of the yield stress at the specified operating temperature. If the metal temperature is in the creep range, the allowable stress will be based upon 1 % of the rupture stress at the 100 000 h life-span.

Each damper shall be equipped with an actuator mounted and linked by the damper manufacturer and tested in his shop before shipment. The actuator and linkage shall be installed outside of the flowing gas stream. The strength of the actuator mount on the damper frame shall be based on seismic loading and required actuator torque. Its strength shall not exceed 10 % of the yield strength of the damper in any mode of stress. Actuators and all drive system components shall be sized with a safety factor of 3,0.

F.9.4.3 Isolation/guillotine damper

The slide-gate damper shall be a complete, self-sufficient structure not requiring additional integral support or bracing. The actuator for slide-gate dampers shall be electric, manual, pneumatic or hydraulic and shall be operated by sprockets, chains, jack screws or a direct-drive piston. If chains are used, a minimum of two chains should be used and arranged to drive evenly on each side of the blade to prevent binding. In the event of chain failure, the remaining chain or chains should be capable of supporting the entire blade load.

The time consumed in complete operation of the slide-gate damper from fully open to fully closed should be specified by the purchaser.

Operator and drive-system sizing shall incorporate a 300 % dead load plus a 200 % live load (push-pull open/close) safety factor as a minimum. For installations that are safe for personnel to enter, incorporate double block-and-bleed or double block-and-purge designs. The space between dual closed damper blades or the space between two rows of edge seals is normally purged with clean air of sufficiently greater pressure than duct stream or outside air pressure to ensure a clean-air barrier to gas leaks into the duct system past the guillotine damper.

F.9.4.4 Louvre dampers

Louvre dampers consist of a series of parallel damper blades. The blade construction may be a solid blade with a central axial round shaft. If the blade of the damper is of airfoil composite design, the central shaft may consist of a structural member as a central axial support of the airfoil blade. At each end, round stub shafts are splined into the axial structural member with suitable clearances to prevent buckling of the shaft as it thermally expands as a result of heat. The stub shafts pass through the bearings mounted on the damper frame. The edges of the blades are fitted with metal seals to minimize leakage past the damper edges when the damper blade is closed. These seals are often of proprietary design.

Airfoil blade designs shall have blade skins provided with elongated bolt holes to compensate for thermal growth of the shaft and blade skin. Consider the use of heating holes in one side of sandwich (airfoil) blade designs if excessive temperatures are encountered across closed dampers. This will reduce thermal stresses and warping of the blades. Blades and shafts shall be of thermally compatible material of similar thermal growth rates. If possible, provide for thermal growth of the damper blade away from the actuator or drive side of the damper.

Louvre-style multiple damper blades shall be linked together exterior to the damper frame. Linkage shall consist of structural bar hinged with shoulder bolts, complete with lock nuts set in self-lubricating bearings of a type specified by the purchaser. Other designs consisting of adjustable linkage to compensate for the differential expansion between the damper frame and the linkage to ensure tight shutoff at the operating temperature should be considered. Completed linkages shall be tested and fixed in position at the damper manufacturer's facility.

The link bars of each individual blade shall be welded to set collars fastened to the damper shaft with shear pins. Linkage shall be tight and vibration-free and shall prevent independent action of the blade. The position of the damper on its shaft shall be scribed on the end of the shaft visible from outside the duct.

Other designs, incorporating stainless steel stub shafts and linkage pins and hardware consisting of cast steel clevis arms attached to stub shaft, may eliminate corrosion and may facilitate rapid removal. These designs should also be considered in situations where dampers may not be used open and tend to freeze.

Bearings shall be mounted in pillow-block assemblies furnished by the bearing manufacturer and shall be bolted to bearing mounts welded to the damper frame. Each bearing and bearing mount, including welds holding the mount, shall have a duty factor capable of withstanding 200 % of the stress transmitted as a result of the system load acting on the blade plus the operator output torque. If removable bearings are specified, linkage cranks shall be removable also. Do not weld linkage cranks to shafts.

A packing gland, if specified, shall be welded to the damper frame at each shaft clearance hole and shall be filled with packing adequate for the service. Design of the packing gland shall allow removal and replacement without removal of bearings or linkage. Packing glands should be applied in negative-pressure flue-gas service if sulfur-bearing fuels are used.

F.9.4.5 Miscellaneous construction details

Dampers constructed integral to ducts, if permitted by the purchaser, shall be of a bolted design to allow replacement of parts.

Damper bearings shall not be covered by insulation.

Damper shafts shall be of austenitic stainless steel or other alloy suitable for the operating conditions.

F.9.5 Ductwork insulation and refractory

F.9.5.1 General

Externally insulated air and flue-gas duct sections shall be covered with weatherproofing and/or metal covers. The insulating material or any layer shall be suitable for a service temperature of at least 165 °C (300 °F) above its calculated hot-face interface temperature.

Where the burner plenum is internally lined and fuel oil is fired in the heater, consider the choice of oil-resistant linings. High density refractory should be considered. Provide lining on the floor of the plenum and for at least 100 mm (4 in) up the side walls.

The minimum internal lining thickness shall be 50 mm (2 in). The minimum service temperature of the castable refractory shall be 165 °C (300 °F) above the maximum calculated temperature of the material.

All insulation except castable (internal or external) should be covered for weather protection during erection. Internal exposed insulation should be treated for stability or rigidity.

Duct internal casing surfaces covered by a blanket or block insulation shall have either a protective coating applied prior to application of insulating material or a vapour barrier if the flue gas contains products of combustion from fuels containing more than 1 % mass fraction of sulfur in fuel oil or 1,5 % volume fraction of hydrogen sulfide in the fuel gas.

F.9.5.2 Ceramic-fibre duct lining

The ceramic-fibre duct lining used for hot flue-gas or combustion-air ducts shall be of needled material at least 25 mm (1 in) thick, with density of 130 kg/m^3 (8 lb/ft^3). The back-up layer of ceramic fibre shall be of needled material at least 25 mm (1 in) thick, with density of 65 kg/m^3 (4 lb/ft^3). If ceramic-fibre construction is used, the casing shall have an internal protective coating to prevent corrosion of metal ductwork. Do not use unprotected ceramic fibre at duct bends, baffles, elbows or constrictions.

F.9.5.3 Block and board insulation

Block insulation is defined as rigid, and board insulation as semirigid. Insulation should be specified as Class 3, ASTM C 612. If such insulation is not to be shielded by other materials, single layers may be used below 260 °C (500 °F) hot face. It may be used as a backup layer with other insulations if the mass fraction of sulfur does not exceed 1 % in liquid fuel or the hydrogen sulfide content does not exceed 100 cm^3/m^3 (100 ppm vol.) in gas fuel.

The velocity of the flowing gas stream should not exceed 6 m/s (20 ft/s), unless the surface is protected with wire mesh, expanded metal or sheet metal. Two layers of insulation are preferred.

F.9.5.4 Fibre blanket insulation (mineral wool)

Blanket insulation is a flexible material specified in accordance with ASTM C 553. Do not use unprotected insulation adjacent to water- or steam-cleaning devices. Surface protection consisting of wire mesh, expanded metal mesh or chemical rigidizers shall be provided for areas where flue-gas or air velocities exceed 12 m/s (40 ft/s). Two layers are preferred. Materials shall be overlapped in the hot face on the first layer to ensure that no exposure of casing or duct envelope to materials insulating for lower temperature occurs.

F.9.6 Fans and drivers

F.9.6.1 General

All fan and driver design and performance shall be in accordance with annex E.

F.9.6.2 Wheel types

Maximum aerodynamic efficiency for fans can be achieved with backward-inclined (non-overloading) blades. The blade construction may be of single thickness or aerofoil design. On applications where the fan provides induced-draught service, avoid airfoil designs that have hollow cross-section blades consisting of metal skin on ribs if they are not furnished with wheel-cleaning facilities. Induced-draught fans handling elevated temperature flue-gas containing significant particulates should be considered and specified as radial or modified radial blades on the fan wheel.

F.9.6.3 Construction

Fans in combustion-gas service shall have all seams continuously welded.

F.9.6.4 Shafts

Fan wheel shafts shall be capable of handling 110 % of rated driver torque from rest to design speed.

F.9.6.5 Elimination of induced-draught fan

A stack of height greater than normally required may replace an induced-draught fan on some systems, thereby improving the mechanical reliability of a system.

F.9.7 Air preheaters

F.9.7.1 Design considerations for direct preheaters

In a fixed-bundle air preheater, consider making the bundle removable if it will be subject to corrosion. Pressure parts of coils or tube bundles handling a combustible fluid shall be of all-welded construction. Do not permit circumferential welds to be located in the air stream.

In rotating exchangers with metallic elements, the heating surface shall be provided in two or more layers. The cold-end layer of elements shall be in baskets for radial removal through a housing. Other layers may be in baskets for removal through hot-end ductwork. Regenerative systems using revolving elements can be mechanically damaged if rotation stops while flue-gas and air flow continue. An auxiliary drive on the preheater is recommended to protect against loss of rotation resulting from a power failure or other cause. An alternative action is to revert to natural draught, bypassing the preheater, until rotation can be re-established.

F.9.7.2 Design considerations for indirect heaters

Fluid pressure-retaining circumferential field welds on the air-heating element of systems employing a pumped, circulating, combustible heat medium shall be external to the air duct. Electric-resistance welded tubing, however, is permitted for coil designs where the coil is internal to duct.

Tubular coils shall meet the requirements of clause 7, except for the extended surface in the air duct, which shall be as required by the application.

Tube wall thickness shall be in accordance with ISO 13704, assuming a design life of 100 000 h and a minimum corrosion allowance of 1,5 mm (1/16 in).

The extended surface shall not be included in designs intended for heavy oil fuel firing, unless cleaning facilities are also included in the system.

Each pass of multiple-pass coils shall be symmetrical and equal in length to all other passes. The design pressure of the coils in heated-liquid service shall be based upon a pressure greater than the vapour pressure of the heating fluid at the operating temperature. This ensures that the coil design pressure is great enough to allow selection of pumping pressures sufficient to prevent possible two-phase (liquid/vapour) flowing regimes in the coils and to contain and hold the fluid, should the blower fail, with no reduction in heat input.

Recirculating reheat coils shall not be oriented to view direct radiation from the firebox or from high temperature refractory surfaces.

The performance of recirculating reheat coils is directly related to and dependent on the characteristics of the recirculating heat-transfer medium in the coil. Some characteristics of the medium deteriorate with extreme service conditions. Systems with pumped closed-circulation heat-medium loops should incorporate provisions to drain the heat-medium fluid from the heating coil in the event of low fluid flow or high flue-gas temperature. Drainage should be manually or automatically actuated. Failure to drain the heating coil under these conditions can lead to thermal degradation or coking of the fluid in the coil.

All heating coils shall be drainable and shall include a high-point vent and a low-point drain, unless specifically deleted by the purchaser because of more appropriate locations in adjacent piping. All connection flanges should be located outside the duct periphery.

F.9.7.3 Two-phase operation

To ensure against “vapour lock” of the heat-transfer fluid in the coils, elevate the system pressure to a level above the vapour pressure of the liquid, which ensures that the coil contains all liquid, and then reduce the pressure directly in a vapour “flash” drum downstream of the coil.

F.9.7.4 Pump design for circulating systems

Pumps shall be designed in accordance with API 610.

Head capacity curves shall rise continuously to shut off. Rated pump capacity shall fall to the left or on the peak efficiency line.

Net positive suction head correction factors may not be required.

Pumps handling flammable or toxic liquids shall have flanged suction and discharge nozzles.

Spare pumps shall be provided, unless used in a system that can be completely bypassed without detriment to the normal heater service.

F.9.7.5 Interconnecting piping

Piping used to interconnect various components in an air preheat system shall be designed and fabricated according to ASME B31.3 or other standard specified by the purchaser.

F.9.8 Burner

Burner front plates shall be insulated to achieve a skin temperature less than or equal to the temperature specified for the air duct and plenum. Where practical, the insulation specifications for the burner shall be the same as for the duct and plenum.

A sight glass, 25 mm (1 in) or more in diameter, shall be provided at each burner front plate to provide visibility of both the ignitor or pilot burner and the main flame. Consider heat-resistant glass in pressurized systems.

Safe removal of oil guns, gas tips and pilots that may be removed during heated-air operation and that are located in a positive-pressure plenum should be considered in the design.

Vertically fired liquid-fuel burners should be designed to catch drips from burner tips and convey the drips outside the plenum. In positive-pressure plenums, a drain tube can be provided with a pet cock to allow periodic blowdown by hand.

Horizontally fired liquid-fuel burners shall be designed to permit drainage of oil into the firebox and prevent drainage into the plenum.

Individual burner air adjustment and air shut-off shall be provided.

Burner systems shall be designed so that light-off can be accomplished without exposing the operator to positive-pressure heated air. Electric ignition pilots may be required in a pressurized plenum for light-off of pilots that cannot be accomplished in a negative-pressure zone of the fire box (pressurized plenum).

All modes of process heater operation, such as mechanical or natural draught or turndown, shall be considered in burner design and selection. The maximum combustion-air pressure drop that is consistent with all modes of operation, if required, shall be used. Note that if natural-draught operation is required, the natural draught available shall determine the burner size for the capacity specified in this mode.

Burner and burner parts intended for use with heated combustion air shall be fabricated from materials suitable for the temperature exposure.

F.10 Environmental impact of air preheat systems

F.10.1 General

There are five basic ways that the use of an air preheat system can have an environmental impact (see F.10.2 through F.10.6). In general, the environmental impact of a properly designed air preheat system is positive.

F.10.2 Energy conservation

The use of an air preheat system is one of the best techniques available to process plant operators for energy conservation. An air preheat system frequently provides adequate savings, through reduced fuel cost, to allow other pollution control systems to become economically feasible.

The use of any system of efficiency improvement results in a lower flue-gas exit temperature, which increases the possibility of an exhaust stack plume and can produce “acid rain.” Although not specific to the use of an air preheat system versus any other system of efficiency improvement, the problem should be recognized. The normal way to eliminate any adverse effect is to increase the stack exit height above grade and increase the effluent velocity, so that natural diffusion and wind currents will prevent acid fallout.

Since the air preheat system incorporates one or more fans, the energy is available to achieve high stack effluent velocities, and energy savings more than justify the taller stack.

In summary, the air preheat system actually provides a means to eliminate the problem of “acid rain” that can occur in many installations.

F.10.3 Stack emissions

F.10.3.1 General

The environmental impact of stack emissions from a fired heater is affected by the installation of an air preheat system. There are four separate pollutants that are normally monitored. These are discussed in F.10.3.2 to F.10.3.5.

F.10.3.2 Sulfur oxides

The sulfur oxide fraction of the flue gas is dependent solely on the composition of the gas or oil burned and is not affected to any extent by the air preheat system. However, since fuel consumption is reduced if an air preheat system is used, the mass of sulfur dioxide (SO_2) emitted is reduced for the same process duty. This results in a net reduction in pollution and an improved environment.

F.10.3.3 Nitrogen oxides

The amount and type of oxides of nitrogen produced depend on the time, temperature and oxygen concentration during combustion of any specific fuel. The reactions involved are many and complex. The following can be stated in general:

a) the amount of NO_x produced increases with increases in firebox or combustion temperature;

b) the amount of NO_x produced decreases with decreases in excess air.

This would indicate that preheating the combustion air can increase the NO_x formed. This has been shown to be true when expressed as concentration in the flue gas. However, as in the case of the sulfur oxides, the mass of nitrogen oxides, expressed as nitrogen dioxide emitted, is reduced as efficiency is increased. This tends to diminish the adverse effect of air preheat and can, in those cases where efficiencies are substantially improved, actually reduce the quantity of NO_x emitted.

Excess air appears to be the most significant factor in the control of NO_x formation. Since air preheat systems most often utilize forced-draught burners, it is not only possible to operate at extremely low excess air levels, but also to more accurately control the fuel/air ratio. On natural-draught burners, the minimum excess air levels previously considered necessary to provide for operational variations have been 20 % on gas fuels and 25 % on oil fuels. Most burner manufacturers represent that using their forced-draught designs and preheated air requires minimum excess air levels of only 5 % on gas and 10 % on oil fuels, and controls can be furnished to ensure that these levels are maintained (see F.7.2.1 for recommendations). This low excess air operation can significantly reduce the NO_x level.

Burner manufacturers have developed special combustion-type units that further reduce NO_x formation on natural-draught or forced-draught systems using preheated or ambient air. This allows the use of a low NO_x burner on most air preheat system applications to achieve the required NO_x levels.

F.10.3.4 Particulates

The formation of particulates during combustion is normally a function of burner application and the specific fuel burned. The use of air preheat and the forced-draught systems involved have allowed burner manufacturers to reduce the formation of carbon when burning normal fuels. This can reduce the particulates formed to essentially the ash formed on combustion of the fuel. Therefore, the use of an air preheat system reduces the total solids emission from many heater applications since the amount of fuel burned, and hence of ash emitted, is reduced.

F.10.3.5 Combustibles

The presence of combustibles, such as unburned hydrocarbons and carbon monoxide, in the flue gases from fired heaters is related to the incomplete combustion of the fuel. This in turn may result from insufficient excess air. The application of an air preheat system enhances the ability to burn fuels completely at the lowest possible excess air level. As a result, whether the burner is of the low NO_x or standard type, unburned hydrocarbons and carbon monoxide can be controlled to acceptable levels (from a pollution control viewpoint) at lower excess air levels than previously possible without the use of an air preheat system.

F.10.4 Noise

The main source of noise associated with a fired heater is normally the burners. The application of an air preheat system requires that the burners be housed in an insulated enclosure. In addition, high efficiency heater systems employ insulation and linings which are thermally more effective. Both of these measures reduce the level of noise from the burners. Consequently, an air preheat system normally attenuates the noise from the burners below the statutory level.

However, the use of fans associated with an air preheat system introduces a new noise source, which should be considered in the initial design. Since adequate silencing techniques have been developed, it is only necessary for the designer to establish the noise level limit required so that the fan manufacturer can offer the appropriate solution.

In summary, although noise should be considered in the design of an air preheat system, it should not have an adverse impact on the overall environment of a typical heater installation.

F.10.5 Heat

The installation of an air preheat system results in a lower flue-gas exit temperature, thereby reducing thermal pollution.

F.10.6 Effluent

The air preheater can collect small quantities of solids combined with sulfur. The liquid effluent resulting from washdown cycles, if required, can contain particulates combined with a weak acid that should be handled in an appropriate disposal system. Normally, the additional quantities produced as a consequence of the air preheat system are negligible.

F.11 Preparing an enquiry

F.11.1 General

The purpose of this clause is to provide guidance and a checklist for obtaining sufficient information and data for selecting the most economical air preheat system and for preparing the required bid enquiry.

Prior to preparing a bid enquiry, it is recommended that an economic study be conducted to justify the installation of an air preheat system.

F.11.2 Enquiry

Final selection of the air preheat system often requires cost and technical information on more than one system. This information is usually obtained from suppliers responding to the bid enquiry.

A bid enquiry for an air preheat system should include

a) data on the existing or proposed fired heater or heaters to be provided with an air preheat system. These data are available from the completed fired-heater data sheet and should include at least the information on combustion design conditions. The fired-heater operating data are required to represent the intended heater operation, which in the case of retrofit may vary from the original design data. If so, both the original and the intended operating data should be supplied,

b) air preheater specification sheet,

c) any information on space restrictions around the fired heater or heaters where the air preheat system is to be located.

F.11.3 Air preheat system checklist

The following is a checklist of information and data to be included in the bid enquiry:

a) applicable local building rules and regulations;

b) environmental restrictions (noise, oxides of nitrogen and sulfur, and others);

c) space limitations;

d) number of fired heaters to be served by the proposed air preheat system;

e) required reliability and service factor of the fired heater or heaters and operating modes in the event of equipment failure;

f) fired heater data sheets:

   1) total duty per heater in megawatts (MW) [British thermal units per hour (Btu/h)], heat absorbed, for each operating mode: normal, maximum and minimum;

   2) all items designated by an asterisk (*);

   3) excess air, percent;

   4) radiation loss (lower heating value);

   5) fuel evaluation cost;

   6) power and other utility evaluation costs;

g) air preheater data sheets:

   1) all performance data;

   2) list of accessories required.

Other special requirements should be indicated on the data sheets at the time of enquiry.

F.12 Flue-gas dew point

F.12.1 General

The furnace designer should be aware of the various design and operational factors that affect flue-gas dew point and corrosion rates, even though the designer only has control over a few of these variables. This summary of some of the more significant published test work describing the potential impact of these factors is intended to

a) broaden the designer’s understanding of this complex phenomenon,

b) serve as a starting point for further individual study.

Wherever possible, results from commercial-size equipment are reported. The results from laboratory-size equipment may not be directly applicable to commercial equipment design.

Flue-gas dew point and corrosion are primarily related to the amount of sulfur trioxide present, not to the predominant amount of sulfur, which is present as sulfur dioxide. The factors that encourage or inhibit the oxidation of sulfur dioxide to sulfur trioxide are the significant factors. Many of these factors can be recognized as similar to the significant factors in the production of oxides of nitrogen. The significant factors are

a) fuel sulfur content,

b) fuel and flue-gas additives,

c) flue-gas oxygen content,

d) flue-gas moisture content,

e) combustion temperature (firing rate),

f) furnace cleanliness,

g) burner design.

F.12.2 Fuel sulfur content

Various investigators have differed on the impact of sulfur content of the fuel on the flue-gas dew point. Corbett [18] in his tests of a commercial-size oil-fired boiler with fuel sulfur content varying from 0,75 % to 3,5 % (mass fraction) found no direct relationship between flue-gas dew point and the sulfur content of the fuel. Corbett's test results along with those of other investigators are plotted in Figures F.8 through F.10. Corbett's test results, along with those of other investigators, using commercial-size boilers are tabulated in Table F.3.

In tests with laboratory-size combustors and fuel sulfur contents (mass fraction) in the range of 1 % to 5 %, Rendle and Wilson [19] report an increase in the flue-gas dew point of approximately 4 °C (7 °F) for each 1 % increase in fuel sulfur. Taylor and Lewis [20] report an increase in the flue-gas dew point of approximately 9 °C (16 °F) for each 1 % increase in fuel sulfur.

F.12.3 Fuel and flue-gas additives

In their laboratory-size combustor, Rendle and Wilson [19] reported that by injecting ammonia vapour into the partially cooled flue gas at a rate of 0,13 kg (0,06 lb) of ammonia per kilogram (pound) of fuel containing 3,2 % (mass fraction) sulfur, they were able to reduce the dew point by 90 °C (160 °F) to very close to the water dew point.

In tests of commercial-size boilers, Clark and Childs [21] report a 14 °C (25 °F) drop in dew point with magnesium hydroxide fuel additives.

F.12.4 Flue-gas oxygen content

If the flue-gas oxygen content can be controlled to less than 0,5 %, the flue-gas dew point can be dramatically lowered. In tests of two operating industrial boilers, Bunz, Niepenberg and Rendle [22] demonstrated reductions in dew point of 150 °C (300 °F) in one boiler and 38 °C (100 °F) in another boiler as the flue-gas oxygen was reduced from 1,4 % to 0,2 %.

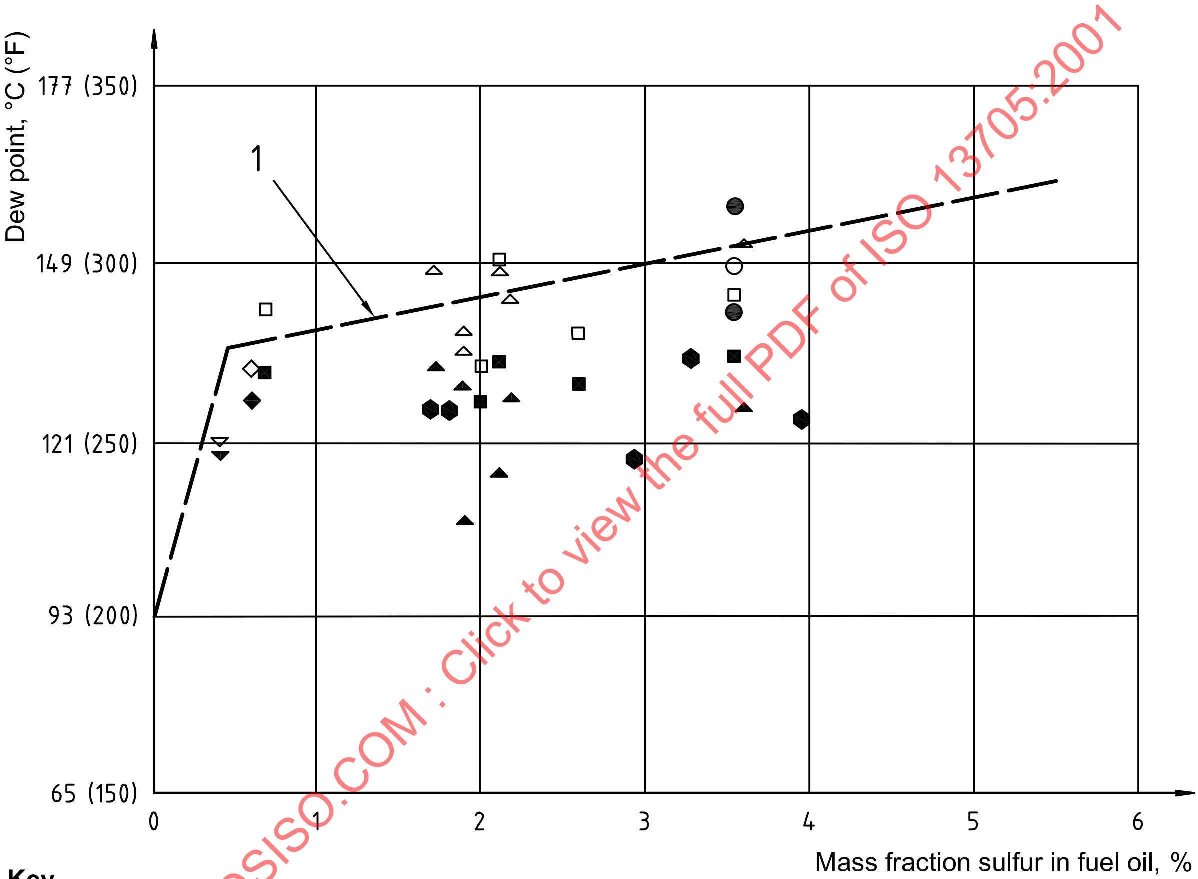
By reducing the excess air from 15 % (approximately 3 % oxygen) to 5 % (approximately 1 % oxygen), Clark and Childs [21] report a dew point reduction of 17 °C (30 °F) in a commercial boiler. With flue-gas oxygen content reductions from 8 % to 3 % at constant boiler load, Corbett's data [18] indicate little change in dew point.

F.12.5 Flue-gas moisture content

Flue-gas moisture is produced by the fuel hydrogen content, ambient humidity and atomizing steam. In analytical laboratory tests, Martin [26] reports an increase in dew point of up to 8 °C (15 °F) as the flue-gas moisture content increased from 10 % (typical fuel oil) to 18 % (typical fuel gas).

F.12.6 Combustion temperature (firing rate)

The commercial boiler data of Draaijer and Pel [24] indicate an 11 °C (20 °F) increase in flue-gas dew point with a 50 % increase in firing rate, and the boiler data of Bunz, Niepenberg and Rendle [22] indicate 25 °C (45 °F) increase in dew point with a 100 % increase in firing rate.

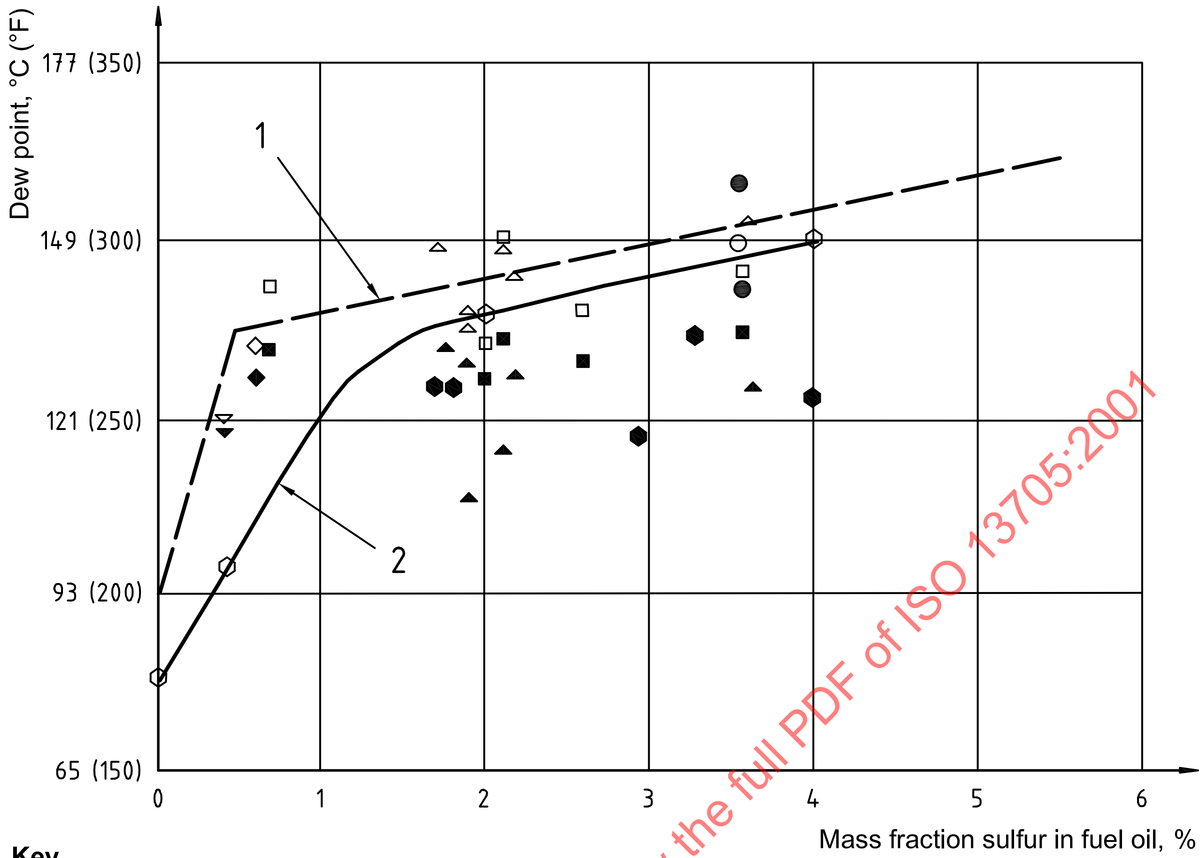


Key

AVG. MAX.

- ● ○ Draaijer and Pel [24]
- ▲ △ Bunz, Niepenberg and Rendle [22]
- ■ □ Corbett [18]
- ⬢ ⬡ Clark and Childs [21]
- ▼ ▽ Martin (oil) [26]
- ◆ ◇ Martin (gas) [26]
- 1 Recommended minimum metal temperature for convection coils, fans and duct steel exposed to flue-gas

Figure F.8 — Dew points of flue-gas versus sulfur in fuel oil (test data from industrial boilers)



Key

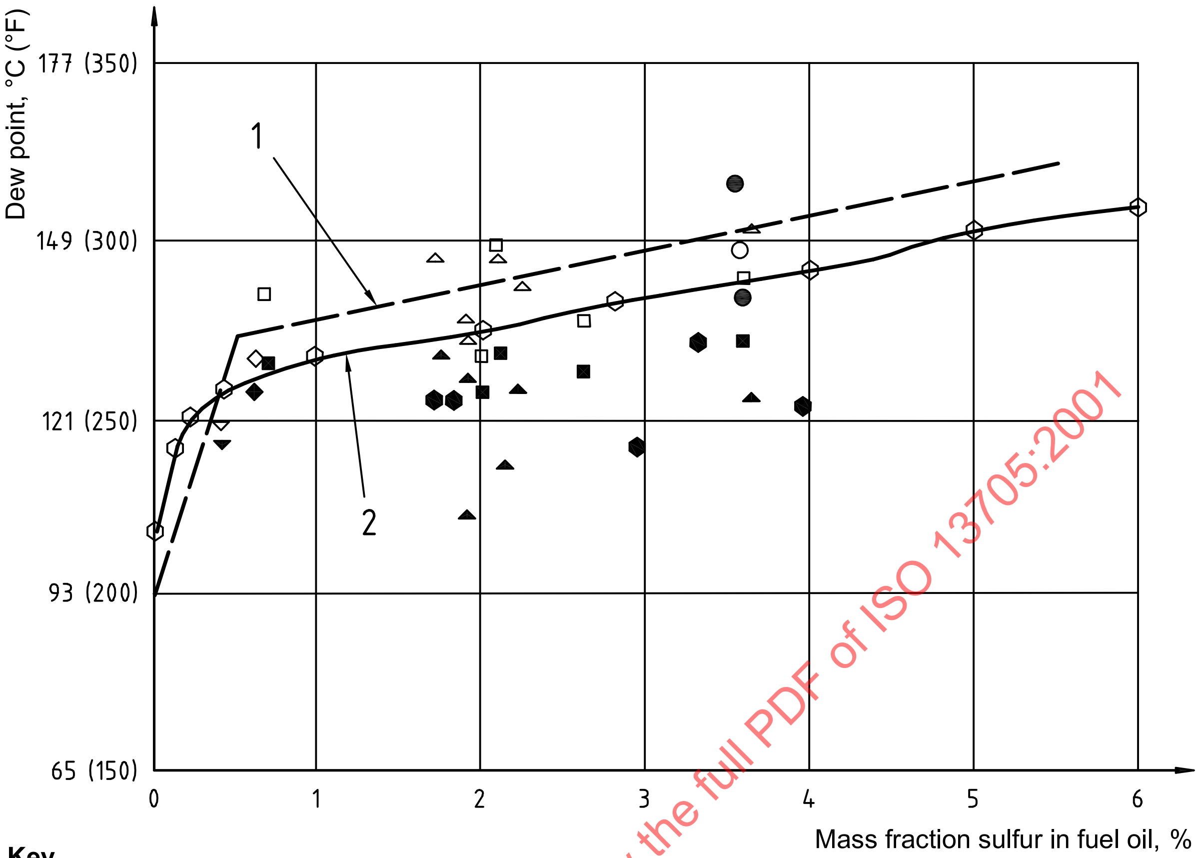
AVG. MAX.

- ● ○ Draaijer and Pel [24]
- ▲ △ Bunz, Niepenberg and Rendle [22]
- ■ □ Corbett [18]
- ⬢ ⬡ Clark and Childs [21]
- ▼ ▽ Martin (oil) [26]
- ◆ ◇ Martin (gas) [26]

1 Recommended minimum metal temperature for convection coils, fans and duct steel exposed to flue-gas

2 Attig and Sedor [25] 0,18 mm to 0,23 mm/y (7 mils/y to 9 mils/y) corrosion rate, 10 % excess air

Figure F.9 — Dew points of flue-gas versus sulfur in fuel oil (test data from industrial boilers and [25])



Key

AVG. MAX.

- ● ○ Draaijer and Pel [24]
- ▲ △ Bunz, Niepenberg and Rendle [22]
- ■ □ Corbett [18]
- ⬢ ⬡ Clark and Childs [21]
- ▼ ▽ Martin (oil) [26]
- ◆ ◇ Martin (gas) [26]

1 Recommended minimum metal temperature for convection coils, fans and duct steel exposed to flue-gas

2 Energy Technology, Inc. standards, 0,7 % to 3,5 % sulfur

Figure F.10 — Dew points of flue-gas versus sulfur in fuel oil (test data from industrial boilers and data of Energy Technology, Inc.)

F.12.7 Furnace cleanliness

In a commercial-size boiler fired with heavy fuel oil, Clark and Childs [21] report that the flue-gas dew point is reduced by 17 °C (30 °F) after each annual furnace cleaning.

F.12.8 Burner design

In a laboratory combustor, Attig and Sedor [25] demonstrated that recirculation of 25 % of the flue gases to the burners reduced flue-gas sulfur trioxide concentration by one half (equivalent to a dew-point reduction of at least 6 °C [10 °F]) and reduced corrosion rates by more than one third. The very low excess-air operations reported by Bunz, Niepenberg and Rendle [22] were achieved with a special low excess-air design burner.

Table F.3 — Flue-gas dew-point data from oil-fired industrial boilers

Investigator	Boiler No.	Sulfur content in fuel (mass fraction) %	Average dew point °C (°F)	Minimum dew point °C (°F)	Maximum dew point °C (°F)	No. test points	Steam load kg/h × 1 000	Excess O_2 %
Draaijer & Pel [24]	1	3,55	158 (317)	157 (315)	159 (318)	4	40	—
	2	3,55	142 (287)	134 (273)	149 (300)	15	9 to 14	—
Bunz, Niepenberg & Rendle [22]	3	1,78	132 (270)	121 (250)	147 (297)	8	24 and 32	0,1 to 0,5
	3	1,90	129 (264)	118 (244)	138 (280)	6	24 and 32	0,1 to 1,5
	4	2,10	116 (240)	74 (165)	147 (297)	10	24 and 32	0,1 to 1,5
	4	2,18	127 (261)	86 (187)	143 (289)	10	24 and 32	0,1 to 1,5
	4	1,90	108 (226)	75 (167)	135 (275)	8	24 and 32	0,1 to 1,4
	4	3,61	127 (260)	70 (158)	152 (306)	16	16, 24 and 32	0,1 to 1,4
Corbett [18]	5	2,60	130 (266)	118 (245)	138 (280)	49	9 to 23	3,4 to 13,2
	5	2,00	127 (260)	118 (245)	132 (270)	25	9 to 23	4,3 to 9,8
	5	2,10	133 (271)	118 (243)	149 (300)	27	9 to 22	3,1 to 10,6
	5	3,55	134 (274)	125 (257)	144 (292)	39	9 to 22	2,7 to 6,3
	5	0,75	131 (267)	121 (250)	141 (285)	22	13 to 18	3,6 to 8,2
Clark & Childs [21]	6	3,97	125 (257)	—	—	—	—	—
	7	1,70	126 (258)	—	—	—	—	—
	8	1,82	126 (258)	—	—	—	—	—
	9	2,94	118 (245)	—	—	—	—	—
	10	3,29	134 (274)	—	—	—	—	—
Martin [26]	11 (oil)	0,4	116 (240) [a]	142 (287) [a]	120 (248) [a]	8	100	2,7 to 3,6
	11 (gas)	0,6	127 (260) [a]	122 (252) [a]	131 (268) [a]	15	100	2,5 to 3,3

[a] Indirect measurements from SO_3 concentration. Electrical conductivity probe method would probably give lower values.

Annex G
(informative)

Measurement of thermal efficiency of fired process heaters

G.1 General

G.1.1 Introduction

This annex is intended to establish a standard approach for measuring the thermal efficiency of fired process heaters. It comprises a comprehensive step-by-step procedure for conducting the necessary tests and reporting the results.

This procedure is intended to be used for fired heaters burning liquid or gaseous fuels. It is not recommended for determining thermal efficiency if a solid fuel is being burned.

The test procedure considers only stack heat loss, radiation heat loss and total heat input. Process data are obtained for the purposes of reference and comparison only. Any modifications of the procedure and any assumptions required for testing should be established before testing.

G.1.2 Terms, definitions and symbols

G.1.2.1 Terms and definitions

The following terms and definitions used in this annex are given for information.

G.1.2.1.1
thermal efficiency
total heat absorbed divided by total heat input

NOTE This definition differs from the traditional definition of fired heater efficiency, which considers only the net heat of combustion of the fuel (h_L) as heat input.

G.1.2.1.2
total heat absorbed
total heat input minus total heat loss

G.1.2.1.3
total heat input
sum of net heat of combustion of the fuel (h_L) and sensible heat of the air, fuel and atomizing medium

G.1.2.1.4
total heat loss
sum of radiation heat loss and stack heat loss

G.1.2.1.5
radiation heat loss
defined percentage of net heat of combustion of the fuel

G.1.2.1.6
stack heat loss
total sensible heat of the flue-gas components at the temperature of flue gas when it leaves the last heat exchange surface

G.1.2.1.7
sensible heat correction
sensible heat differential at test temperatures when compared with a datum temperature of 15 ºC (60 ºF) for air, fuel and the atomizing medium

NOTE With steam as an atomizing medium, the datum enthalpy is 2 530 kJ/kg (1 087,7 Btu/lb).

G.1.2.2 Symbols

The following symbols are used in this annex:

e net thermal efficiency, expressed as a percentage.

e_{g} gross thermal efficiency, expressed as a percentage.

h_{L} lower massic heat value of the fuel burned, in J/kg (Btu/lb).

h_{H} higher massic heat value of the fuel burned, in J/kg (Btu/lb).

$c_{p\,\mathrm{a}}$ specific heat capacity of the air, in J/kg·K (Btu/lb·°F).

$c_{p\,\mathrm{f}}$ specific heat capacity of the fuel, in J/kg·K (Btu/lb·°F).

$c_{p\,\mathrm{m}}$ specific heat capacity of the atomizing medium, in J/kg·K (Btu/lb·°F).

Δh_{a} air sensible massic heat correction, in J/kg (Btu/lb).

Δh_{f} fuel sensible massic heat correction, in J/kg (Btu/lb).

Δh_{m} atomizing medium sensible massic heat correction, in J/kg (Btu/lb).

h_{r} radiation massic heat loss, in J/kg (Btu/lb).

h_{s} stack massic heat loss, in J/kg (Btu/lb).

T_{a} air temperature, in °C (°F).

$T_{\mathrm{a,a}}$ ambient air temperature, in °C (°F).

T_{d} design datum temperature, in °C (°F).

T_{e} exit flue-gas temperature, in °C (°F).

T_{f} fuel temperature, in °C (°F).

T_{m} atomizing medium temperature, in °C (°F).

G.1.3 Instrumentation

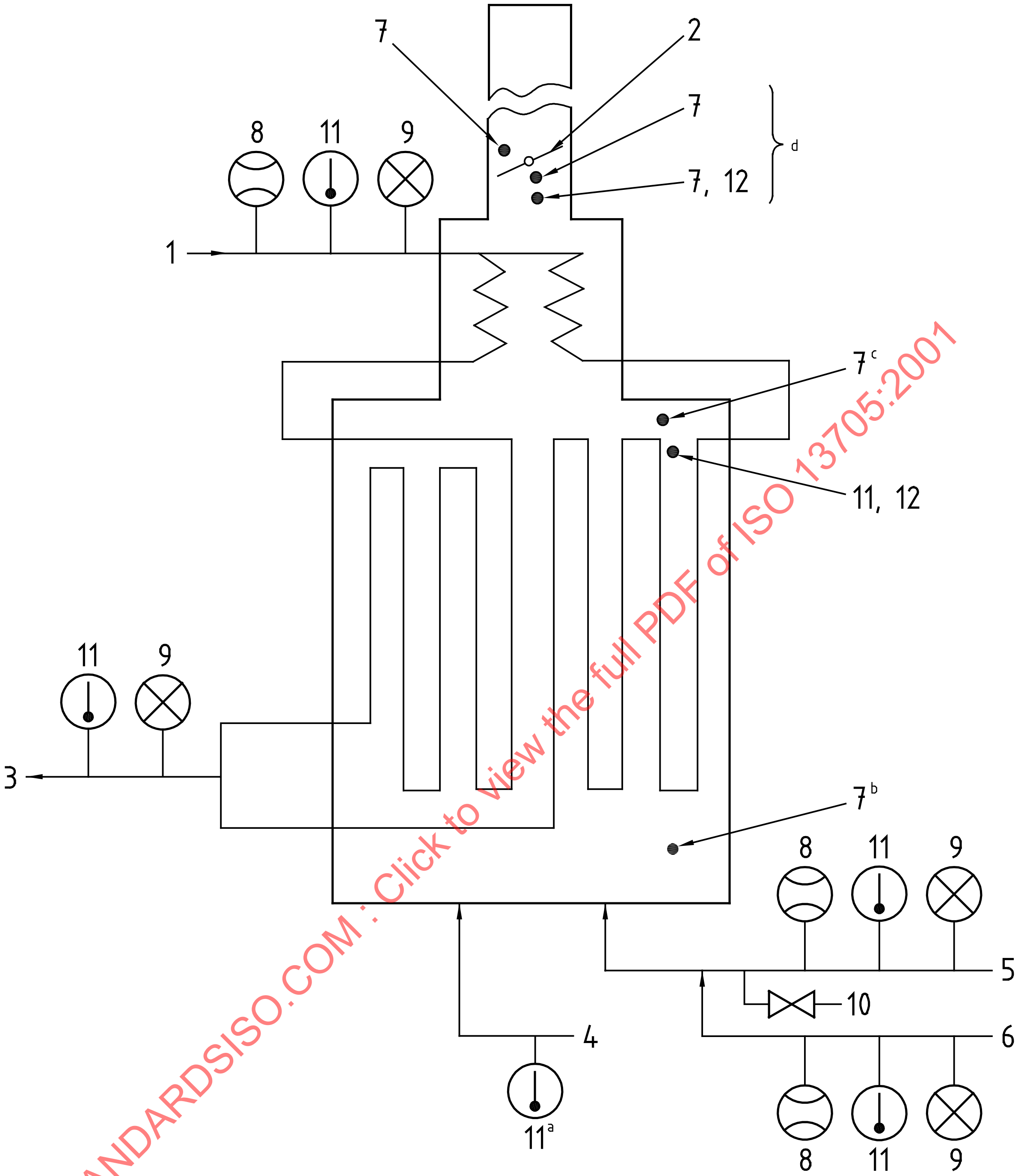
G.1.3.1 General

The instrumentation specified in G.1.3.2 and G.1.3.3 is required for the collection of data and the subsequent calculations necessary to determine the thermal efficiency of a heater (see Figure G.1).

G.1.3.2 Temperature

A multi-shielded aspirating (high-velocity) thermocouple (see Figure G.2) shall be used to measure all temperatures of the flue gas and temperatures of the preheated combustion air above 260 °C (500 °F). Thermocouples with thermowells may be used to measure temperatures at or below 260 °C (500 °F).

Conventional measuring devices may be used to measure the temperatures of the ambient air, the fuel and the atomizing medium. For a discussion of conventional temperature measurements, refer to API RP 554.



Key

1	Feed in	7	Draught gauge
2	Damper	8	Flow indicator
3	Feed out	9	Pressure indicator
4	Air in	10	Sampling connection
5	Fuel in	11	Temperature indicator
6	Atomizing medium	12	Oxygen sampling

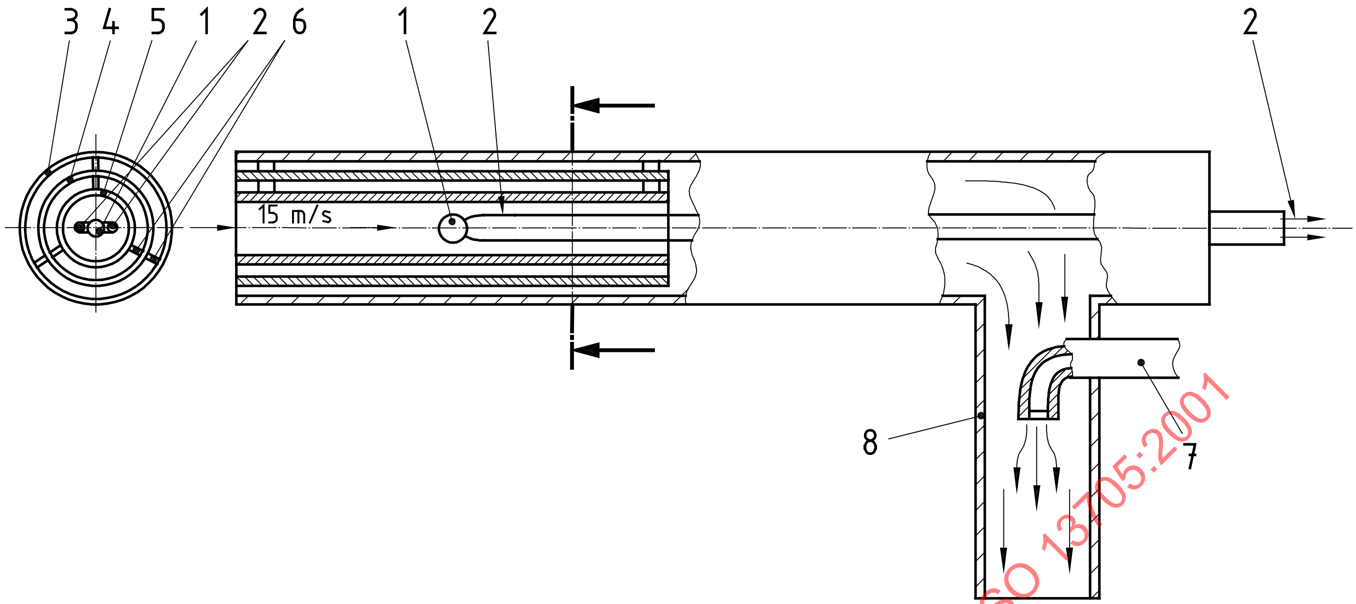
a Before preheater for internal heat source or after preheater for external heat source.

b Near burners.

c Arch.

d After preheater for internal heat source system.

Figure G.1 — Instrument and measurement locations



Key

1 Thermocouple junction
2 Thermocouple wires to temperature-indicating instrument
3 Outer thin-wall 310 stainless steel tube
4 Middle thin-wall 310 stainless steel tube
5 Centre thin-wall 310 stainless steel tube
6 Centring tripods
7 Air or steam at 6 bar (ga) or more, in increments of 6 bar until stable
8 Hot gas eductor

Figure G.2 — Typical aspirating (high-velocity) thermocouple

G.1.3.3 Flue-gas analysis

A portable or permanently installed analyser shall be used to analyse for oxygen and combustible gases in the flue gas. The analysis of the flue gas may be made on either a wet or a dry basis, but the calculations shall be consistent with the basis used. For a discussion of sampling systems and flue-gas analysers, refer to API 555.

G.1.4 Measurement

The following measurements shall be taken for reference purposes and for identification of heater operating conditions. If more than one process service or auxiliary stream is present, the data should be taken for all services.

a) Fuel flowrate;

b) process flowrate;

c) process-fluid inlet temperature;

d) process-fluid outlet temperature;

e) process-fluid inlet pressure;

f) process-fluid outlet pressure;

g) fuel pressure at the burner;

h) atomizing-medium pressure at the burner;

i) flue-gas draught profile.

G.2 Testing

G.2.1 Preparation for testing

G.2.1.1 The following ground rules shall be established in preparation for the test, prior to the date of the actual test run:

a) the operating conditions that will prevail during the test;

b) any re-rating that will be necessary to account for differences between the test conditions and the design conditions;

c) the acceptability of the fuel or fuels to be fired;

d) the selection of instrumentation types, methods of measurement and specific measurement locations.

G.2.1.2 All instrumentation that is to be used during the test shall be calibrated before the test.

G.2.1.3 Immediately before the actual test, the following items shall be verified:

a) that the fired process heater is operating at steady-state conditions;

b) that the fuel to be fired is acceptable;

c) that the heater is operating properly with respect to the size and shape of the flame, excess air, flue-gas draught profile, cleanliness of the heating surfaces and balanced burner firing.

G.2.2 Testing

G.2.2.1 The heater shall be operated at a uniform rate throughout the test.

G.2.2.2 The test shall last for a minimum of 4 h. Data shall be taken at the start of the test and every 2 h thereafter.

G.2.2.3 The duration of the test shall be extended until three consecutive sets of collected data fall within the prescribed limits listed in Table G.1.

Table G.1 — Allowed variability of data measurements

Datum	Limit
Heating value of fuel	± 5 %
Fuel rate	± 5 %
Flue-gas combustibles content	< 0,1 %
Flue-gas temperature	± 5 °C (9 °F)
Flue-gas oxygen content	± 1 %
Process flowrate	± 5 %
Process temperature in	± 5 °C (9 °F)
Process temperature out	± 5 °C (9 °F)
Process pressure out	± 5 %

G.2.2.4 The data shall be collected as follows.

— All of the data in each set shall be collected as quickly as possible, preferably within 30 min.

— The quantity of fuel gas shall be measured and recorded for each set of data, and a sample shall be taken simultaneously for analysis.

— For gaseous fuels, the net heating value shall be obtained by composition analysis and calculation.

— The quantity of liquid fuel shall be measured and recorded for each set of data. It is only necessary to take one sample for analysis during the test run.

— For liquid fuels, the net heating value shall be obtained by calorimeter test. Liquid fuels shall also be analysed to determine the hydrogen-carbon ratio, sulfur content, water content and the content of other components.

— Flue-gas samples shall be analysed to determine the content of oxygen and combustibles. Samples shall be taken downstream of the last heat-exchange (heat-absorbing) surface. If an air heater is used, samples shall be taken after the air heater. The cross-sectional area shall be traversed to obtain representative samples. A minimum of four samples shall be taken, not more than 1 m (3 ft) apart.

— The flue-gas temperature shall be measured at the same location used to extract samples of flue gas for analysis. Systems designed to operate on natural draught upon loss of preheated air shall also measure the flue-gas temperature above the stack damper. If the measured temperature reveals leakage (that is, if the stack temperature is higher than the temperature at the exit from the air heater), then flue-gas samples shall also be taken at this location to determine the correct overall thermal efficiency. The cross-sectional area shall be traversed to obtain the representative temperature. A minimum of four measurements shall be taken, not more than 1 m (3 ft) apart.

G.2.2.5 The thermal efficiency shall be calculated from each set of valid data. The accepted final results will then be the arithmetic average of the calculated efficiencies

G.2.2.6 All of the data shall be recorded on the standard forms presented in G.4.

G.3 Determination of thermal efficiency

G.3.1 Calculation of thermal efficiency

G.3.1.1 Net thermal efficiency

Figures G.3, G.4 and G.5 illustrate heat inputs and heat losses for typical arrangements of fired process heater systems.

For the arrangements in Figures G.3, G.4 and G.5, the net thermal efficiency (based on the lower heating value of the fuel) can be determined by the following equation:

$$\text{Efficiency} = \frac{\text{Total heat absorbed}}{\text{Total heat input}} \times 100$$

Also,

$$\text{Efficiency} = \frac{\text{Total heat input} - \text{Total heat losses}}{\text{Total heat input}}$$

Therefore,

$$e = \frac{(h_\mathrm{L} + \Delta h_\mathrm{a} + \Delta h_\mathrm{f} + \Delta h_\mathrm{m}) - (h_\mathrm{r} + h_\mathrm{s})}{(h_\mathrm{L} + \Delta h_\mathrm{a} + \Delta h_\mathrm{f} + \Delta h_\mathrm{m})} \times 100 \qquad \text{(G.1)}$$

where

e is the net thermal efficiency, expressed as a percentage;

h_L is the lower massic heat value of the fuel burned, in kJ/kg (Btu/lb);

Δh_a is the air sensible massic heat correction, in kJ/kg (Btu/lb)

$= c_{pa} \cdot (T_a - T_d) \cdot$ [kg (lb) of air per kg (lb) of fuel], or the enthalpy difference multiplied by kg (lb) of air per kg (lb) of fuel;

Δh_f is the fuel sensible massic heat correction, in kJ/kg (Btu/lb)

$= c_{pf} \cdot (T_f - T_d)$;

Δh_m is the atomizing medium sensible massic heat correction, in kJ/kg (Btu/lb);

$= c_{pm} \cdot (T_m - T_d) \cdot$ [kg (lb) of medium per kg (lb) of fuel], or the enthalpy difference multiplied by kg (lb) of medium per kg (lb) of fuel;

h_r is the assumed radiation massic heat loss, in kJ/kg (Btu/lb) of fuel;

h_s calculated stack massic heat loss (see Stack Loss Work Sheet, G.5), in kJ/kg (Btu/lb) of fuel.

G.3.1.2 Gross thermal efficiency

The gross thermal efficiency of a fired process heater system is determined by substituting, in equation (G.1), the higher heating value, h_H, in place of h_L and adding to h_s a value equal to 2 464,9 kJ/kg (1 059,7 Btu/lb) of H_2O multiplied by the mass, m, in kilograms (pounds), of H_2O formed in the combustion of the fuel, as follows:

$$e_g = \frac{(h_H + \Delta h_a + \Delta h_f + \Delta h_m) - \left[h_r + h_s + (m_{H_2O} \times 2\,464{,}9)\right]}{(h_H + \Delta h_a + \Delta h_f + \Delta h_m)} \times 100$$

However,

$$h_H = h_L + m_{H_2O} \times 2\,464{,}9$$

Making this substitution, the equation reduces to the following:

$$e_g = \frac{(h_L + \Delta h_a + \Delta h_f + \Delta h_m) - (h_r + h_s)}{(h_L + \Delta h_a + \Delta h_f + \Delta h_m) + (m_{H_2O} \times 2\,464{,}9)} \times 100$$

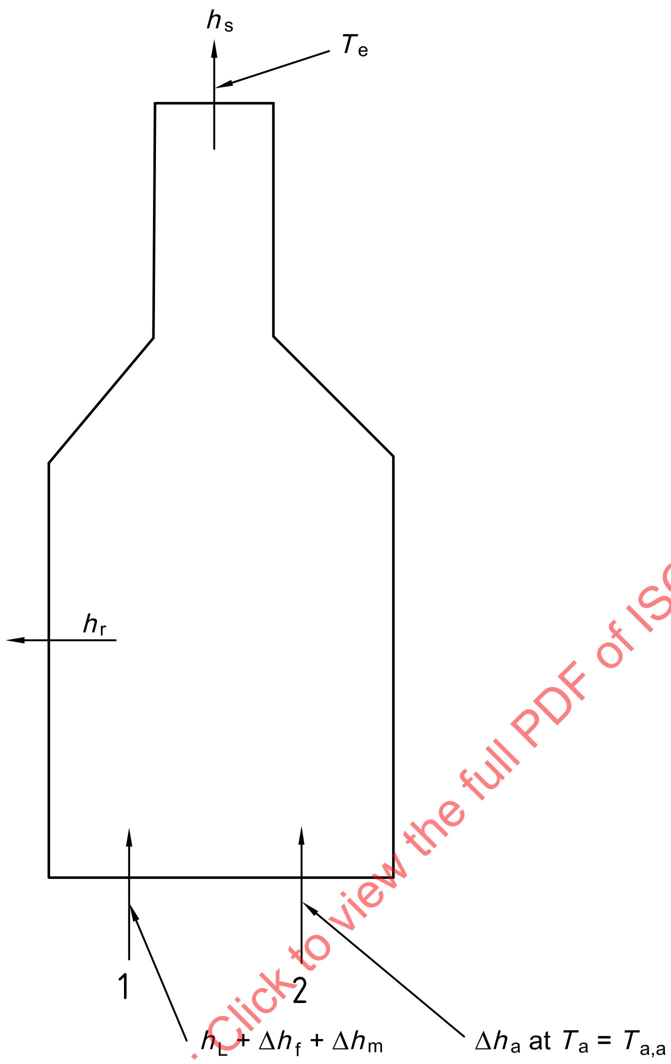
Reducing further,

$$e_g = \frac{(h_L + \Delta h_a + \Delta h_f + \Delta h_m) - (h_r + h_s)}{(h_H + \Delta h_a + \Delta h_f + \Delta h_m)} \times 100 \qquad \text{(G.2)}$$

where

e_g is the gross thermal efficiency, expressed as a percentage;

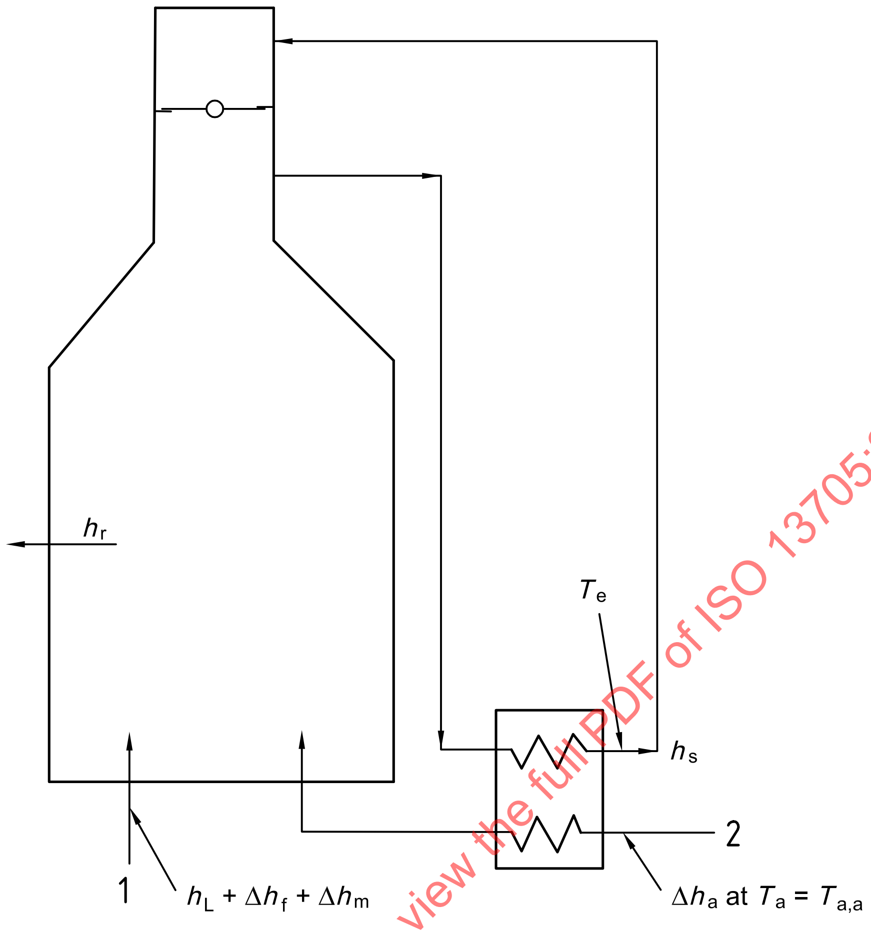
h_H is the higher massic heat value of the fuel burned, in kJ/kg (Btu/lb) of fuel.



Key

1 Fuel
2 Ambient air

Figure G.3 — Typical heater arrangment with non-preheated air

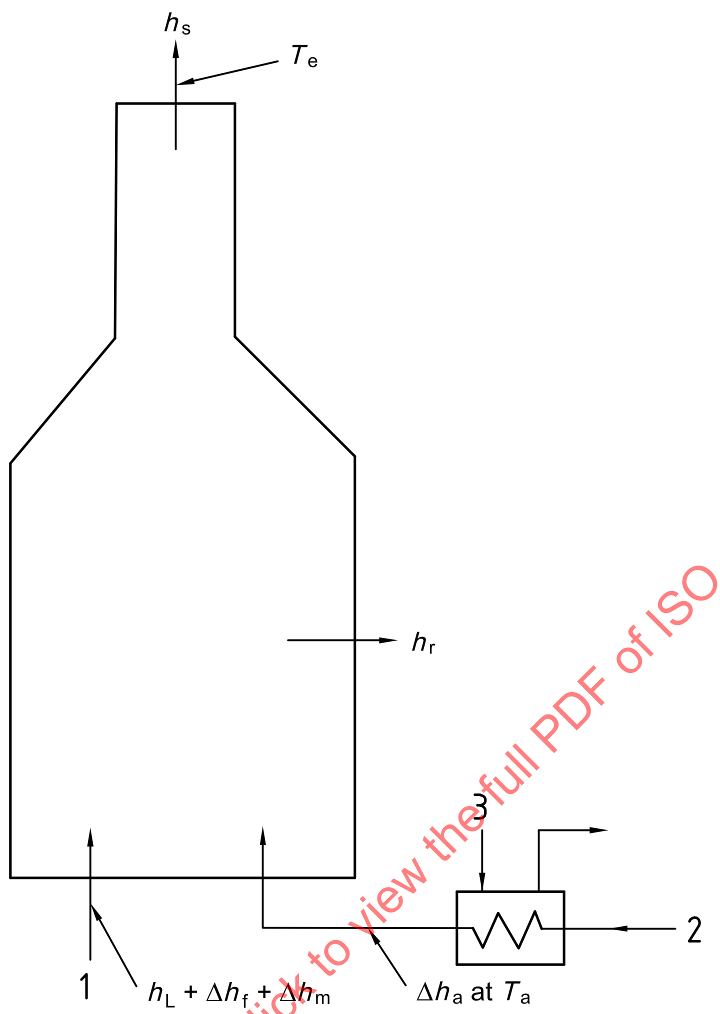


Key

1 Fuel

2 Ambient air

Figure G.4 — Typical heater arrangment with preheated air from an internal heat source



Key

1 Fuel
2 Ambient air at $T_{a,a}$
3 External heat

Figure G.5 — Typical heater arrangement with preheated air from an external heat source

G.3.2 Sample calculations

G.3.2.1 General

The examples in G.3.2.2 through G.3.2.4 illustrate the use of the preceding equations to calculate the thermal efficiency of three typical heater arrangements.

G.3.2.2 Oil-fired heater with natural draught

In this example (see Figure G.3), the ambient air temperature ($T_{a,a}$) is 26,7 °C (80 °F), the air temperature (T_a) is 26,7 °C (80 °F), the flue-gas temperature to the stack (T_e) is 232 °C (450 °F), the fuel oil temperature (T_f) is 176 °C (350 °F), and the relative humidity is 50 %. The flue-gas analysis indicates that the oxygen content (on a wet basis) is 5 % (volume fraction) and that the combustibles content is nil. The radiation heat loss is 1,5 % of the lower massic heat value of the fuel. The analysis of the fuel indicates that its gravity is 10° API, its carbon-hydrogen ratio is 8,06, its higher massic heat value (by calorimeter) is 42 566 kJ/kg (18 300 Btu/lb), its sulfur content is 1,8 % (mass fraction), and its inerts content is 0,95 % (mass fraction). The temperature of the atomizing steam (T_m) is

185 °C (366 °F) at a pressure of 1,03 MPa (150 psi) gauge; the mass of atomizing steam per unit mass of fuel is 0,5 kg/kg (0,5 lb/lb). G.6 contains the work sheets from G.5 filled out for this example.

The fuel's carbon content and the content of the other components are entered as mass fractions in Column 3 of the Combustion Work Sheet (see G.6) to determine the flue-gas components. By entering the fuel's higher massic heat value (h_H) and its components on the Lower Massic Heat Value (Liquid Fuels) Work Sheet (see G.6), the fuel's lower massic heat value (h_L) and carbon content (as a percentage) can be determined. Using this method, h_L = 40 186 kJ/kg (17 277 Btu/lb) of fuel.

The radiation massic heat loss, h_r, is determined by multiplying h_L by the radiation loss expressed as a percentage. Therefore, h_r = 0,015 × 40 186 = 602,8 kJ/kg (= 0,015 × 17 277 = 259,2 Btu/lb) of fuel.

The stack massic heat loss, h_s, is determined from a summation of the heat content of the flue-gas components at the exit flue-gas temperature, T_e (see Stack Loss Work Sheet, G.6). Therefore, h_s = 4 788,4 kJ/kg (2 058,5 Btu/lb) of fuel at 232 °C (450 °F).

The sensible massic heat corrections (Δh_a for combustion air, Δh_f for fuel and Δh_m for atomizing steam) are determined as follows:

$$\Delta h_a = c_{pa} \cdot (T_a - T_d) \cdot \text{[kg (lb) of air per kg (lb) of fuel]}$$

where

kg (lb) of air per kg (lb) of fuel = the sum of the values from lines (b) and (e) on the Excess Air and Relative Humidity Work Sheet (see G.6).

In SI units:

$$\Delta h_a = 1{,}005\ (26{,}7 - 15{,}6) \times (13{,}86 + 4{,}896)$$

$$= 209{,}3 \text{ kJ/kg of fuel}$$

$$\Delta h_f = c_{p\text{fuel}} \cdot (T_f - T_d)$$

$$= 2{,}099\ (176{,}7 - 15{,}6)$$

$$= 323{,}8 \text{ kJ/kg of fuel}$$

In US Customary units:

$$\Delta h_a = 0{,}24\ (80 - 60)\ (13{,}86 + 4{,}896)$$

$$= 90{,}0 \text{ Btu/lb of fuel}$$

$$\Delta h_f = c_{p\text{fuel}} \cdot (T_f - T_d)$$

$$= 0{,}48\ (350 - 60)$$

$$= 139{,}2 \text{ Btu/lb of fuel}$$

$$\Delta h_m = \text{Enthalpy difference} \times \text{[kg (lb) of steam per kg (lb) of fuel]}$$

In SI units:

$$= (2\ 780{,}7 - 2\ 530{,}0) \times 0{,}5$$

$$= 125{,}4 \text{ kJ/kg of fuel}$$

In US Customary units:

$= (1\ 195{,}5 - 1\ 087{,}7) \times 0{,}5$

$= 53{,}9$ Btu/lb of fuel

The net thermal efficiency can then be calculated as follows [see equation (G.1)]:

In SI units:

$$e = \frac{(40\ 186 + 209{,}3 + 323{,}8 + 125{,}4) - (602{,}9 + 4\ 788{,}1)}{(40\ 186 + 209{,}3 + 323{,}8 + 125{,}4)} \times 100$$

$= 86{,}8$ %

In US Customary units:

$$e = \frac{(17\ 277 + 90{,}0 + 139{,}2 + 53{,}9) - (259{,}2 + 2\ 058{,}5)}{(17\ 277 + 90{,}0 + 139{,}2 + 53{,}9)} \times 100$$

The gross thermal efficiency is determined as follows [see equation (G.2)]:

In SI units:

$$e_g = \frac{(40\ 186 + 209{,}3 + 323{,}8 + 125{,}4) - (602{,}9 + 4\ 788{,}1)}{(42\ 566 + 209{,}3 + 323{,}8 + 125{,}4)} \times 100$$

$= 82{,}0$ %

In US Customary units:

$$e_g = \frac{(17\ 277 + 90{,}0 + 139{,}2 + 53{,}9) - (259{,}2 + 2\ 058{,}5)}{(18\ 300 + 90{,}0 + 139{,}2 + 53{,}9)} \times 100$$

$= 82{,}0$ %

G.3.2.3 Gas-fired heater with preheated combustion air from an internal heat source

In this example (see Figure G.4), the ambient air temperature ($T_{a,a}$) is – 2,2 °C (28 °F), the air temperature (T_a) is also – 2,2 °C (28 °F), the flue-gas temperature at the exit from the air heater is 148,9 °C (300 °F), the fuel gas temperature is 37,8 °C (100 °F) and the relative humidity is 50 %. The flue-gas analysis indicates that the oxygen content (on a wet basis) is 3,5 % (vol. fraction) and that the combustibles content is nil. The radiation heat loss is 2,5 % of the lower heating value of the fuel. The analysis of the fuel indicates that the fuel's methane content is 75,4 % (vol. fraction), its ethane content is 2,33 % (vol. fraction), its ethylene content is 5,08 % (vol. fraction), its propane content is 1,54 % (vol. fraction), its propylene content is 1,86 % (vol. fraction), its nitrogen content is 9,96 % (vol. fraction), and its hydrogen content is 3,82 % (vol. fraction). G.7 contains the Combustion Work Sheet, Excess Air and Relative Humidity Work Sheet, and Stack Loss Work Sheet from G.5 filled out for this example.

The fuel's h_L is determined by entering the fuel analysis in Column 1 of the Combustion Work Sheet (see G.7) and dividing the total heats of combustion (Column 5) by the total fuel mass (Column 3). Therefore, h_L = 354 858/8,420 = 42 147 kJ/kg of fuel (h_L = 335 629/18,523 = 18 120 Btu/lb of fuel).

The radiation massic heat loss, h_r, is determined by multiplying h_L by the radiation loss expressed as a percentage. Therefore, h_r = 0,025 × 42 147 = 1 053,7 kJ/kg of fuel (= 0,025 × 18 120 = 453,0 Btu/lb of fuel).

The stack massic heat loss, h_s, is determined from a summation of the heat content of the flue-gas components at the exit flue-gas temperature, T_e (see Stack Loss Work Sheet, G.7). Therefore, h_s = 2 747,5 kJ/kg of fuel at 148,9 °C (1 181,2 Btu/lb of fuel at 300 °F).

The sensible massic heat corrections , Δh_a for combustion air and Δh_f for fuel, are determined as follows:

$\Delta h_a = c_{pa} \times (T_a - T_d) \times$ [kg (lb) of air per kg (lb)of fuel]

In SI units:

$= 1{,}005\ (-\ 2{,}2 - 15{,}6) \times (14{,}344 \times 1{,}2 + 0{,}201)$

$= -\ 313{,}3$ kJ/kg of fuel

In US Customary units:

$= 0{,}24\ (28 - 60)\ (14{,}344 \times 1{,}2 + 0{,}201)$

$= -\ 134{,}7$ Btu/lb of fuel

$\Delta h_f = c_{pf} \times (T_f - T_d)$

In SI units:

$= 2{,}197\ (37{,}8 - 15{,}6)$

$= 48{,}8$ kJ/kg of fuel

In US Customary units:

$= 0{,}525\ (100 - 60)$

$= 21{,}0$ Btu/lb of fuel

The net thermal efficiency can then be calculated as follows [see equation (G.1)]:

In SI units:

$$e = \frac{(42\,147\ - 313{,}3 + 48{,}8) - (1\,053{,}7 + 2\,747{,}5)}{(42\,147\ - 313{,}3 + 48{,}8)} \times 100$$

$= 90{,}9\ \%$

In US Customary units:

$$e = \frac{(18\,120\ - 134{,}7 + 21) - (453{,}0 + 1\,181{,}2)}{(18{,}120\ - 134{,}7 + 21)} \times 100$$

$= 90{,}9\ \%$

To determine the gross thermal efficiency, follow the procedure in G.3.1.2 (see also G.3.2.1).

G.3.2.4 Gas-fired heater with preheated combustion air from an external heat source

This example (see Figure G.5) uses the same data that were used in G.3.2.2 except for the following changes: The air temperature (T_a) is 148,9 °C (300 °F), the flue-gas temperature to the stack (T_e) is 260 °C (500 °F), and the flue-gas analysis indicates that the oxygen content (on a dry basis) is 3,5 % (volume fraction). G.8 contains the Excess Air and Relative Humidity Work Sheet and Stack Loss Work Sheet from G.5 filled out for this example.

h_L and Δh_f are determined exactly as they were in G.3.2.2. Therefore, h_L = 42 147 kJ/kg (18 120 Btu/lb) of fuel, and Δh_f = 1053,7 kJ/kg (453,0 Btu/lb) of fuel.

In this example, the oxygen reading was taken on a dry basis, so the values for kg (lb) of water per kg (lb) of fuel should be entered as zero when correcting for excess air (see Excess Air and Relative Humidity Work Sheet, G.8). The calculation for total kg of H_2O per kg (lb of H_2O per lb) of fuel (corrected for excess air) is again performed using values for water and moisture (see Excess Air and Relative Humidity Work Sheet).