INTERNATIONAL STANDARD

ISO 23309

Second edition
2020-05

Hydraulic fluid power systems — Assembled systems — Methods of cleaning lines by flushing

Transmissions hydrauliques — Systèmes assemblés — Méthodes de nettoyage des canalisations par curage

Reference number
ISO 23309:2020(E)

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Published in Switzerland

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 6, *Contamination control*.

This second edition cancels and replaces the first edition (ISO 23309:2007) which has been technically revised.

The main changes compared to the previous edition are as follows:

— identifies the shortfall of the Reynolds formula when it's used in isolation;

— identifies the importance of flushing oil velocity, temperature, and viscosity;

— identifies to the practitioners who perform flushing procedures that if they only consider the *Re* value the flushing velocity could be much less than the system oil flow within the system and what it will be subjected to in normal service;

— raises awareness and importance of the factors other than the *Re* valve that affect the effectiveness, efficiency and reliability of any flushing process.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In hydraulic fluid power systems, power is transmitted and controlled through a liquid under pressure within an enclosed circuit.

The initial cleanliness level of a hydraulic system can affect its performance and useful life. Unless removed, particulate contamination present after manufacturing, assembly, component failure and repair of a system can circulate through the system and cause damage to the system components. To reduce the probability of such damage, the fluid and the internal surfaces of the hydraulic fluid power system needs to be flushed clean to a specified level.

Flushing of lines in a hydraulic system needs to be viewed as one means of removing in-built and residual contamination and should not be the sole method for cleaning such systems unless other methods are impractical.

Hydraulic fluid power systems — Assembled systems — Methods of cleaning lines by flushing

1 Scope

This document specifies the procedures for flushing particulate contamination from the hydraulic lines and components of hydraulic fluid power systems which is:

— residual in the components after manufacture;

— introduced into the system during the assembly of a new system; or

— introduced into the system after system failure, maintenance or modification of an existing system.

The aim of flushing the system is to quickly remove this contamination to reduce the amount of wear and damage that results if these particles are allowed to circulate around the system.

This document is not applicable to:

— the chemical cleaning and pickling of hydraulic tubes;

— the cleaning of major system components (this is covered in ISO/TR 10949).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4021, *Hydraulic fluid power — Particulate contamination analysis — Extraction of fluid samples from lines of an operating system*

ISO 4406, *Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles*

ISO 4407, *Hydraulic fluid power — Fluid contamination — Determination of particulate contamination by the counting method using an optical microscope*

ISO 5598, *Fluid power systems and components — Vocabulary*

ISO/TR 10949, *Hydraulic fluid power — Component cleanliness — Guidelines for achieving and controlling cleanliness of components from manufacture to installation*

ISO 12669, *Hydraulic fluid power — Method for determining the required cleanliness level (RCL) of a system*

ISO 16431, *Hydraulic fluid power — System clean-up procedures and verification of cleanliness of assembled systems*

ISO 16889, *Hydraulic fluid power — Filters — Multi-pass method for evaluating filtration performance of a filter element*

ISO 18413, *Hydraulic fluid power — Cleanliness of components — Inspection document and principles related to contaminant extraction and analysis, and data reporting*

ISO 21018-1, *Hydraulic fluid power — Monitoring the level of particulate contamination of the fluid — Part 1: General principles*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
flushing
process of cleaning a hydraulic piping system that involves the circulation of turbulent hydraulic fluid at high velocities within the piping system loops to remove, transport and filter out particles that have been introduced into the system during manufacture, building, maintenance, or after repairs

3.2
flushing level
the cleanliness level to be achieved after *flushing* (3.1) which shall be cleaner than the *required cleanliness level (RCL)(3.3)*

Note 1 to entry: A cleanliness level of one ISO code cleaner than the *RCL* (3.3) is suitable (see ISO 4406).

3.3
required cleanliness level
RCL
liquid cleanliness level specified for a system or process

Note 1 to entry: See ISO 16431.

3.4
Reynolds number
Re
dimensionless ratio of the internal flow forces to the viscous forces within a fluid which is an indicator of the flow characteristics (laminar or turbulent) of a moving fluid

4 Principle of flushing

The purpose of flushing is to quickly remove surface particulate contamination to both limit the amount of damage to the components and to quickly achieve the RCL by the customer. This is achieved by circulating clean fluid under conditions of high fluid velocity, temperature and turbulence that are higher than that experienced in normal service and that will pick up the particles from the surfaces and transport them to a clean-up or flushing filter.

The RCL is usually specified by the customer, but for the case where the RCL is not stated, Annex A provides selection guidelines. Component suppliers shall be able to specify the cleanliness level of their components. ISO/TR 10949 and ISO 18413 specify methods of evaluating and documenting the cleanliness level.

5 Flushing lines in a hydraulic system

5.1 Initial factors to consider

Some factors to be considered for the achievement of a satisfactory cleanliness level for lines in a hydraulic system are:

a) the selection of components that have been cleaned in accordance with ISO/TR 10949;

b) the initial cleanliness of the fitted lines;

c) service or flushing fluid, which is cleaned to a level that, when added, is cleaner than the final flushing level, see 3.2;

d) selection of suitable line-mounted filters that have a rating capable of achieving the RCL within an acceptable time period;

e) the establishment of a high fluid velocity and turbulent flow regime that will pick up the particles and transport them to the filters.

5.2 System layout

5.2.1 Designers of hydraulic systems shall plan for system flushing in the design phase. Dead ends without circulation shall be avoided. If there is a risk of particulate contamination moving from the dead end to the rest of the system, then the dead end shall be capable of being flushed out.

5.2.2 Circuits should preferably be connected in series as the fluid velocity and *Re* of each single circuit can be calculated when the overall flow is given. Parallel connection of line sections however, is acceptable provided that turbulent flow can be achieved, maintained and monitored via flow meters.

5.2.3 Components that can prevent a high flow velocity being achieved or that can themselves be damaged by high velocities of particulate contamination shall be disconnected from the circuit or by-passed.

5.2.4 Sampling valves in accordance with ISO 4021 shall be provided at strategic locations.

5.2.5 The rating of any flushing filter shall be equal to or finer than the rating of any built-in filter elements, and any built-in filter shall be replaced for flushing, if required. The original specified and new filters may be reinstated after flushing.

5.2.6 Connectors and conductors shall be of uniform inside diameter to avoid trapping any particles for possible release later. They shall also be suitably sized to avoid large pressure losses.

5.3 Component cleanliness level

Components and assemblies that are fitted into the system shall be at least as clean as the specified system cleanliness. Component suppliers should be able to give information regarding component cleanliness levels.

NOTE The effect of component cleanliness on the whole system cleanliness level can be assessed using ISO/TR 10686. In order to estimate the component cleanliness level after flushing, in reciprocal approach, the final system flushing level could be redefined to the individual cleanliness of each component of the system. This requires knowledge of the whole system volume and each component of the system.

5.4 Anti-corrosion agents

If the components contain anti-corrosion agents that are not compatible with the flushing or system fluid, the components shall be flushed before assembly using a degreasing agent that is compatible with the intended system fluid. The degreasing agent shall not affect component seals. The degreasing agent shall be of a suitable cleanliness, ideally to the RCL selected.

6 Treatment of lines

6.1 Preparation of lines during fabrication

Tube or pipe to be used as a hydraulic line shall be deburred in accordance with procedures agreed between the manufacturer and the user. Tubes or pipes with scale or corrosion shall be treated in accordance with procedures agreed between the manufacturer and user.

6.2 Surface treatment

To maintain cleanliness until installation, lines shall be treated with a suitable clean protection liquid and be suitably capped immediately after treatment. Corrosion protection measures will be required during storage.

6.3 Storage of lines and connectors

Cleaned and surface-treated assembled lines and connectors shall be blanked off and capped immediately with clean caps and shall be stored under dry controlled conditions. If this is not possible, the assembled lines and connectors shall be protected against moisture, e.g. rain. If assembled lines and connectors are not stored under adequate conditions, additional cleaning and surface treatment may be necessary.

7 Installation of piping systems

7.1 During installation of piping systems, welding, soldering or heating the lines shall be avoided to prevent scaling. If this is not possible, the relevant lines shall be cleaned and re-protected according to ISO/TR 10949.

7.2 Flanges or approved connectors shall be used. All protection items fitted to lines and components, e.g. blanking plugs and caps, shall be removed as late as possible in the installation process, see ISO/TR 10949.

8 Flushing requirements

8.1 Flushing document

A project-specific document ('flushing document') shall be produced to identify the lines that shall be flushed, in which order they shall be flushed and any additional equipment that is needed. Each identified flushing line should also show the highest flow rate the lines will be subjected to in normal service and what the minimum flushing flow rate should be. To record the cleanliness level that is achieved, see 8.6.1. This shall be signed by the customer and the system co-ordinator.

8.2 Flushing criteria

A flushing procedure shall be adapted to suit the requirements of the system concerned. The following criteria shall be met to ensure that a satisfactory result is obtained:

— if a portable flushing power pack is used, its reservoir shall be cleaned to a level at least matching that of the specified system cleanliness, see Clause 4;

— the fluid used to fill the system shall pass through a suitable filter, see 8.6.2 c). Air shall not be brought into the system during filling with hydraulic fluid. If necessary, the system shall be topped up and re-bled;

— if additional pumping equipment is used, it shall be located as close as possible to the supply end of piping systems to minimise the flow resistance and pressure losses;

— hydraulic flow and temperature measuring devices shall be installed to monitor the flushing fluid and to verify the flushing parameters;

— the flushing filter shall be located at the end of the circuit just before the reservoir. Additional filters may be used, see 8.4.2;

— a sampling valve for extracting samples or sample taps for the connection of field contamination monitors shall be positioned at the end of the section being flushed in a line, before the reservoir, or both.

8.3 Flushing parameters

8.3.1 To effectively flush particulate contamination from hydraulic lines, the system shall be subjected to a combination of all the main flushing elements (a, b and c) at the same time.

a) *Re* shall be greater than that which exists in the system during operation or greater than 4 000, whichever is higher;

b) The flow rate in the pipe lines should be at least 1,5 times the actual flow rate in service.

c) The oil temperature is greater than the minimum temperature likely to be experienced in service, but should be at least 40 °C.

In practice, it is not always possible to achieve all of these parameters. In the event of a conflict, e.g. *Re* can be achieved but the 1,5 times flow rate condition cannot, priority should be placed upon achieving the highest possible *Re*.

The importance of these factors is shown in Annex C.

8.3.2 *Re* and the required flow rate (q_v) can be calculated using Formulae (1) and (2):

$$Re = \frac{21\,220 \times q_v}{v \times d} \tag{1}$$

$$q_v = \frac{d \times Re \times v}{21\,220} \tag{2}$$

where

q_v is the flow rate in L/min;

v is the kinematic viscosity at the flushing fluid temperature in mm^2/s;

d is the inside diameter of the line in mm.

If there is difficulty in obtaining *Re* greater than 4 000, *Re* should be raised by either reducing the viscosity or increasing the flow rate. Reduction of viscosity is the preferred method. Viscosity can be reduced by increasing the temperature or by using a compatible flushing fluid with a lower viscosity.

If the fluid temperature is increased, the temperature rise shall be limited to ensure that the fluid properties or the components are not adversely affected. If a special flushing fluid is used it shall be compatible with the intended system fluid. The preferred options are to use the system fluid for flushing or a lower viscosity grade of the same system fluid.

In a cold environment, the flushing fluid can suffer from heat loss. In such a case, in order to verify that *Re* is greater than 4 000, the temperature of the fluid shall be measured at the estimated coldest point of the system. Flushing shall only be accepted when the lowest temperature measured provides for *Re* greater than 4 000 (consult the manufacturer's data for the viscosity and temperature of the relevant flushing fluid). Under very cold conditions, the system shall be insulated to keep the temperature above the minimum necessary to provide for *Re* greater than 4 000.

8.3.3 The use of vibration, high frequency sound, or a change in flow direction can contribute to a faster removal of particles. This is a supplement and not an alternative to high velocity and turbulent flow.

8.3.4 The pressure in the piping system shall be monitored to ensure that it does not exceed the system's maximum allowable working pressure.

8.4 Filters and separation of particles

8.4.1 General requirements

8.4.1.1 The filters used for flushing determine the final cleanliness level and the clean-up time.

8.4.1.2 Choose a filter with the optimum filtration ratio. If filters with a filtration ratio inadequate for the application are used, situations can arise where the specified cleanliness level cannot be achieved or is achieved after an extended flushing period.

NOTE The time required and the effectiveness of flushing is determined by the filtration or Beta Ratio of the filter. The higher the Beta Ratio, the faster and more effective flushing is, see Annex B.

The filtration ratio shall be determined in accordance with ISO 16889 (see B.2).

8.4.1.3 Filters shall have a means to monitor blockage, e.g. a differential pressure indicator. Filter elements shall be replaced immediately on indication of the blockage indicator so that the effectiveness of the filter element is maintained.

8.4.2 Additional external flushing filters

8.4.2.1 Additional filters can be required during the flushing process so that:

— if components are protected from the ingress of particles, the filter shall be mounted upstream and as close to the component as possible;

— if protection is given to a component that is considered sensitive to particles, a non-bypass assembly shall be used;

— if particles released from the component are captured, it shall be located immediately downstream of that component;

— the flushing time is reduced.

8.4.2.2 Large flushing filters should be used when possible. The smallest acceptable flushing filter shall have a maximum pressure drop through a clean element of no more than 5 % of the setting of the bypass valve or the indicator, calculated at the actual viscosity and maximum flow rate of the flushing fluid.

8.5 Monitoring the progress of flushing

8.5.1 Options for monitoring

The progress of flushing shall be monitored by one of three methods:

a) extracting samples of the fluid from the system being flushed in accordance with 8.5.2 and analysing the samples for their cleanliness level using the methods described in ISO 16431. These techniques shall be used for final certification of cleanliness, see 8.6.5;

b) connecting an on-line particle counter or Particulate Contamination Monitor (PCM) to an approved sampling point and analysing the fluid either continuously or periodically in accordance with ISO 21018-1. This technique shall not be used for final certification of the cleanliness, unless agreed with the customer;

c) extracting a sample (8.5.2) preparing a filter membrane in accordance with ISO 4407 and assessing the concentration of particles using an approved comparison membrane technique. PCMs shall not be used for final certification of the cleanliness unless agreed with the customer.

8.5.2 Sampling procedures

The samples taken from the system shall:

a) use sampling valves that conform to ISO 4021;

b) be taken in accordance with ISO 4021 for offline analysis;

c) be taken in accordance with ISO 21018-1 for on-line analysis;

d) be collected, using an in-line membrane holder, in accordance with the manufacturer's instructions.

8.5.3 Minimum flushing time before oil samples are taken

a) The minimum required flushing time depends upon the capacity and complexity of the hydraulic system. Even if fluid samples from the system indicate that the flushing cleanliness level has been reached after only a short period of time, flushing at turbulent flow shall continue.

NOTE 1 Continued flushing increases the possibility of removing particles that can adhere to the line walls.

b) The recommended minimum flushing time before samples are taken can be calculated from Formula (3):

$$t = \frac{20 \times V}{q_v} \tag{3}$$

where

t is the flushing time before samples are taken, in min;

q_v is the flow rate, in L/min;

V is the volume of the section being flushed, in L.

NOTE 2 Experience has shown that the RCL is rarely achieved within the minimum flushing time calculated using Formula (3).

8.6 Flushing procedures

8.6.1 General

Subclause 8.6.2 details a list of procedures that can be used for flushing but the actual procedures used depend upon the system being flushed and the requirements of the customer. These procedures shall be used to draw up a flushing document, see 8.1.

8.6.2 Preliminary stages

a) review the flushing plan, see 8.2 for the need for changes in the procedure;

b) if required, fit any ancillary equipment and either remove or bypass any sensitive equipment. Fit filters of the correct rating as required, see 8.4.1.2;

c) fill with hydraulic or flushing fluid dispensed through a filling filter, see 8.2;

d) bleed the system of air, see 8.2, starting the system momentarily if necessary.

8.6.3 Stage 1 — Flushing at low pressure

Flush the system at the lowest pressure in the following manner:

a) start the system at the lowest possible pressure with all filters in circuit and run up to the required temperature. Add additional fluid and bleed as required;

b) start flushing the first line section in the flushing plan for the minimum time determined using 8.5.2 for that section. Operate components during this period if required. Verify the fluid flow rate, temperature and *Re* values;

c) at the end of this period determine the cleanliness level of the fluid using one of the methods stated in 8.6.1;

d) if the contamination level is above the flushing level, repeat 8.6.3 b) as required, otherwise proceed to 8.6.3 e);

e) if it is cleaner than the flushing level, confirm this by analysing at least one other sample, then proceed to the next section in the flushing document;

f) repeat 8.6.3 b) to 8.6.3 e) for all other sections;

g) when the first stage is complete, stop the system, remove any low pressure ancillary equipment and go to 8.6.4.

8.6.4 Stage 2 — Flushing at higher pressures

Flush the system at higher pressures in the following manner:

a) restart the system and increase the pressure slowly to 30 % of its operating pressure;

b) repeat 8.6.3 b) to 8.6.3 f) as required.

NOTE The flushing time and frequency of sampling could be less than used previously as the system should be cleaner.

8.6.5 Verification of final cleanliness level

The measurement of the final cleanliness shall be determined in accordance with 8.6.1.

9 Identification statement (reference to this document)

Manufacturers who have chosen to conform to this document, should use the following statement in their catalogues, sales literature, test sheets and flushing plans: "In accordance with ISO 23309, *Hydraulic fluid power systems — Assembled systems — Methods of cleaning lines by flushing.*"

Annex A
(informative)

Guidelines for obtaining the Required Cleanliness Level (RCL) for a system

A.1 General

For a system, the RCL is the cleanliness level that the customer requires for their system and it should be specified by that customer. It should be based upon the system's contaminant sensitivity and the reliability that the user requires, and be system specific. If this is not supplied, then there are two options for its determination:

a) a comprehensive method using ISO 12669 (see A.2) where the RCL is based upon the individual requirements;

b) the method described in A.2 involves consideration of more parameters. Its use is recommended because it should give an RCL that is more relevant to a specific user.

A.2 Comprehensive method — ISO 12669

The basis of this method is the identification of six operational characteristics or requirements for the system which are influenced by the level of particulate contamination. These parameters are sub-divided into levels of severity, for which a weighting (score) is given:

a) operating pressure and duty cycle;

b) component sensitivity to particulate contaminant;

c) life expectancy required;

d) total cost of component replacement;

e) cost of downtime;

f) risk or safety requirements.

The user systematically examines each of these parameters and selects the condition that best describes the system and the user's requirements. A weighting is assigned to each selected condition and this is summated into a system weighting which is then used to select the RCL from ISO 12669:2017, Figure 1.

A.3 Recommendations based upon component cleanliness requirements

A.3.1 General

These recommendations are based upon RCL that were typical of those systems experiencing the tabulated conditions seen in Table A.1. The user defines which conditions of sensitivity to particulate contamination and operating pressure level closely reflect those of the system where the RCL is required, then selects the RCL. The RCL selected should be agreed between the supplier and customer.

A.3.2 Applications that can require high system cleanliness levels

Typical applications requiring high cleanliness levels are:

— systems where high reliability is the controlling factor;

— systems with proportional valves or servo-valves;

— systems with flow control and pressure-reducing valves that meter small quantities of fluid, particularly when subjected to high pressure drops;

— systems with hydraulic motors or pumps operating near their maximum ratings;

— systems requiring a high life expectancy.

A.3.3 Applications that can require medium system cleanliness levels

Using Table A.1, select the operating pressure and system cleanliness requirement that closely resembles the system where the RCL is required and read off the RCL.

Table A.1 — Guidelines for fluid cleanliness levels in operating systems for meeting high and medium cleanliness requirements

System operating pressure	Minimum system fluid cleanliness requirement expressed in accordance with ISO 4406	
	High	Medium
≤ 16 MPa (160 bar)	17/15/12	19/17/14
> 16 MPa (160 bar)	16/14/11	18/16/13

NOTE The RCL in Table A.1 has been derived using sample bottles and can differ from the RCL derived from ISO 12669 which uses on-line analysis. This is due to the use of sample bottles that can cause errors by the inclusion of extraneous particles in the sample, see B.1.

Annex B
(informative)

Factors influencing the effectiveness and duration of flushing

B.1 Process factors affecting the effectiveness of flushing

The effectiveness of flushing and, consequently, the flushing time, is affected by a number of factors, most of which are identified below, together with brief comments regarding ways of improving process efficiency:

— appropriate means of monitoring: the method selected depends upon the individual requirements and preferences, and also the RCL. If a clean RCL is specified (for example: (16/14/11) in accordance with ISO 4406, then on-line monitoring is recommended as analysis using sample bottles can significantly extend the flushing time due to the errors that are inherent with this process;

— high fluid velocity and turbulent mixing conditions: to more effectively pick up and remove the particles from the component surfaces;

— solvency of flushing fluid: the solvency can break the chemical bond between the particle and surface, which can be improved by increasing the temperature of the fluid (this also increases *Re*, see 8.3) and by using a detergent-based flushing fluid, see Annex C;

— high efficiency filter, see B.2;

— strategic placement of additional filters: to stop contaminant particles flushed from one component generating further particles in another component;

— systematic approach to flushing: generally flushing the 'dirtiest' components first and the most expensive last.

B.2 The effect of filter rating on flushing time

The rating of the flushing filter is one of the most important factors governing the time it takes and for the efficiency of flushing. It controls the concentration of particles passed downstream, hence into the next component where it can generate more particles through the 'regenerative wear' process. This increase in particles will extend the flushing time, see Clause 4. The amount of particles passing through the filter is directly proportional to the filtration or Beta Ratio of the filter. The higher the Beta Ratio, the cleaner the effluent fluid. This is illustrated in Figure B.1 which shows the effect of filter rating on the relative clean-up time of three filters of different ratings.

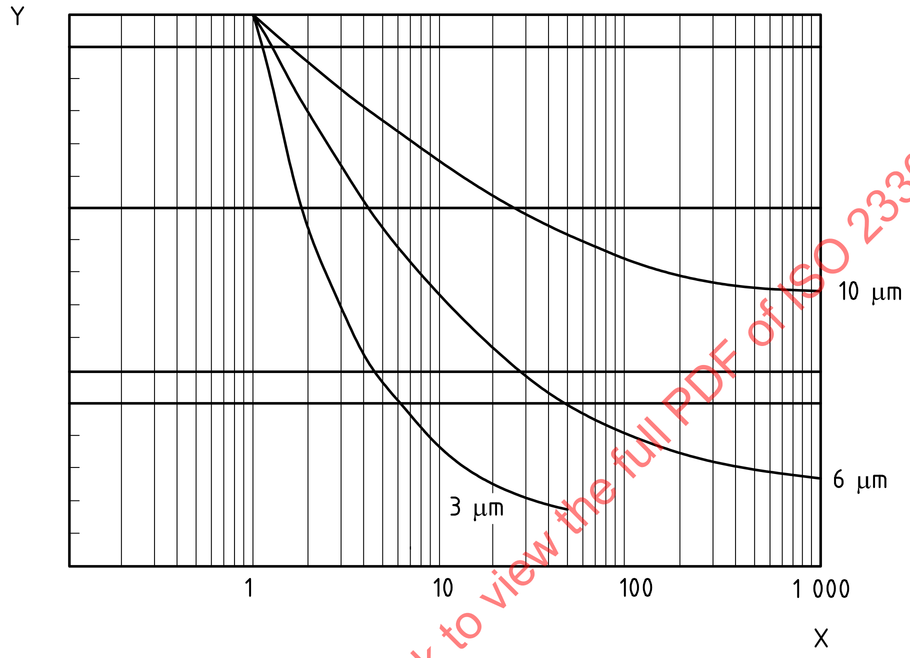
The data shown in Figure B.1 was obtained in a re-circulatory test stand using ISO Medium Test Dust (ISO MTD) and should be considered as the best possible for the following reasons:

— particle distribution in the system: the multi-pass test stands are designed to promote '100 %' mixing and any unevenness in the distribution of particles leads to a change in the relative flushing time. Generally, the finer the distribution, the longer the removal time and vice versa;

— particle size and shape: the particles in ISO MTD are generally regularly shaped whereas system particles tend to be acicular (long and thin), and the smaller ones can penetrate through the filter. This can extend the flushing time;

— slow release of particles: the surfaces of components should be viewed as separate 'generators' of contaminant, each with a separate release factor. Thus, the release rate might not be regular and usually results in an extension in flushing time. For this reason, '20 passes' through a section before sampling is recommended (see 8.5.2) and not a shorter 'theoretical' time that is sometimes used;

— presence of circuit conditions: affects how the filter performs as pressure ripple, surges and increased differential pressure can reduce the filter's effectiveness. It is affected by both the severity of the unsteady condition and the structure of the filter.



Key

X flushing time min

Y particle concentration

Figure B.1 — Effect of filter rating on flushing time

Annex C
(informative)

Identification and relationship between the main flushing requirements

C.1 General

The hydraulic system is generally at its most vulnerable when it first starts up because it can contain particles that are residual from the components manufacturing processes and added when a complete system is being assembled with inter-connecting components such as hose and tube assemblies, especially when the assemblies include some form of fabrication process. The passage of these particles, through the system at start-up, will cause substantial amounts of wear and damage which, in turn, causes regenerative wear in the system. The net result is substantial wear to the system in a relatively short time which will significantly reduce the component's life, cause unreliability and, perhaps, even a catastrophic failure. To reduce the potential for this type of damage, systems are 'flushed'.

C.2 Requirements for effective flushing

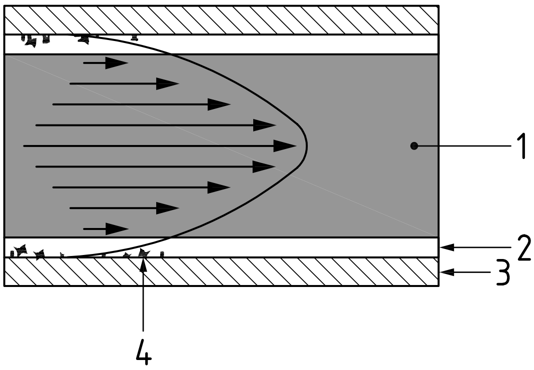
C.2.1 General

The main requirements for flushing are to have flow conditions in relation to high fluid velocity, turbulence and temperature so that it picks up the particles from the walls of the components, pipes, etc. and keeps them in suspension whilst transporting them to the flushing or clean-up filter. The aim is to remove all of the residual particles at the flushing stage so that they are not released in service. Thus, the flow force and conditions in flushing shall be higher than is seen in service, otherwise they may not.

There are a number of requirements for flushing, some of which are dependent upon others, and these are detailed below:

C.2.2 Flow condition

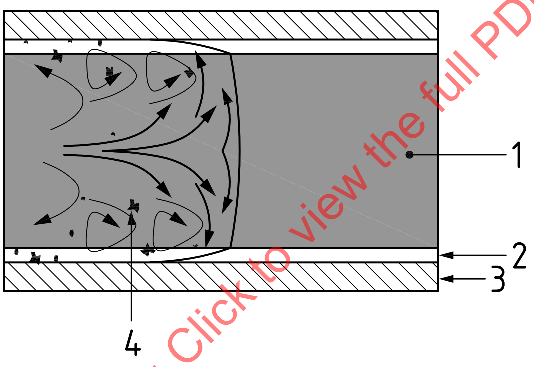
The flow condition shall be 'turbulent' rather than 'laminar' or 'stream-lined'. With laminar flow (see Figure C.1) the velocity profile is parabolic, i.e. it is zero at the pipe wall and increases to a maximum at the centre of the pipe. The velocity, hence the flow force, will be reduced close to the pipe wall where most of the particles are and the flow force may not be sufficient to disturb the particles from the pipe wall nor keep them in suspension. When the flow is 'turbulent' (Figure C.2) the flow direction is more random and the velocity is more uniform across the pipe, so that particles are more likely to be kept in suspension within the flow stream. Although the velocity at the pipe wall is still zero in the boundary layer, the velocity gradient is much higher than it is with laminar flow and the flow forces closer to the pipe wall are substantially higher.



Key

1 velocity profile
2 boundary layer
3 pipe wall
4 contamination particles

Figure C.1 — Laminar flow



Key

1 velocity profile
2 thinner boundary layer
3 pipe wall
4 contamination particles

Figure C.2 — Turbulent flow

The flow condition is defined by the *Re* that exists in the stream and this is the ratio of the inertial force to the viscous force, thus $Re = v\,d/\nu$. This depends upon a number of factors:

— velocity (v);

— inside pipe diameter (d);

— kinematic viscosity of the fluid (ν).

The value of *Re,* where the flow becomes turbulent, varies and is dependent upon both the attributes of the piping system and the flow, but is guaranteed when the *Re* is >4 000. Hence, the use of this value in the majority of flushing documents.