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

*Transmissions hydrauliques — Propreté des composants —
Documents d'inspection et principes d'extraction et d'analyse des
contaminants et d'expression des résultats*



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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 meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: [Foreword — Supplementary information](#).

The committee responsible for this document is ISO/TC 131, *Fluid power systems*, Subcommittee SC 6, *Contamination control*.

This second edition cancels and replaces the first edition (ISO 18413:2002), of which it constitutes a minor revision.

Introduction

In hydraulic fluid power systems, power is transmitted and controlled through a pressurized liquid within an enclosed circuit. Contaminants present in the circulating working liquid can degrade system performance. The presence of particles residual from the manufacturing and assembly processes can cause a substantial increase in the wear rates to the system during the initial run-up and early life and can even cause catastrophic failures. In order to achieve reliable performance of components and the system, control over the amount of particles introduced during the build phase is necessary. Accurate assessment of the effectiveness of part and component cleaning requires documentation of both the cleanliness requirement and the methods used for contaminant extraction and analysis and data reporting.

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

1 Scope

This International Standard specifies the content of an inspection document that specifies both the cleanliness requirement for the specified hydraulic fluid power component and the inspection method to be used for evaluating its cleanliness level. In addition, guidelines for relevant extraction methods and analysis methods are given.

Determination of what constitutes as an appropriate cleanliness level requirement for any particular component is beyond the scope of this International Standard. ISO 12669 provides a method of determining the required cleanliness of a hydraulic system. ISO TR 10686 provides a method of relating the required cleanliness of components to the required cleanliness of the hydraulic system.

For the purposes of this International Standard, approved functional liquids are considered to be components.

This International Standard is applicable to the particulate contamination on the wetted surfaces and volumes of any hydraulic fluid power system component. Appearance defects and liquid or gaseous contamination are not covered by this International Standard.

This International Standard does not address safety problems that might arise from hazardous materials, operations, and equipment associated with its use. The user of this International Standard is responsible for establishing appropriate safety and health practices and determining the applicability of regulatory limitations prior to use.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3722, *Hydraulic fluid power — Fluid sample containers — Qualifying and controlling cleaning methods*

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

ISO 4405, *Hydraulic fluid power — Fluid contamination — Determination of particulate contamination by the gravimetric method*

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 11500, *Hydraulic fluid power — Determination of the particulate contamination level of a liquid sample by automatic particle counting using the light-extinction principle*

ISO 11171, *Hydraulic fluid power — Calibration of automatic particle counters for liquids*

ISO 11943, *Hydraulic fluid power — On-line automatic particle-counting systems for liquids — Methods of calibration and validation*

ISO 12103-1, *Road vehicles — Test dust for filter evaluation — Part 1: Arizona test dust*

ISO 14644-1, *Cleanrooms and associated controlled environments — Part 1: Classification of air cleanliness*

ISO 21018 (all parts), *Hydraulic fluid power — Monitoring the level of particulate contamination in the fluid*

3 Terms and definitions

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

3.1

blank level

amount of contaminant introduced from sources other than the test component, such as reagents, glassware, preparation of test units, and the environment

3.2

blank test

analysis carried out in the same operating conditions as on the test component but without the test component

Note 1 to entry: The blank test enables quantification of the contamination introduced from sources other than the test component, such as reagents, glassware, preparation of test units, and the environment.

3.3

clean

state of cleanliness of a component or fluid that meets the specified cleanliness level

3.4

cleanliness

condition of a product, surface, device, liquid, etc., characterized by the absence of particulate contamination

3.5

component

general term to cover a part, a component, a sub-assembly, or a part assembly used in a hydraulic system

Note 1 to entry: This definition differs from that given for the same term in ISO 5598.

3.6

component contamination

amount or nature of contaminants extracted from the wetted or controlled surfaces of a component, as measured by an applicable analysis method

3.7

contaminant

undesirable solid substance that is in suspension in a fluid or in a component or on a controlled surface of a component

Note 1 to entry: For the purposes of this International Standard, contaminants include solid material suspended in liquids, but exclude liquids and gases. This definition differs from ISO 5598 in its exclusion of liquids and gases.

3.8

controlled surface

wetted surface of a component that is subject to a cleanliness requirement

3.9

controlled volume

wetted volume of a component that is subject to a cleanliness requirement

3.10

end-point sample

last in a series of repetitive samples, which produces a result that is ≤ 10 % of all the samples

3.11**external surface**

surface of the component which is not wetted by the system fluid in normal operation

3.12**extraction**

operation required to transfer as much contaminant as possible that is present within a controlled volume or on a controlled surface into a test liquid and its collection for subsequent analysis

3.13**extraction curve**

progress curve of the cleanliness level of an extraction liquid applied to the test component as a function of the number of extractions

Note 1 to entry: This is related to the extraction time or to the volume of test liquid passed through or over the test component.

3.14**extraction liquid**

test liquid loaded with contaminants extracted from the test component

3.15**fluid contamination monitor****FCM**

instrument that quantitatively evaluates the particulate contamination level of a liquid in an on-line mode

3.16**inspection document**

written description of the component cleanliness requirement and the agreed inspection method

3.17**inspection method**

procedure for contaminant extraction, contaminant analysis, and data reporting which is used to evaluate component cleanliness as specified by the inspection document

3.18**representative sample**

material extracted such that it is typical of the amount and nature of the contaminant contained in or on a component

3.19**test liquid**

suitable liquid of known initial cleanliness used to remove, suspend, and extract contaminant from a component and which is compatible with the component being tested and the apparatus used

3.20**validation**

process by which a test method evaluates the capability of the contaminant removal process

3.21**wetted surface area**

A_c

surface area of the component that is exposed to system liquid

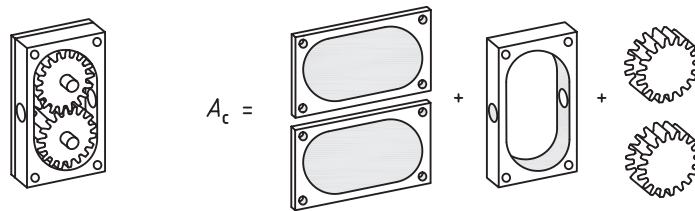


Figure 1 — Wetted surface area (A_c)

3.22

wetted volume

V_c

volume of the component that is exposed to system liquid

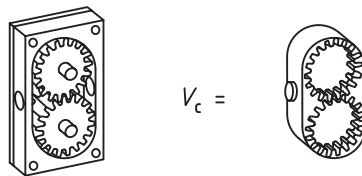


Figure 2 — Wetted volume (V_c)

4 Inspection document principles

4.1 Content

This International Standard specifies the content of the inspection document, not its format. The inspection document may exist as a single document or as a series of related documents. Regardless of format, the inspection document shall clearly identify the component cleanliness requirement and the agreed inspection method.

4.2 Component cleanliness requirement

The inspection document shall define the component cleanliness requirement when this is known. The cleanliness requirement shall be consistent with the known or anticipated function or application of the component. ISO TR 10686 and ISO 12669 give guidance and tools to establish such requirements. The component cleanliness requirement shall be established and agreed upon by the parties involved.

International Standards should be used in preference to other references sources (e.g. example historical data, existing company, industry, and national standards, functional performance, reliability, and durability requirements of the component, and data on similar components to determine the cleanliness requirement for a particular component).

4.3 Inspection method

4.3.1 The inspection document shall specify the inspection method to be used to evaluate component cleanliness. The inspection method shall be established and agreed upon by the parties involved. The inspection method shall be consistent with the design and the cleanliness requirement of the component.

4.3.2 The inspection document shall specify the appropriate parameters applicable to extracting contaminants, conducting analyses, and reporting results. Typical reference sources for consideration in determining the agreed inspection method include: International Standards, previously used methods of contaminant extraction, contaminant analysis, and data reporting; existing company, industry, and

national, standards; functional, reliability, and durability requirements of the component; and methods used on similar parts or components.

4.4 Effectivity

The inspection document shall become effective upon mutual agreement between the parties involved, both of which shall maintain a copy of the applicable inspection document.

4.5 Conformance

Unless otherwise stated in the inspection document,

- a) all components for which a cleanliness level has been specified shall meet that requirement when evaluated in accordance with the agreed inspection method and
- b) it is not necessary to inspect those components for which no cleanliness level has been specified (it is possible that some components are required to meet a specified cleanliness level and others are not).

4.6 Verification of conformance to specified component cleanliness requirements

4.6.1 Conformance to component cleanliness requirements can be verified either by the use of industry-accepted statistical sampling methods or by joint purchaser-supplier monitoring of the inspection processes.

4.6.2 Verification of test results requires special care because differences in method of contaminant extraction or analysis of the same component affect the results obtained. In addition, because the contaminant extraction process results in cleaning of the component used as a test item, that same test item shall not be reused for subsequent conformance verification.

4.7 Additional information

4.7.1 Unless otherwise agreed by purchaser and supplier, [4.7.2](#) to [4.7.5](#) shall apply.

4.7.2 The inspection document shall specify both the required cleanliness level for the component and the scope of its applicability. The points in the process at which the cleanliness requirement applies shall be stated in the inspection document. Because prolonged or improper storage of components can result in the introduction of new contaminants, such as oxidation products, the inspection document shall, when applicable, address these factors.

4.7.3 Temporary shipping covers are excluded from the inspection process; however, any contaminants contributed by such covers shall be included in the evaluation of component cleanliness.

4.7.4 Contaminants contributed by such defects as nicks, blemishes, and discoloration shall be included in the evaluation of component cleanliness.

4.7.5 Where applicable, a requirement for allowable residual magnetic density may be included as part of the inspection document.

NOTE Residual magnetism can cause retention of contaminant on component surfaces and the formation of agglomerates, both of which affect contaminant extraction or analysis or both.

5 Guidelines for selecting contamination extraction and analysis procedures

5.1 Overview

The following information is intended to be neither exhaustive nor restrictive. It is intended only to assist the user of this International Standard by indicating methods of sample extraction, sample analysis, and data reporting that are widely recognized as appropriate under selected conditions. The requirements applicable to a specific component shall be stated in the inspection document.

5.2 Contaminant extraction

Select the extraction method most suited to the component being inspected from [Table 1](#). The method of contaminant extraction shall be agreed upon and stated in the inspection document.

NOTE [Table 1](#) is a summary of guidelines for selection of contaminant extraction methods as they relate to categories of hydraulic components.

Table 1 — Guidelines for selection of contaminant extraction methods

Component	Contaminant extraction method			
	Agitation	Pressure rinse	Ultrasonic vibration	Functional test
Assemblies				
Pumps and motors	NR	NR	NA	R
Valves and cylinders	NR	NR	NA	R
Manifold and body assemblies	NR	A	A	R
Accumulators	A	NR	NA	R
Simple shapes and housings				
Gears, plates, and shafts	A	R	R	NA
Spools, rods, and pistons	A	R	R	NA
Hardware and seals	A	R	R	NA
Tanks and reservoirs	A	R	NA	NR
Hollow parts				
Manifolds and bodies	R	A	A	A
Hoses and tubes	R	A	A	R
Fittings	A	R	A	A
Filtration components				
Filter elements — cleanable	Method shall be agreed between the supplier and purchaser			
Filter elements — non-cleanable	Method shall be agreed between the supplier and purchaser			
Filter housings	R	A	A	R
R = Recommended A = Acceptable NR = Not recommended NA = Not applicable				

5.3 Contaminant analysis

Select the contaminant analysis method from [Table 2](#). The method of contaminant analysis shall be agreed upon and stated in the inspection document.

Table 2 — Guidelines for selection of contaminant analysis methods

Contaminant extraction method	Contaminant analysis method					
	Gravimetric analysis	Particle size	Chemical composition	Particle size distribution		
				Microscopy	APC ^a (bottle)	APC or FCM ^b (on line)
Agitation	R	R	R	R	R	NA
Pressure rinse	R	R	R	R	R	A
Ultrasonic vibration	R	R	R	R	R	NA
Functional test	A	A	A	R	A	R
R = Recommended A = Acceptable NR = Not recommended NA = Not applicable ^a Determined using a light extinction APC used in accordance with ISO 11500. ^b Determined using a fluid contamination monitor used in accordance with one of the parts of ISO 21018.						

6 Contaminant extraction principles

6.1 General

The method of contaminant extraction shall be agreed upon and stated in the inspection document. The measured component cleanliness level depends upon the effectiveness of the extraction procedures chosen and upon whether those extraction methods have been validated (see 6.3). The effectiveness of the contaminant extraction process should be validated by using the end point concept (see 3.10). Testing personnel shall follow the contaminant extraction method(s) specified in the inspection document. Inspection facilities and environment shall be as clean as practicable so as not to significantly affect the measurement of component cleanliness, which is quantified by the blank test (see 6.4.).

6.2 Overview

Contaminant extraction consists of various techniques for removing contaminants from controlled surfaces of components by the hydraulic and chemical action of a suitable liquid, suspending contaminant in the test liquid, then collecting the extraction liquid and suspended contaminant for analysis. This International Standard describes four basic contaminant extraction techniques: agitation, pressure rinse, ultrasonic vibration, and functional test method. Other methods of contaminant extraction may also be used when agreed upon between supplier and purchaser. The contaminant extraction method shall be properly validated. The entire extraction fluid volume used shall be analysed and processed as such.

6.3 Extraction procedure setup and validation

6.3.1 Setup environment

6.3.1.1 The number of components to be analysed shall be chosen so as to measure a significant amount of contaminant that complies with the requirement for a blank.

6.3.1.2 If the break-in of the component is part of its manufacturing process, the extraction procedure shall be agreed between parties and included in the inspection document because break-in can alter its initial cleanliness level.

6.3.1.3 The contaminants included in the inspection process are particles that have been detached from controlled surfaces during transportation of the test component, particles from the packaging, and those

in the shipping liquid. They shall be extracted using an appropriate extraction method (e.g. low pressure rinsing). The extraction processes shall be included in the inspection document.

6.3.1.4 For active components, it might be necessary to operate them in order to pass the test liquid through during the extraction process. In this case, the initial contamination level can be altered. The extraction conditions should be agreed upon between parties and included in the inspection document.

6.3.1.5 Apply the appropriate extraction method on the component to be tested, and analyse the whole extraction liquid volume in accordance with [Clause 7](#) and label the results obtained as S1.

6.3.1.6 Repeat [6.3.1.5](#) on the same component, using, when necessary, a different container for each extraction liquid sample, and label the results obtained as S2. The extractions shall be made one after the other.

6.3.1.7 If six extractions have been performed without achieving the end point in the required number of extractions, as specified in [6.3.2.2.1](#), this means that the extraction parameters are not suitable and shall be changed. Repeat operations [6.3.1.5](#) to [6.3.1.7](#) with new parameters on a new component.

6.3.1.8 If the criterion is not fulfilled, set up a new extraction protocol and validate it according to [6.3](#), or apply another extraction method.

6.3.2 Validation

6.3.2.1 Blank test

6.3.2.1.1 Whichever extraction method is used, a blank test is performed to verify that the operating conditions, equipment, and products used in the extraction procedure do not contribute a significant amount of contamination to the component analysed. A blank test should be performed, using identical test parameters, at intervals as established in the testing laboratory's quality control plan.

6.3.2.1.2 System blank values shall be determined under conditions identical to the ones applied during testing of the component, but with the component omitted.

The blank value shall be determined and shall comply with the requirements for each analysis method specified in the inspection document.

6.3.2.1.3 Proceed as specified in [6.3.1.5](#) to [6.3.1.7](#) with the same equipment and total volume of test liquid as required for the extraction process, but without the component.

6.3.2.1.4 Analyse the entire extraction liquid volume as specified in [Clause 7](#).

6.3.2.1.5 The blank value depends on the presumed or specified cleanliness level of the component(s) and on the analysis method. If this is not stated in the inspection document, then the following blank values shall be applied:

- a) gravimetric analysis: less than 10 % of the presumed or specified gravimetric cleanliness level of the component.

When using a four-digit balance in uncontrolled environmental conditions (that is, uncontrolled humidity and temperature), the minimum measurable blank value is 0,3 mg; a five-digit balance with an accuracy of 0,1 mg should be used. Because of this, at least 3 mg should be extracted during the component test in order to meet the 10 % blank criterion.

- b) particle counting and sizing:

- 1) Particle counts: less than 10 % of the presumed or specified numbers, at the relevant sizes, each calculated number being rounded down. For example, if no more than 167 particles for

a particular particle size are presumed or specified, no more than 16 particles of that size are allowed in the blank. If zero particle is stated at a given size, the blank value is zero particle at the next smaller size range. The particle sizes for the blank test shall be those specified in the inspection document for the component contamination analysis.

- 2) If the component's presumed contamination level is not known or if the inspection document states no requirement, the blank shall contain the following:
 - i) less than 4 000 particles $\geq 5 \mu\text{m}$ and less than 500 particles $\geq 15 \mu\text{m}$ per 100 mL of extraction liquid;
 - ii) no particle $\geq 50 \mu\text{m}$.

6.3.2.1.6 If the blank level exceeds 10 %, there are two possible reasons:

- a) the equipment is not clean; in which case, clean all equipment and solvents again and repeat [6.3.2.1](#) and [6.3.2.1.4](#);
- b) the components are too clean for the blank obtained; in which case, increase the number of test components analysed in order to extract more particles and, thus, fulfil the 10 % limit.

6.3.2.2 Validation of contamination extraction

6.3.2.2.1 Validate the contamination extraction procedure to ensure its efficacy as follows:

- a) For each of the two analyses described in [6.3.1.4](#) and [6.3.1.5](#), establish the total cumulated mass of contaminants or the total cumulated number of particles larger than the particle sizes specified in the inspection document.
- b) Divide the result of the last sample by the sum of all the values obtained in [6.3.2.2.1 a\)](#).
- c) If the value obtained is less than or equal to 0,10 (10 %), the end-point is reached and the extraction is completed.

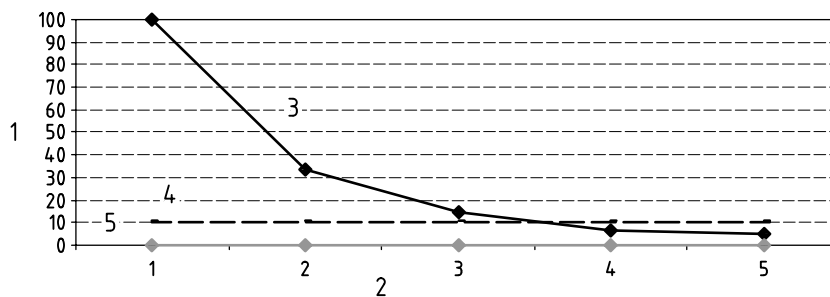
$$S_n \leq \frac{10}{100} \sum_{i=1}^n S_i$$

- d) If not, repeat [6.3.1.5](#) through [6.3.2.2.1 b\)](#) until the last sample S_n produces a result $\leq 10 \%$ of the sum of all samples, as calculated in [6.3.2.2.1 c\)](#), or until six extractions have been performed without reaching the $\leq 10 \%$ value (see [6.3.1.7](#)), whichever occurs first.

NOTE 1 This procedure enables the extraction curve to be drawn and the end-point ($\leq 10 \%$) to be demonstrated (see [Figure 3](#)). Alternatively, the data and calculation can be shown in tabular form.

NOTE 2 The cleanliness level of the component is the sum of contamination collected with all extractions.

In some cases (for example, a very low or a stable contamination level, difficulties in extracting particles, inappropriate blank level, etc.), the extraction curve might not be of the form seen in [Figure 3](#). If this is the case, ensure that all extraction parameters have been properly investigated.



Key

- 1 percentage of cumulated contamination extracted
- 2 number of extraction samples, i
- 3 extraction curve in percentage of cumulated contamination extracted
- 4 10 % of cumulated contamination extracted: end point = extraction 4
- 5 blank level

Figure 3 — Example of extraction curve

6.3.2.3 Routine test

6.3.2.3.1 If agreed between parties, a simplified extraction procedure known as a routine test could be established for identical components. Its principle is that the total parameters of a validated extraction procedure, whatever the technique used (i.e. agitation time, rinsing volume, sonication time, or flushing time) are used in a single extraction without drawing the extraction curve. This is then repeated to confirm compliance with the 10 % criterion.

6.3.2.3.2 Apply the agreed extraction procedure described in one of [6.4](#) to [6.7](#) to the component as many times as determined by the validation procedure and analyse the whole extraction liquid volume as specified in [Clause 7](#).

6.3.2.3.3 If the cleanliness inspection is to include particles that are detached during transportation of the test component or particles from the packaging, these particles shall be extracted using an appropriate extraction method (e.g. low pressure rinsing). This agreement shall be included in the inspection document.

6.3.2.3.4 A combination of extraction methods can be used with different conditions than those used to validate the extraction procedure, provided the conditions are shown to be sufficient to extract contaminant and achieve the end-point criterion. In this case, the resulting cleanliness level might be different. This simplified method shall be validated by performing at least one further extraction to see if the end point has been achieved. If not, further extractions are necessary. It should be agreed between parties and included in the inspection document. The following procedure can be applied to validate routine extractions by pressure rinsing and the functional test method:

- a) Condition and clean the equipment so as to achieve the required blank level.
- b) If the blank value exceeds the agreed level, proceed as in [6.3.2.1.6](#).
- c) Apply the extraction procedure to the component using the revised extraction parameters defined in [6.3.2.3.4](#).
- d) Analyse all of the extraction liquid as specified in [Clause 7](#), and record the result as S1.

NOTE A combination of extraction methods may be used provided that at least one has been validated.

- e) Repeat step c) and record the resulting value as S2. If $S2 \leq 0,1 \times (S1 + S2)$, sum S1 and S2 and report the result. If the 10 % level is not achieved after a second extraction, repeat [6.3.2.3.4](#) until the 10 % level is achieved.

NOTE The 10 % criterion should be reached in two extractions; failure to do so indicates either a change in the contamination level of the component or a reduced effectiveness of the extraction procedure and should be investigated.

6.3.2.3.5 When an extraction method is applied to several components due to their low level of contamination (e.g. in relation to the value of the blank level), it is not necessary to measure the contamination level of the extraction sample from each component. In this case, the liquids from all extractions shall be mixed and analysed as specified in [Clause 7](#), provided that the concentration of contaminant does not affect the analysis method chosen.

6.4 Agitation

6.4.1 Contaminant extraction by agitation is best suited to hollow components with characteristics (weight, size) allowing them to be hand shaken by an operator or agitated by an appropriate mechanical device. See [Table 1](#) for examples of its application.

6.4.2 Contaminant contained within simple enclosed surfaces shall be removed by partially filling the component under the test with an appropriate test liquid, sealing the openings, and agitating the component to remove the contaminant from the controlled surface and to suspend the contaminant in the test liquid. Immediately after agitation, all extraction liquid used in the test shall be drained and collected for analysis. [Annex A](#) provides additional information.

6.4.3 Primary process variables to be controlled include: test liquid and its relevant properties, test liquid volume and temperature, type and duration of agitation, the number of samples extracted up to and including the end-point sample, and the volume of test liquid extracted for analysis.

6.4.4 Consideration should be given to the size and mass of the component, the need for slings or fixtures, and any auxiliary equipment necessary for proper contaminant extraction.

6.5 Pressure rinse

6.5.1 Contaminant extraction by pressure rinsing is best suited to components where the surface to be controlled is easily accessible by a jet of pressurized test liquid. It may be used as a second phase of another extraction procedure such as ultrasonic vibration. See [Table 1](#) for examples of its application.

6.5.2 Contaminant on exposed and accessible surfaces shall be removed by directing a stream of test liquid onto the controlled surface of the component, which is placed over an appropriate liquid collection apparatus. Immediately after rinsing, all test liquid used in the test shall be collected for analysis. [Annex B](#) provides additional information.

6.5.3 Primary process variables to be controlled include shape of the jet or nozzle, test liquid and its relevant properties, test liquid pressure and flow rate, test liquid volume and temperature, the sequence followed in rinsing the component, and the number of samples extracted up to and including the end-point sample.

6.5.4 Consideration should be given to the overall accessibility of controlled surfaces for rinsing, the size and mass of the component, the need for slings and fixtures, and auxiliary equipment necessary for proper contaminant extraction.

6.6 Ultrasonic vibration

6.6.1 Contaminant extraction by ultrasonic vibration is best suited for small- and medium-sized components where internal or external surfaces or both are exposed. It is also recommended for testing batches of several small components. See [Table 1](#) for examples of its application.

6.6.2 Contaminant on surfaces accessible to ultrasonic vibrations shall be detached from the surface by immersing the component in test liquid and applying ultrasonic vibration, either directly or via a sonotrode. Upon removal of the component from the ultrasonic bath, all extraction liquid used in the test shall be collected for analysis. [Annex C](#) provides additional information. The test liquid can be contained either directly in the ultrasonic bath or in a container immersed in the bath.

6.6.3 Because ultrasonic vibrations only detach particles from the surface, a subsequent rinsing of the component, e.g. by pressure rinsing, is required to ensure correct extraction.

6.6.4 Primary process variables to be controlled include test liquid and its relevant properties, test liquid volume and temperature, equipment power settings, duration of exposure, the number of samples extracted up to and including the end-point sample, the volume of test liquid extracted for analysis, and the effectiveness of removing detached contaminant from the component surface and extracting the sample from the ultrasonic bath for analysis.

6.6.5 Consideration should be given to the size and mass of the component relative to the capacity of the ultrasonic bath and to the shape of the component because both factors affect the effectiveness of the extraction process.

6.7 Functional test method

6.7.1 Contaminant extraction by functional test is used for active and passive components where the test liquid can pass through the component. See [Table 1](#) for examples of its application.

6.7.2 Contaminant on internal surfaces with limited accessibility shall be extracted by installing the component on a test stand that simulates the end use application. The component is actuated while test liquid is circulated through the test stand. Upon completion of the simulation cycle, a representative sample of test liquid shall be extracted for analysis. [Annex D](#) provides additional information.

6.7.3 A production test stand may be used for the functional test method. When a production test stand is used for the final testing process (for example, with a clean-up filter online) it shall be agreed by purchaser and supplier that the component cleanliness is determined from the analysis of samples extracted from a suitable point downstream from the component; the parties to this agreement shall also agree on the risk that the result might be poorly representative because only a portion of the extraction liquid is examined.

6.7.4 Primary process variables to be controlled include test liquid and its relevant properties, test liquid volume and temperature, the test cycle used, circulation time, the size and number of samples extracted, and the procedures for controlling any carryover effects from previous tests.

6.7.5 Care should be used in the selection of test cycles (for example, cycles that generate contamination associated with break-in of the component) and in addressing potential sources of cross-contamination from other parts or components in the hydraulic system, especially when components are fitted to the test stand. It is important to minimize the generation of contaminant because generated contaminant introduces additional variability in subsequent contaminant analysis results.

7 Contaminant analysis principles

7.1 General

The method of contaminant analysis shall be agreed upon and stated in the inspection document. The measured cleanliness level of a component depends upon the procedures used to analyse the contaminant in the extraction liquid. Because the sample extracted often contains small amounts of contaminant diluted significantly in extraction liquid, good laboratory techniques are necessary to avoid both loss of contaminant and cross-contamination from other sources during analysis.

A basic principle of component cleanliness assessment is to analyse the entire extraction liquid volume. Analysis of a portion of the extraction liquid volume can be acceptable if only small particles (<50 µm) are analysed. In such cases, the mixing and sampling techniques shall be agreed upon between purchaser and supplier.

Testing personnel shall follow the analysis method specified in the inspection document.

NOTE The presence of residual materials (such as liquids, protective films, or grease) can cause problems during analysis if these materials are not miscible with the test liquid.

7.2 Overview

A variety of standard laboratory methods can be used to produce the required component cleanliness data. The data reporting format and contaminant analysis method are closely related. This International Standard describes four basic contaminant analysis methods: gravimetry, determination of particle size by microscope counting, chemical composition, and particle size distribution. Other methods of analysis may be used when agreed upon between supplier and purchaser.

Analytical procedures are given in [Annex E](#).

7.3 Gravimetric analysis

In gravimetric analysis, contaminants are separated from the extraction liquid by filtration through a membrane filter under controlled conditions. Contaminant concentration (mass per area, mass per volume, or mass per component) is determined by weighing the amount of material deposited on the membrane filter after filtration (see ISO 4405). Analyse the entire extraction liquid volume to ensure that all of the contaminants extracted from controlled surfaces are analysed.

NOTE The sample prepared for gravimetric analysis can be used for other analyses (i.e. [7.4](#), [7.5](#), and [7.6](#)), provided that the particles on the membrane filter are separated and do not overlap.

7.4 Determination of the largest particle size

In optical counting, contaminants are separated from the extraction liquid by filtration through a membrane filter under controlled conditions. Contaminants are examined to determine the maximum particle size as defined in the inspection document by means of optical microscope with or without an image analyser (see ISO 4407), scanning electron microscope, or other image producing instruments. Analyse the entire extraction liquid volume to ensure that all of the contaminants extracted from controlled surfaces are analysed.

7.5 Chemical composition

In a test to determine chemical composition, contaminants are generally separated from the extraction liquid by filtration through a membrane filter under controlled conditions. Contaminants are examined to determine their chemical composition by means of appropriate instrumentation, such as a scanning electron microscope equipped with X-ray fluorescence spectrometer, fluorescence spectrometer, or other

analytical devices. Analyse the entire extraction liquid volume to ensure that all of the contaminants extracted from controlled surfaces are analysed.

NOTE The sample from [7.3](#) may be used in [7.5](#).

7.6 Particle size distribution

7.6.1 The number and size of particles are determined by means of an appropriate counting method, such as an automatic optical particle counter using light extinction sensors (see ISO 11500), a fluid contamination monitor that uses a narrow sensor (see ISO 21018) and an optical microscope with or without an image analyser (see ISO 4407). Analyse the entire extraction liquid volume to ensure that all of the contaminants extracted from controlled surfaces are analysed.

7.6.2 If an automatic optical particle counter or fluid contamination monitor is to be used, ensure by visual inspection followed by sedimentation or sieving that no particle is of a size larger than the window of the sensor. Because sieving can remove some particles of interest, its use shall be agreed between the parties and included in the inspection document.

7.6.3 If it is necessary to size and count contaminant particles by microscopy, then care shall be taken to ensure the following:

- a) The particles are homogeneously deposited over the entire surface of the membrane filter.
- b) The surface density of particles, i.e. their number per unit surface area of the membrane filter, is low enough to allow their individual sizing and counting. This can require that the same extraction liquid volume is filtered onto several membrane filters. Then, all results shall be summed.

When using microscopy, select a membrane filter whose pore size is commensurate with the size of the particles being monitored to ensure that it is not plugged prematurely by particles that are much smaller than the size of interest. Care should be taken when analysing by microscopy a membrane filter prepared for gravimetric analysis. In this case, particle density is likely too high to allow the correct counting and sizing of individual particles due to overlapping. Gridded membrane filters are not suitable for counting by image analysis.

8 Data reporting principles

8.1 General

The presentation of data shall be agreed upon and stated in the inspection document. The format selected generally indicates the contaminant properties of greatest interest. The format can also indicate the importance attributed to the cleanliness requirement specified for a given component.

8.2 Overview

Contaminants can be characterized in several ways, so no single data reporting format applies to all applications. It is therefore important to determine the contaminant properties of greatest interest and to specify an appropriate data reporting format in the inspection document. This International Standard describes four contaminant properties that are often of interest: contaminant mass, particle size, chemical composition, and particle size distribution. When data are to be reported as a concentration or a normalized distribution, the area or volume of the component shall be clearly defined. This data should be supplied by the component manufacturer. But if not, the procedure described in [Annex G](#) can be used to estimate the wetted volume or wetted surface area of the component.

The entire extraction liquid volume shall be analysed to quantify the total amount of contaminant that was within the component tested. If only an aliquot of this whole extraction volume is analysed, which is only acceptable when small particles [e.g. <70 µm(c)] in large quantity (more than 200) are counted, then

the amount of contaminant presumably present in the component shall be calculated by multiplying the result by the ratio of the volume analysed to the total extraction liquid volume.

8.3 Contaminant mass

Perform gravimetric analysis methods to obtain information about the mass of contaminant on component surfaces. Data on contaminant mass are often used to monitor in-process control of contaminants but it is not suitable for individual clean components where the mass collected is low [see 6.3.2.1.5 a)].

Report the mass of contaminant.

8.4 Particle size

Perform microscopic analysis to obtain information about the size of specific particles or to measure the size of the largest particle found in or on the test component. Data on particle size are often used for critical components known to be sensitive to contaminants of a specific size or to monitor in-process control of contaminants.

Report the size of contaminants in micrometres.

8.5 Particle size distribution

Perform particle counting and sizing to obtain information on the size distribution of contaminants. Data on particle size distribution are often used as a final cleanliness check of assembled components and process fluids. Particle size distributions can also be used as cleanliness requirements for surfaces of parts or components.

Report the particle size distribution of contaminants.

8.6 Chemical composition

Perform specialized laboratory analysis methods to obtain information about the chemical composition of contaminants. Data on contaminant chemical composition are often used for critical parts and components known to be sensitive to contaminants of a specific composition or to monitor in-process control of contaminants.

9 Criterion for acceptance

Accept the component if the reported cleanliness, as determined by the agreed inspection method, is equal to or better than component cleanliness requirement specified in the inspection document.

10 Identification statement (reference of this International Standard)

Use the following statement in test reports, catalogues, and sales literature when electing to comply with this International Standard:

“Component cleanliness inspection document conforms to ISO 18413, Hydraulic fluid power — Cleanliness of components — Inspection document and principles related to contaminant extraction and analysis, and data reporting.”

Annex A **(normative)**

Contaminant extraction principles — Agitation method

A.1 General

This annex presents contaminant extraction principles for the agitation method. The cleanliness level of a component as determined by this method depends greatly upon the test parameters, the main ones being type of agitation, duration of agitation, and choice of test liquid. These parameters shall be stated in the inspection document and strictly followed by testing personnel. Care should be taken that no moving parts exist in the test component so as to avoid them creating additional contamination by movement of the internal parts.

A.2 Summary of method

A.2.1 Contaminants are extracted by partially filling the test item with a known volume of test liquid, sealing the openings, and agitating the test item in order to remove the contaminant from the controlled surfaces and suspend it in the test liquid. Agitation and contaminant extraction should be performed with the highest practicable liquid turbulence.

A.2.2 Multiple agitations with a new test liquid can be required to achieve maximum contaminant removal as proven during the validation of the extraction procedure.

A.2.3 If a means of mechanical agitation supplemental to the test liquid is used, the method of mechanical agitation should be carefully selected so as to limit any resultant cross-contamination and shall be described in the inspection document.

A.2.4 Immediately after agitation, the extraction liquid used in each contaminant extraction sequence is drained and collected.

A.2.5 The samples of test liquid are analysed in accordance with the inspection document.

A.3 Materials and equipment

A.3.1 Test liquid

WARNING — Exercise care when using test liquids with low flash points.

The supplier and purchaser should agree upon the test liquid to be used in the extraction process and its required initial cleanliness level, prior to the test. The test liquid shall be compatible with all materials used in the component, as well as with the functional liquid of the final system. Test liquid shall be compatible with all test equipment, including seals and filters, and filtered to the agreed initial cleanliness level. The test liquid should have a low viscosity, e.g. $\leq 5 \text{ mm}^2/\text{s}$ at test temperature and should preferably be a solvent for grease and machining fluids.

Test liquid contamination level should be sufficiently low to minimize its contribution to the total measured component contamination. This is verified by the blank test (see [6.3.2.1](#)).

A.3.2 Collection equipment

The extraction and rinsing liquid collection equipment shall allow easy and effective draining of particles. Such equipment can consist of glass, or plastic, or stainless steel containers, or trays, or be self-contained units, many of which are mobile. Clean all collection apparatus to fulfil the requirements of [6.3.2.1.5](#).

Any collection equipment shall be covered using a suitable, clean, non-shedding lid such as glass, plastic film or stainless steel after cleaning and prior to use in order to limit contamination from the environment.

Any contaminant remaining on the equipment shall be transferred to the sample and erroneously included as part of the contaminant attributed to the component.

A.3.3 Test component containers

A closed container should be used for the transfer of the component from the place of sampling to the place of contaminant extraction. The sample container shall be sufficiently clean so as not to affect the results of contaminant analysis. If the expected contamination level is unknown, a maximum contamination level of three particles larger than or equal to 6 µm(c), or equivalent, per millilitre of container volume is considered appropriate.

NOTE The term “µm(c)” refers to the particle size when counted by an automatic particle counter calibrated to ISO 11171. For particles counted using microscopic methods, 5 µm is equivalent to 6 µm(c).

A.3.4 Pressure rinsing liquid dispenser

The pressure rinsing liquid dispenser is a device that provides a clean liquid at a pressure and flow rate capable, in an effective manner, of rinsing residual contaminants from sampling containers, extraction and collection equipment, test component, and analysis apparatus. A pressurized dispenser with a membrane filter of ≤1µm rating fitted at its outlet or a line cartridge clean-up filter of ≤1µm rating or both and a relief valve is a convenient and safe way to achieve the requirements. This device can be same as the one used for providing the test liquid.

A.3.5 Vacuum suction system

If necessary, use an assembly consisting of a source of vacuum, a vacuum flask previously cleaned, and a flexible tube of suitable dimensions and shape for recovery of the extraction liquid and any particles that have accumulated in the component under examination. All parts of the vacuum system which come into contact with the test liquid should be cleaned prior to testing to fulfil the requirements of [6.3.2.1.3](#).

A.3.6 Measuring cylinders

A range of measuring cylinders with the appropriate accuracy to suit the test component volume shall be used.

A.3.7 Forceps

Use a flat-bladed, non-serrated forceps to handle membrane filters to avoid damage and cross-contamination.

A.4 Procedure

A.4.1 The volume or surface area, or both, of the component for which cleanliness is to be controlled shall be specified in the inspection document.

Data on the controlled volume or surface area which is provided by the component manufacturer should be used, as these data are expected to be the most accurate. If such data are not available, [Annex G](#) gives procedures for estimating the controlled volume and surface area.

A.4.2 Take care not to introduce contaminant to controlled surfaces. Even though external surfaces are defined as those that are not in contact with the system liquid during normal operation of the component, the external surfaces shall be cleaned to avoid the transfer of contamination from these surfaces to the controlled surface during handling.

A.4.3 Remove shipping plugs as necessary to add test liquid, leaving as many plugs as necessary to fill the required volume stated in [4.4](#). If a component is shipped partially filled with test liquid, drain the liquid and measure its volume. If the residual liquid is miscible with the test liquid, analyse the contaminant in accordance with [A.4.7](#); otherwise, completely drain the residual liquid and analyse it in accordance with [Annex E](#).

A.4.4 Transfer an amount of test liquid of between 30 % and 40 % the total component volume into a properly prepared measuring vessel, such as a graduated cylinder. Take care to measure the volume of test liquid as accurately as possible. A minimum accuracy of ± 5 % is recommended. The volume may be calculated from the mass of test liquid used.

A.4.5 Carefully pour the measured test liquid into the test item. Reseal with plugs that do not introduce contamination.

A.4.6 Agitate the test item in accordance with the predetermined method. Record and report all relevant agitation data (duration, frequency, amplitude, direction). Drain extraction liquid from the test item into clean collection equipment. A vacuum suction system may be used to drain extraction liquid. Take care to avoid contact with non-wetted surfaces. Cover the extraction vessel to avoid contamination by outside sources.

A.4.7 Carefully rinse the collection equipment. Analyse all liquid samples as specified in the inspection document (see [Annex E](#)).

A.4.8 Repeat the procedure detailed in [A.4.4](#) to [A.4.7](#) on the same test item as many times as necessary to validate the extraction method or the routine test procedure. Use a separate container or clean collection equipment for each extraction.

A.4.9 Report the extraction procedure as specified in the inspection document (see [Table A.1](#)).

Table A.1 — Example of data sheet for the extraction procedure by the agitation method

Laboratory identification							
Date:		Operator:		Company:			
Test item identification							
Type:		Controlled volume, $V_c =$		cm ³			
Reference:		Controlled surface area, $A_c =$		cm ²			
Supplier:		Number analysed:					
Prior external rinse: ☐ yes ☐ no		Plugging caps: ☐ yes ☐ no					
Dismantling: ☐ yes ☐ no		Reference:					
Demagnetising: ☐ yes ☐ no							
Packaging or container rinsing: ☐ yes ☐ no		Analysis of shipping liquid: ☐ yes ☐ no					
Time between production ☐ or shipment		☐ and test:		h			
Test environment							
☐ Industrial		☐ Laboratory		☐ Controlled (ISO 14644-1, class)			
Test liquid (see A.3.1)							
Identification:		Kinematic viscosity: mm ² /s		Temperature: °C			
Conditions of filling, agitation and emptying							
Volume of one filling: mL		Number of fillings:		Openings: (see A.4.3)			
Means (see A.4.5): ☐ manual ☐ automatic		Reference:					
Agitation (see A.4.6): Duration: s		Frequency: /min		Amplitude: mm			
Procedure: See illustrations and detailed description sections of this data sheet.							
Extraction data — Validation or routine test							
Extraction number, i	Blank level	1	2	3	4	5	6
Extraction volume (mL)							
Cumulative volume (mL)							
Extracted mass (mg)							
Cumulative mass (mg)							
Extracted particle counts at size μm or $\mu\text{m(c)}$							
Cumulative particle counts at size μm or $\mu\text{m(c)}$							
NOTE 1 Extraction is validated when an analysis result is less than or equal to 10 % of the sum of all the results.							
$\left(S_n \leq \frac{10}{100} \sum_{i=1}^n S_i \text{ with } n \leq 6 \right)$							
NOTE 2 Report particle count data on as many lines as particle sizes used for this validation.							

Table A.1 — Example of data sheet for the extraction procedure by the agitation method *(concluded)*

Illustrations — pictures or drawings to be provided by the author of the report (optional)	
Figure A.1 — Diagram or view in 2D or 3D of the component	Figure A.2 — Position or state at filling (A.4.5)
Figure A.3 — Movements imposed during agitation (A.4.6)	Figure A.4 — Position or state at draining (A.4.6)
Detailed description of the extraction protocol (optional) <i>(Write a precise sequential list of the functions performed and the conditions of operation of the component before and during the sampling operation.)</i>	

Annex B (normative)

Contaminant extraction principles — Pressure rinse method

B.1 General

This annex presents contaminant extraction principles for the pressure rinse method. The cleanliness level of a component as determined by this method depends greatly upon the test parameters such as rinse pressure, liquid volume, type of spray nozzle, etc. These parameters shall be stated in the inspection document and strictly followed by the testing personnel.

B.2 Summary of method

B.2.1 A pressurized stream of clean test liquid is directed at all controlled surfaces of the test item to displace contaminants. Rinsing should be performed with the highest practicable liquid turbulence.

B.2.2 Multiple rinsing can be required to achieve maximum contaminant removal.

B.2.3 Immediately after rinsing, the extraction liquid used in each sample extraction sequence is collected.

B.2.4 The samples of extraction liquid are analysed in accordance with the inspection document.

B.3 Materials and equipment

B.3.1 Test liquid

WARNING — Exercise care when using test liquids with low flash points. Care shall be taken not to generate aerosol mists, because these can increase the risk of combustion.

The supplier and purchaser should agree upon the test liquid to be used in the extraction process and its required initial cleanliness level, prior to the test. The test liquid shall be compatible with all materials used in the component, as well as with the functional liquid of the final system. Test liquid shall be compatible with all test equipment, including seals and filters, and filtered to the agreed initial cleanliness level. The test liquid should have a low viscosity, e.g. $\leq 5 \text{ mm}^2/\text{s}$ at test temperature, and should preferably be a solvent for grease and machining fluids.

Test liquid contamination level should be sufficiently low to minimize its contribution to the total measured component contamination. This is verified by the blank test (see [6.3.2.1](#)).

B.3.2 Test component containers

A closed container should be used for the transfer of the component from the place of sampling to the place of contaminant extraction. The component sample container shall be sufficiently clean so as not to affect the results of contaminant analysis. If the expected contamination level is unknown, a maximum contamination level of three particles larger than or equal to $6 \mu\text{m(c)}$, or equivalent, per millilitre of container volume is considered appropriate.

NOTE The term “ $\mu\text{m(c)}$ ” refers to the particle size when counted by an automatic particle counter calibrated in accordance with ISO 11171.

B.3.3 Pressure rinsing liquid dispenser

The pressure rinsing liquid dispenser is a device that provides a clean liquid at a pressure and flow rate capable, in an effective manner, of rinsing residual contaminants from sampling containers, extraction and collection equipment, test component and analysis apparatus. A pressurized dispenser with a membrane filter of $\leq 1 \mu\text{m}$ rating fitted at its outlet or a line cartridge clean-up filter of $\leq 1 \mu\text{m}$ rating or both and a relief valve, is a convenient and safe way to achieve the requirements. This device can be same as the one used for providing the test liquid.

B.3.4 Liquid dispensing gun

The liquid dispensing gun should be equipped with in-line filter holder and support screens compatible with the filter. This allows the liquid to be filtered as close as possible to the point of delivery. An optional in-line clean-up filter with sufficient retention capacity to avoid being replaced too frequently can be installed between the dispensing pressure vessel and the dispensing gun. A range of dispensing nozzles should be available to suit the contours of the controlled surface being pressure rinsed.

B.3.5 Clean-up filter

The clean-up filter should have a pore size that is 25 % the size of the smallest particle to be analysed. Filter material should be compatible with test liquid. Choose the filter so as to achieve the liquid cleanliness specified in [B.3.1](#) and an appropriate retention capacity so that it does not have to be changed too often.

B.3.6 Filter forceps

Use a flat-bladed, non-serrated forceps to handle membrane filters to avoid damage and cross contamination.

B.3.7 Collection equipment

The extraction liquid collection equipment shall allow easy effective draining of particles. Such equipment can consist of glass, or plastic, or stainless steel containers, or trays, or be self-contained units, many of which are mobile. Clean all collection equipment to fulfil requirements of [6.3.2.1.5](#). Any collection equipment should be covered after cleaning and prior to use in order to limit contamination from the environment.

Any contaminant remaining on the equipment shall be transferred to the sample and erroneously included as part of the contaminant attributed to the component.

B.3.8 Vacuum suction system

If necessary, use an assembly consisting of a vacuum source, a previously cleaned vacuum flask, and a flexible tube of suitable dimensions and shape to recover the extraction liquid and any particles that have accumulated in the component being examined.

B.4 Procedure

B.4.1 The volume or surface area, or both, of the component for which cleanliness is to be controlled shall be specified in the inspection document.

Data on the controlled volume or surface area which is provided by the component manufacturer should be used, as these data are expected to be the most accurate. If such data are not available, [Annex G](#) gives procedures for estimating controlled volume and surface area.

B.4.2 Even though external surfaces are defined as those that are not in contact with the system liquid during normal operation of the component, the external surfaces shall be cleaned to avoid the transfer of contamination from these surfaces to the controlled surface during handling. If the test item is large, for example, a reservoir, clean only those external surfaces that could potentially contribute as contaminant

during the extraction process. External surfaces are defined as those that are not in contact with the system liquid during normal operation of the component.

B.4.3 Remove all shipping caps and plugs. If the test item contains residual liquid, the liquid should be extracted in a clean container and included as part of the final analysis volume only if the two liquids are completely miscible. If not, completely drain the residual liquid and analyse it in accordance with [Annex E](#).

B.4.4 If possible, place the test item in a clean collection container prepared as specified above.

Many components are too large to be handled conveniently in the collection equipment. When such components are being evaluated, the primary objective should be to place the test item in a convenient position for sample retrieval. Ideally, this position allows test liquid and residue to drain into the extraction liquid container. This can require using a form of support (for example, a sling, jig, or hoist) to manipulate the test item into position.

For components that cannot be effectively drained, such as reservoirs, a vacuum system can be used to provide optimum residue retrieval. All parts of the vacuum system that come into contact with the test liquid should be cleaned prior to testing to fulfil the requirements of [6.3.2.1.5](#).

B.4.5 This method of contaminant extraction is most suited for components that require no disassembly because the disassembly process itself can generate contaminant. If disassembly is required to gain access to all controlled surfaces, carefully remove the necessary parts and components. The operator should exercise extreme care to minimize the generation of contaminant when disassembly is necessary.

B.4.6 Set the pressure of the liquid dispensing pressure vessel to a level that delivers a spray with optimal turbulence.

B.4.7 When all controlled surfaces are accessible, carefully rinse them with test liquid sprayed using the dispensing gun. To dislodge any contaminant, make every reasonable effort to rinse any areas that come in contact with the system liquid during normal operation of the component. All residues should be rinsed into the collection equipment or, where appropriate, extracted by the vacuum system.

B.4.8 Combine all extracted residue and liquids. Carefully rinse all equipment used for extraction of all accumulated materials into a single collection container.

B.4.9 Analyse samples as specified in the inspection document. Refer to [Annex E](#).

B.4.10 Repeat the procedure detailed in [B.4.7](#) to [B.4.9](#) on the same test item as many times as necessary to validate the extraction method or the routine test procedure. Use a separate container or clean collection equipment for each extraction.

B.4.11 Report extraction procedure as specified in the inspection document (see [Table B.1](#)).

Table B.1 — Example of data sheet for the extraction procedure by the pressure rinse method

Laboratory identification							
Date:		Operator:		Company:			
Test item identification							
Type:		Controlled volume, $V_c =$		cm ³			
Reference:		Controlled surface area, $A_c =$		cm ²			
Supplier:		Number analysed:					
Prior external rinse: ☐ yes ☐ no		Plugging caps: ☐ yes ☐ no					
Dismantling: ☐ yes ☐ no		Reference:					
Demagnetising: ☐ yes ☐ no							
Packaging or container rinsing: ☐ yes ☐ no		Analysis of shipping liquid: ☐ yes ☐ no					
Time between production		☐ or shipment		☐ and test:		h	
Test environment							
☐ Industrial		☐ Laboratory		☐ Controlled (ISO 14644-1, class)			
Test liquid (see B.3.1)							
Identification:		Kinematic viscosity: mm ² /s		Temperature: °C			
Conditions of pressure rinsing (see B.3.3 and B.3.4)							
Shape of nozzle or jet: ☐ conical ☐ flat ☐ straight ☐ multiple hole ☐ other							
Extraction liquid:		Pressure: hPa		Flow rate: L/min		Volume: L	
Extraction data — Validation or routine test (see B.4.7 and B.4.8)							
Extraction number, i	Blank level	1	2	3	4	5	6
Cumulative volume (mL)							
Cumulative mass (mg)							
Cumulative particle counts at size μm or $\mu\text{m(c)}$							
% extraction							
NOTE 1 Extraction is validated when an analysis result is less than or equal to 10 % of the sum of all the results.							
$\left(S_n \leq \frac{10}{100} \sum_{i=1}^n S_i \text{ with } n \leq 6 \right)$							
NOTE 2 Report particle count data on as many lines as particle sizes used for this validation.							

Table B.1 — Example of data sheet for the extraction procedure by the pressure rinse method
(concluded)

Illustrations — pictures or drawings to be provided by the author of the report (optional)	
Figure B.1 — Diagram or view in 2D or 3D of the component	Figure B.2 — Position or state at rinsing (B.4.4)
Figure B.3 — Movements imposed on the jet (B.4.7)	Figure B.4 — Position or state during collection (B.4.7)
Detailed description of the extraction protocol (optional) (Write a precise sequential list of the functions performed and the conditions of operation of the component before and during the sampling operation.)	

Annex C **(normative)**

Contaminant extraction principles — Ultrasonic vibration method

C.1 General

This annex presents contaminant extraction principles for the ultrasonic vibration method. The cleanliness level of a component as determined by this method depends greatly upon the test parameters such as test liquid volume, test liquid properties, the placement and orientation of the component in relation to the ultrasonic source, the material the component is made of and the ultrasonic power level. These parameters should be stated in the inspection document and strictly followed by the testing personnel.

Care should be taken that ultrasonic vibrations do not “damage” test component and create additional contamination.

C.2 Summary of method

C.2.1 The contamination is removed from controlled surfaces by ultrasonic agitation at the surface of the component, which ‘plucks’ the contaminant off the surface. An ultrasonic bath or tank is used to remove contamination from external surfaces, while a sonotrode is more suited to remove contamination from hollow inside surfaces.

NOTE The effect in the ultrasonic bath is normally not homogeneous. This can have a major effect on the test result depending on where in the bath the test piece is placed.

C.2.2 Immediately after agitation by ultrasonic vibration, the extraction liquid used is poured into the collection equipment. A final pressure rinsing might be required.

C.2.3 The entire volume of extraction liquid is analysed in accordance with the inspection document.

C.3 Materials and equipment

C.3.1 Test liquid

WARNING — Exercise care when using test liquids with low flash points.

The supplier and purchaser should agree upon the test liquid to be used in the extraction process, and its required initial cleanliness level, prior to the test. The test liquid should be compatible with all materials used in the component, as well as with the functional liquid of the final system. Test liquid shall be compatible with all test equipment, including seals and filters, and filtered to the agreed initial cleanliness level. The test liquid should have a low viscosity, e.g. $\leq 5 \text{ mm}^2/\text{s}$ at test temperature and should preferably be a solvent for grease and machining fluids.

Test liquid contamination level should be sufficiently low to minimize its contribution to the total measured component contamination. This is verified by the blank test (see [6.3.2.1.5](#)).

C.3.2 Ultrasonic tank or bath

The ultrasonic tank or bath should be made of stainless steel. The important characteristics of the ultrasonic equipment should be specified in the inspection document. If the extraction liquid is in direct contact with the ultrasonic tank or bath, the latter shall be processed like a collection container.

If the tank or bath is provided with a transfer pump, it shall be of a design that does not alter the particle size distribution of the contaminant nor create additional contamination. Centrifugal and progressive cavity designs have proved suitable for use in contaminant systems. However, the shape of machining debris and other acicular (needle-shaped) particles means that fracture is probable.

C.3.3 Sonotrodes

Another method for transferring ultrasonic energy to the test liquid is by using sonotrodes. These are mechanical components that transmit ultrasonic oscillations produced by the transducer and transfer them to the test liquid to be sonically treated. The mass and geometry of these elements are aligned with the frequency of the ultrasound. For this application, they are usually rod-shaped and made of titanium, and most of the ultrasonic energy is radiated via the tip.

Sonotrodes are used in extraction procedures for such internal geometries as through-boring, blind holes, and channels, which are less suitable for cleaning in an immersion ultrasonic tank. Due to the high power densities that can be attained using sonotrodes, care shall be taken to avoid cavitation damage to components under test.

C.3.4 Collection equipment

The extraction liquid collection equipment shall allow easy and effective draining of particles. Such equipment can consist of glass, or plastic, or stainless steel containers, or trays, or be self-contained units, many of which are mobile. Clean all extraction equipment to fulfil requirements of [6.3.2.1.5](#).

Any collection equipment shall be covered using a suitable, clean, non-shedding lid such as glass, plastic film, or stainless steel after cleaning and prior to use in order to limit contamination from the environment.

Any contaminant remaining on the equipment shall be transferred to the sample and erroneously included as part of the contaminant attributed to the component.

C.3.5 Test component container

A closed container should be used for the transfer of the component from the place of sampling to the place of contaminant extraction. Component sample containers shall be sufficiently clean so as not to affect the results of contaminant analysis. If the expected contamination level is unknown, a maximum contamination level of three particles larger than or equal to 6 µm(c), or equivalent, per millilitre of container volume is considered appropriate.

NOTE The term “µm(c)” refers to the size when counted by an automatic particle counter calibrated in accordance with ISO 11171. For particles counted using microscopic methods, 5 µm is equivalent to 6 µm(c).

C.3.6 Pressure rinsing liquid dispenser

The pressure rinsing liquid dispenser is a device that provides a clean liquid at a pressure and flow rate capable, in an effective manner, of rinsing residual contaminants from sampling containers, extraction and collection equipment, test component, and analysis apparatus. A pressurized dispenser with a membrane filter of ≤1µm rating fitted at its outlet or a line cartridge clean-up filter of ≤1 µm rating or both and a relief valve is a convenient and safe way to achieve the requirements. This device can be the same as the one used for providing the test liquid.

C.3.7 Vacuum suction system

If necessary, use an assembly consisting of a vacuum source, a previously cleaned vacuum flask, and a flexible tube of suitable dimensions and shape for recovery of the extraction liquid and any particles that have accumulated in the component under examination. Vacuum system cleanliness level shall fulfil the requirements of [6.3.2.1.5](#).

C.4 Procedure

C.4.1 Determine the controlled volume or the controlled surface area of the component to be analysed. The volume or surface area of the component for which cleanliness is to be controlled shall be specified in the inspection document.

Data on the controlled volume or surface area which is provided by the component manufacturer should be used, as these data are expected to be the most accurate. If such data are not available, [Annex G](#) gives procedures for estimating controlled volume and surface area.

C.4.2 Remove all shipping caps and plugs. If the test item contains residual liquid, the liquid should be extracted in a clean container and included as part of the final analysis volume only if the two liquids are completely miscible. If not, completely drain the residual fluid and analyse it in accordance with [Annex E](#).

C.4.3 This method of contaminant extraction is most suited for components that require no disassembly because the disassembly process itself can generate contaminant. If disassembly is required to gain access to all controlled surfaces, carefully remove the necessary parts and components. The operator should exercise extreme care to minimize the generation of contaminant when disassembly is necessary.

C.4.4 If the component is to be sonicated in a container, follow the procedure specified in [C.4.4.1](#) through [C.4.4.4](#). Otherwise, proceed to [C.4.5](#).

C.4.4.1 Submerge the test item into either a sample container with clean test liquid or into the ultrasonic tank with the appropriate volume of clean test liquid. When testing components that have cleanliness requirements only on internal surfaces, carefully rinse the external surface without rinsing particles into the controlled surface, then fill the test item as full as possible with test liquid, seal the test item, and submerge it in the ultrasonic bath.

C.4.4.2 Sonicate the test item at the power level indicated for the appropriate period of time as required by the inspection document.

C.4.4.3 Transfer the extraction liquid from either the component, a container, or the ultrasonic tank into suitable clean collection containers and cap to avoid contamination. When testing parts and components have cleanliness requirements only on internal surfaces, remove the test item from the bath, remove any closures, and carefully dry its outer surface using a lint-free cloth or jet of clean air.

Extract all residual contamination from the ultrasonic tank and rinse the tank with a suitable jet of test liquid. Pour the extraction liquid into collection equipment and rinse the inner surface of the component using a suitable jet of test liquid.

If port plugs were used, rinse the surfaces that might have come into contact with the extraction liquid and transfer this liquid into the collection container.

C.4.4.4 Extract all residual contamination from either the ultrasonic bath or containers; rinse the equipment with a suitable jet of test fluid and transfer it into the collection container.

C.4.5 If the component is to be sonicated using sonotrodes, follow the procedure specified in [C.4.5.1](#) through [C.4.5.4](#).

C.4.5.1 Place the component in a precleaned beaker or other suitable container so that the opening of the component faces upwards and can be accessed by the sonotrode. Fill the component with clean test liquid to a level that allows immersion of the sonotrodes into the liquid and subsequent sonication without any overflowing of test liquid.

C.4.5.2 Clean the outside of the sonotrode over its complete length with a jet of clean test liquid before introducing the sonotrode into the cavity of the component. If necessary, fix the sonotrode to a stand. The sonotrode should not touch any surface. Sonicate with the power and frequency and for the duration specified in the inspection document. If several borings or cavities of the component are to be tested, repeat sonication for each individual controlled surface. It might be necessary to move or relocate the component to gain access by the sonotrode. This should be done carefully so as not to lose contaminant particles that should be collected.

C.4.5.3 Remove the component and the sonotrode, empty the extraction liquid into a suitable collection container, and rinse the component carefully with clean test liquid. After rinsing, ensure that the component has been completely emptied.

C.4.5.4 All equipment that has come into contact with the extraction liquid or the component, e.g. tip of the sonotrode, operator's gloves, forceps, etc., shall be thoroughly rinsed with clean test liquid, extracted in a suitable container, and subsequently analysed. For convenience, this extraction liquid can be added to the main sample extracted.

C.4.6 Analyse samples and report data as specified in the inspection document (see [Annex E](#)).

C.4.7 Repeat the procedure detailed in [C.4.4](#) or [C.4.5](#) on the same test item as many times as defined to validate the extraction method or in the routine test procedure, using a separate container for each extraction.

C.4.8 Report extraction procedure as specified in the inspection document (see [Table C.1](#)).

Table C.1 — Example of data sheet for the extraction procedure by ultrasonic techniques

Laboratory identification							
Date:		Operator:		Company:			
Test item identification							
Type:		Controlled volume, $V_c =$		cm ³			
Reference:		Controlled surface area, $A_c =$		cm ²			
Supplier:		Number analysed:					
Prior external rinse: ☐ yes ☐ no		Plugging caps: ☐ yes ☐ no					
Dismantling: ☐ yes ☐ no		Reference:					
Demagnetising: ☐ yes ☐ no							
Packaging or container rinsing: ☐ yes ☐ no		Analysis of shipping liquid: ☐ yes ☐ no					
Time between production		☐ or shipment		☐ and test:		h	
Test environment							
☐ Industrial		☐ Laboratory		☐ Controlled (ISO 14644-1, class)			
Test liquid (see C.3.1)							
Identification:		Kinematic viscosity: mm ² /s		Temperature: °C			
Conditions of pressure rinsing (see C.3.2 through C.3.7)							
Ultrasonic technique used:		☐ ultrasonic bath ☐ sonotrode					
Container:		☐ glassware ☐ ultrasonic bath ☐ other; specify:					
Volume under ultrasonic treatment (e.g. beaker and bath volume:		mL)					
Duration: min							
Ultrasound:		Power: W		Frequency: Hz		Tank volume: L	
Shape of nozzle or jet:		☐ conical ☐ flat ☐ straight		☐ multiple hole ☐ Other			
Nozzle diameter:		mm					
Extraction liquid:		Pressure: hPa		Flow rate: L/min		Volume: L	
Extraction data — Validation or routine test (see C.4)							
Extraction number, i	Blank level	1	2	3	4	5	6
Cumulative volume (mL)							
Cumulative mass (mg)							
Cumulative particle counts at size μm or $\mu\text{m(c)}$							
% extraction							
NOTE 1 Extraction is validated when an analysis result is less than or equal to 10 % of the sum of all the results.							
$\left(S_n \leq \frac{10}{100} \sum_{i=1}^n S_i \text{ with } n \leq 6 \right)$							
NOTE 2 Report particle count data on as many lines as particle sizes used for this validation.							

Table C.1 — Example of data sheet for the extraction procedure by ultrasonic techniques *(concluded)*

Illustrations — pictures or drawings to be provided by the author of the report (optional)	
Figure C.1 — Diagram or view in 2D or 3D of the component	Figure C.2 — Position of the component in the ultrasonic bath
Figure C.3 — Relative position of the spray nozzle and the component during rinsing	Figure C.4 — Schematic of the spray nozzle with dimensions
Detailed description of the extraction protocol (optional)	
<i>(Write a precise sequential list of the functions performed and the conditions of operation of the component before and during the sampling operation.)</i>	

Annex D **(normative)**

Contaminant extraction principles — Functional test method

D.1 General

This annex presents contaminant extraction principles for the functional test method. The cleanliness level of a component as determined by this method depends greatly upon the test parameters, such as the ability of the test stand to reproduce functional conditions and requirements of the component, including test liquid operating flow, temperature, turbulence, and surges; test liquid circulation time; and, in the case of partial sampling of the extraction liquid, the ability to obtain a representative sample of test liquid. These parameters shall be stated in the inspection document and strictly followed by the testing personnel.

D.2 Summary of method

D.2.1 The component is installed on a validated functional test stand (see [D.4](#)), then operated with a test liquid of known cleanliness. Operation of the test stand removes contaminant from the component surfaces and transfers contaminants to the test liquid.

D.2.2 Upon completion of the functional test, a representative sample of test liquid is either analysed directly online or extracted for subsequent analysis. The sample size should be as large as possible and not less than 10 % of the total fluid volume.

D.2.3 Test items should be exercised for a time sufficient to pass at least 10 times the wetted volume of the test item. The functional test method and contaminant extraction should be performed with the highest practicable test liquid turbulence.

D.2.4 The samples of test liquid are analysed in accordance with the inspection document.

NOTE Unless otherwise stated in the inspection document, this method is not intended to measure contaminant generated during break-in under load.

D.3 Materials and equipment

D.3.1 Test liquid

WARNING — Exercise care when using test liquids with low flash points.

The supplier and purchaser should agree upon the test liquid to be used in the extraction process and its required initial cleanliness level, prior to the test. The test liquid should be compatible with the following:

- all materials used in the component, as well as with the functional liquid of the final system;
- all test equipment, including seals and filters;
- any residual liquid.

If the test liquid is not compatible with any of the above mentioned, particle counting problems could be experienced.

The test liquid shall be filtered to the agreed initial cleanliness level, sufficiently low to minimize its contribution to the total measured component contamination; this is verified by the blank test (see [6.3.2.1.5](#)). The test liquid should preferably be a solvent for grease and machining fluids and should have a low viscosity, e.g. $\leq 5 \text{ mm}^2/\text{s}$ at test temperature. If test liquids with a higher viscosity are used, then the flow rate shall be increased to increase the turbulence in the component.

D.3.2 Test stand

Use a test stand with a reservoir, pump, liquid conditioning equipment, and instrumentation that are capable of accommodating the range of flow rates, pressures, and volumes required by the procedure and is capable of meeting the validation requirements of [D.4](#). See [Annex F](#) for guidance in designing an appropriate test stand.

System liquid volume shall be as small as feasible to prevent aeration. It is recommended to use a fluid volume (in L) less than half the flow rate (in L/min) to ensure proper mixing of contaminants in the test circuit.

D.3.3 Test fixture

Use a test fixture capable of operating the test item under conditions similar to those the test item is likely to see in service, as specified in the inspection document and agreed between parties.

D.3.4 Clean-up filter

A clean-up filter capable of providing the initial system contamination level specified in [D.4.6](#) shall be installed in the system.

D.3.5 Liquid sampler and sampling bottles

The liquid sampler shall conform to ISO 4021 and be fitted in the system downstream of the test item.

Sampling bottles shall conform to ISO 3722, have a capacity suited to the volume of fluid to be analysed, and be cleaned to the level specified in [6.3.2.1.5](#).

D.3.6 Contamination analysis equipment

The level of contamination of the extraction fluid can be measured either

- a) in a laboratory after bottle sampling, either in accordance with ISO 11500 using a light extinction APC calibrated in accordance with ISO 11171 or in accordance with ISO 4407 using a microscope after collecting all contaminants on one or several membranes,
- b) online using a light extinction APC calibrated and validated in accordance with ISO 11943 or a fluid contamination monitor (FCM) used and calibrated in accordance with the appropriate part of ISO 21018, or
- c) online by passing a known volume of fluid through a membrane filter which is then processed and analysed with a microscope in accordance with ISO 4407.

The volume of test fluid analysed shall be chosen to obtain sufficient particle counts according to the standard method used.

The particle counting or contamination monitoring technique shall be specified in the inspection document.

D.3.7 Component sample containers

A closed container should be used for the transfer of the component from the place of sampling to the place of contaminant extraction. The component sample container shall be sufficiently clean so as not to affect the results of contaminant analysis. If the expected contamination level is unknown, a maximum

contamination level of three particles larger than or equal to 6 µm(c), or equivalent, per millilitre of container volume is considered appropriate.

NOTE The term “µm(c)” refers to the size when counted by an automatic particle counter calibrated to ISO 11171. For particles counted using microscopic methods, 5 µm is equivalent to 6 µm(c).

D.4 Test stand validation

D.4.1 Validate the test stand following its initial construction and whenever the stand is modified.

D.4.2 Install a section of pipe equal in diameter to the inlet pipe. A clean steel tube can serve as an acceptable dummy test item.

D.4.3 Fill the system to a known volume and record the volume of test liquid used.

D.4.4 Operate the system pump to clean the circuit using the system clean-up filter.

D.4.5 Maintain the temperature of the test fluid within ± 2 °C of the specified value.

D.4.6 Operate the test stand at rated flow until test liquid cleanliness at particle sizes larger than or equal to 10 µm is $\leq 0,10$ particles per millilitre, preferably determined using online analysis. Alternatively, extract samples in clean sample bottles for subsequent analysis. If sample bottles are used, bottle cleanliness shall be included in the test liquid cleanliness specification.

D.4.7 Remove or bypass the system clean-up filter.

D.4.8 Add 5 mg of ISO Medium Test Dust, in accordance with ISO 12103-1, per litre of test liquid.

D.4.9 Begin contamination analysis or sample extraction 15 min after the addition of the test dust. Perform an initial online analysis or extract an initial 200 mL sample of the test liquid in a clean bottle at one-quarter of the operating time and the second to tenth every one-twelfth of the operating time passed since the previous sampling and analysis.

D.4.10 For each sample, determine the cumulative particle count at the sizes stated in the inspection document.

D.4.11 The test equipment shall be considered validated if the particle count obtained for a given size at each sample interval deviates no more than one as per ISO 4406 code level from the average particle count of all sample intervals for that particle size.

D.4.12 If the validation criteria are not fulfilled, re-evaluate the size of the equipment compared to the flow rate, the type of the circulation pump and the design of other components.

D.4.13 After corrective actions have been taken, repeat the validation procedure.

D.5 Procedure

D.5.1 Determine the controlled volume or controlled surface area, or both, of the component to be analysed. Include the volumes and surface areas of all spaces that system liquid occupies during normal operation.

Data on the controlled volume or surface area which is provided by the component manufacturer should be used, as these data are expected to be the most accurate. If such data are not available, [Annex G](#) gives procedures for estimating controlled volume and surface area.

D.5.2 Clean external surfaces of the test item. Take care not to introduce contaminant to controlled surfaces, e.g. by wearing gloves during handling. Do not disassemble components. Contaminant can be generated as a result of the disassembly process.

D.5.3 Remove all shipping caps and plugs from the test item.

D.5.4 If the residual liquid is not compatible with the test liquid and APC used for the analysis, drain all traces of residual liquid, if possible, into a clean container, using a pressure dispenser if necessary, and analyse it in accordance with [Annex E](#). If complete draining is not possible, use another method of analysis.

D.5.5 Install and bypass the test item.

D.5.6 Fill the test reservoir and system with the test fluid. Measure to ± 2 % the volume of test liquid used in the test stand, excluding the volume of clean-up filters. The accurate measurement of the fluid volume is not required if the entire extraction fluid volume is drained and analysed after the test.

D.5.7 If a test fixture is used, operate it with a clean-up filter until cleanliness conforms to [D.4.6](#).

D.5.8 Remove or bypass the clean-up filter.

D.5.9 Perform the functional test method using the test parameters specified in the inspection document.

D.5.10 Unless otherwise specified, operate the test circuit until three consecutive particle counts taken at 2 min. intervals are within ± 15 % of their mean.

D.5.11 Perform online analysis or extract samples of test liquid for subsequent analysis. Samples shall be as large as possible and not less than 10 % of the total fluid volume.

D.5.12 If required, analyse off-line samples in accordance with [Annex E](#), and report the extraction procedure as specified in the inspection document. See [Table D.1](#).

Table D.1 — Example of data sheet for the extraction procedure by the functional test method

Laboratory identification							
Date:		Operator:		Company:			
Test item identification							
Type:		Controlled volume, $V_c =$		cm ³			
Reference:		Controlled surface area, $A_c =$		cm ²			
Supplier:		Number analysed:					
Prior external rinse:	☐ yes	☐ no	Filling orifice(s) reference:	☐ yes	☐ no		
Dismantling:	☐ yes	☐ no	Reference:				
Demagnetising:	☐ yes	☐ no					
Packaging or container rinsing:	☐ yes	☐ no	Analysis of shipping liquid:	☐ yes	☐ no		
Time between production	☐ or shipment	☐ and test:	h				
Test bench identification							
Type:		Functions:		Reference:			
Test liquid (see D.3.1)							
Identification:		Kinematic viscosity:		mm ² /s	Temperature:	°C	
Test conditions (see D.3 and D.5)							
Procedure reference:							
Liquid volume:	mL	Pressure:	MPa (bar)	Flow rate:	L/min		
Frequency:	Hz	or rotational speed:	min ⁻¹	Duration:	min		
Extraction data — Validation or routine test (see D.4 and D.5)							
Extraction number, i	Blank level	1	2	3	4	5	6
Cumulative volume (mL)							
Cumulative mass (mg)							
Cumulative particle counts at size μm or $\mu\text{m(c)}$							
% extraction							
NOTE 1 Extraction is validated when an analysis result is less than or equal to 10 % of the sum of all the results.							
$\left(S_n \leq \frac{10}{100} \sum_{i=1}^n S_i \text{ with } n \leq 6 \right)$							
NOTE 2 Report particle count data on as many lines as particle sizes used for this validation.							

Table D.1 — Example of data sheet for the extraction procedure by the functional test method
(concluded)

Illustrations — pictures or drawings to be provided by the author of the report (optional)	
Figure D.1 — Diagram or view in 2D or 3D of the component	Figure D.2 — Position on test bench
Figure D.3 — Circuit diagram of test bench	
Detailed description of the extraction protocol (optional) <i>(Write a precise sequential list of the functions performed and the conditions of operation of the component before and during the sampling operation.)</i>	

Annex E **(normative)**

Contaminant analysis principles and data reporting principles

E.1 General

This annex presents information on the analysis of contamination samples obtained from any of the contaminant extraction methods described in [Annex A](#), [Annex B](#), [Annex C](#), and [Annex D](#) and on the reporting of data generated by such analyses.

E.2 Analysis

E.2.1 Gravimetric

Prepare and analyse samples in accordance with the inspection document. Refer to ISO 4405.

E.2.2 Largest particle size

Prepare and analyse samples in accordance with the inspection document. Refer to ISO 4407.

E.2.3 Chemical composition

Prepare and analyse samples in accordance with the inspection document.

E.2.4 Particle size distribution

E.2.4.1 Prepare and analyse samples in accordance with the inspection document. Use either bottle samples or online particle counting. Calibrate particle counters or fluid contamination monitors in accordance with the relevant standard.

E.2.4.2 When extracting fractional samples from a bulk sample of test liquid, agitate the bulk sample for about 30 s to suspend the particles, then immediately pour a portion of the liquid into a clean sample bottle. Fill the bottle to 50 % to 70 % full, then cap immediately. Analyse the test sample in accordance with an approved particle counting method.

E.2.4.3 Ensure that particle concentrations are well below the maximum concentration allowed for accurate particle counting by the method being used. Dilute samples where appropriate, or use smaller liquid volumes for microscopic counting methods. Record the dilution factor and the liquid volume used for analysis.

E.2.4.4 For each sample, determine the particle concentration in particles per millilitre at the selected sizes. Multiply this count by any dilution factor from [E.2.4.3](#) to determine the particle concentration (in particles per millilitre) in the test liquid.

E.2.4.5 To determine the number of particles per component, multiply the value determined in [E.2.4.4](#) by the total volume (in mL) of test liquid.

E.2.4.6 To determine the number of particles per controlled volume, divide the value determined in [E.2.4.5](#) by the controlled volume of the component.

E.2.4.7 To determine the number of particles per controlled area, divide the value determined in [E.2.4.5](#) by the controlled area of the component.

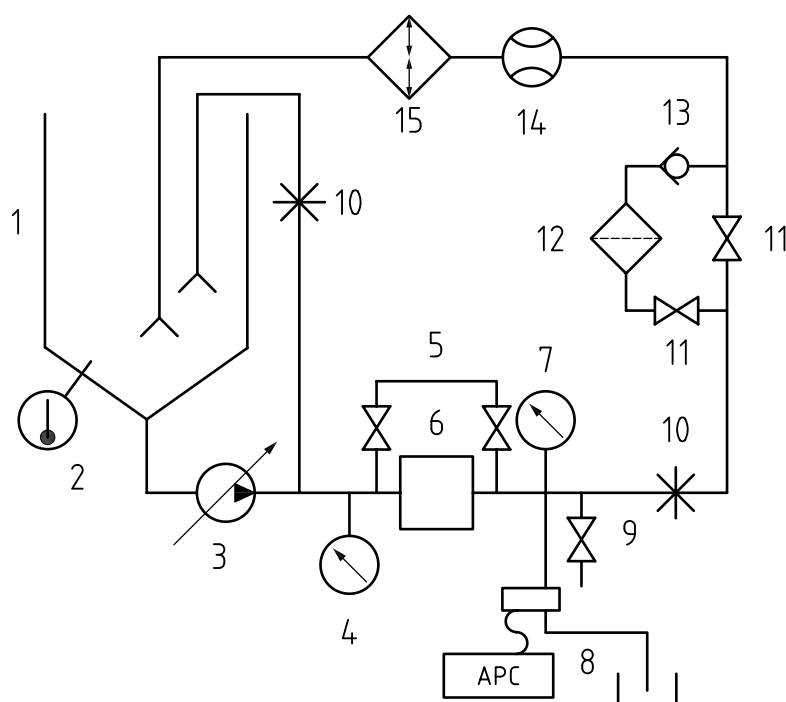
E.2.4.8 The value calculated in [E.2.4.5](#), [E.2.4.6](#), or [E.2.4.7](#) is the particle count level of the component.

Annex F (informative)

Guidelines for the design of a functional test method test stand

F.1 General

This annex provides some basic guidelines for constructing a test stand that is intended to meet the test equipment validation requirements of [Annex D](#) for the functional test method. Conformance to these guidelines does not guarantee successful validation of the equipment. A typical test stand circuit diagram is shown in [Figure F.1](#).



Key

1	reservoir	9	sampling valve
2	temperature sensor	10	restrictor valve
3	pump	11	ball valve
4	upstream pressure sensor	12	clean-up filter
5	component bypass line	13	non-return (check) valve
6	test component	14	flowmeter
7	downstream pressure sensor	15	heat exchanger
8	particulate contamination analysis system		

Figure F.1 — Circuit diagram for typical test stand

F.2 Guidelines for the design of a functional test method test stand

F.2.1 General guidelines

F.2.1.1 Lines

All lines should be sized to provide turbulent mixing flow. Long straight runs should be avoided.

F.2.1.2 Connectors

Connectors should not have internally exposed threads or lips that can trap contaminant.

F.2.1.3 Arrangement of lines and connectors

Lines and connectors should be arranged to eliminate dead flow zones. Where possible, vertical runs are preferable to horizontal runs.

F.2.1.4 Valves

Ball valves with PTFE or similar seats are preferable to other types of valves because they have a self-cleaning action and do not trap contaminants.

F.2.2 Test system elements

F.2.2.1 Reservoir

Use a reservoir constructed with a conical bottom with an included angle of $\leq 90^\circ$, designed so that the liquid entering the reservoir is diffused below the liquid surface.

NOTE 1 This construction technique eliminates horizontal surfaces that can promote contaminant settling.

NOTE 2 Reservoirs with conical bottoms and included angles between 60° and 90° offer the best balance between ease of construction and the ability to completely extract fluid without contaminants remaining on bottoms.

Install a monitoring device that ensures that the liquid level in the reservoir remains constant.

F.2.2.2 Pump and drive

Use a type of pump that is relatively insensitive to contaminant at the desired operating pressures.

The system pump should exhibit flow pulsation of $<10\%$ peak-to-peak pressure variations at the maximum working pressure.

The system pump shall not alter the extracted contaminant.

The pump drive should be the variable speed type capable of adjusting the test flow rate.

The pump drive should be relatively insensitive to changes in load so as to maintain a constant speed.

NOTE Variable frequency AC drives and DC drives exhibit these desirable characteristics.

F.2.2.3 Clean-up filter

The system clean-up filter shall be capable of providing an initial system cleanliness level as specified in [D.4.6](#).

F.2.2.4 Heat exchanger

Depending upon system power capabilities, it can be necessary to heat or cool the system liquid. A conventional shell and tube heat exchanger can be used. A vertical mounting configuration, in which the liquid enters the tube side from the top, is recommended to reduce the possibility of particle sedimentation or capture in the heat exchanger. Side and multi-pass heat exchangers have also been used successfully. Some data indicate that up to a 65 % loss in thermal transfer can occur when operating with the liquid on the tube side. Care should be taken to size the heat exchanger accordingly.

Liquid heating, if required, can be achieved by use of heating tapes on external surfaces or by use of a second heat exchanger with a high temperature liquid on the shell side.

F.2.2.5 Flowmeter

The flowmeter should be located between the test item and the downstream sample port to read the true flow rate in the test section. Flowmeters located in other parts of the system can require correction for sample flow rates that cannot be measured. Turbine flowmeters using sealed bearings have proven suitable.

F.2.2.6 Temperature sensor

A temperature sensor shall be fitted in the system to monitor test liquid temperature to an accuracy of $\pm 0,5$ °C over the expected temperature range.

F.2.2.7 Upstream pressure gauge

A pressure gauge shall be installed in the system to monitor pressure at the inlet of test item.

F.2.2.8 Downstream pressure gauge

A pressure gauge shall be installed in the system to monitor pressure at the outlet of test item.

F.2.2.9 Sampling valve

The sampling valve shall conform to ISO 4021.

F.2.2.10 Particulate contamination analysis system

Use the instruments and techniques specified in the inspection document to quantify the particulate contamination level of the test and extraction liquids. A light extinction APC calibrated in accordance with ISO 11171 or an FCM calibrated in accordance with the relevant part of ISO 21018 shall be used either in accordance with ISO 11500 (if the fluid is sampled using bottles) or ISO 11943 (if samples are analysed online).

Annex G

(informative)

Determination of geometric characteristics of components

G.1 General

The expression of particulate cleanliness level of a component as specified in this International Standard includes reference to the wetted volume and the wetted surface area of the component.

These data should be supplied by the component manufacturer. In the case where these data are not available, this annex gives guidance on how to calculate or measure the wetted volume or wetted surface. The wetted volume is calculated in [G.3](#) and the wetted surface area in [G.4](#).

The determination of wetted volume is described first, as it is the base of a harmonized approach of system contamination including components, sub-assemblies, assembled system, and hydraulic fluid as explained in ISO TR 10686.

The calculation of wetted surface area is also given to express the cleanliness level of solid parts that do not have an included wetted volume but are instead surrounded by the fluid, e.g. the gears of a gear pump.

G.2 Equipment

The following equipment is used in the following procedures:

- a) a graduated cylinder with a volume suited to the volume of liquid estimated to be contained in the test component plus 30 % and an accuracy of 1 % of the read value;
- b) a graduated syringe with a volume equal to about 30 % of the capacity of the graduated cylinder in a) and an accuracy of 1 % of the read value;
- c) a weighing balance covering the range of the mass of the liquid specified in item a) plus the mass of the filling liquid with an accuracy of 1 %.

G.3 Determination of wetted volume of a component

G.3.1 Calculation method

The wetted volume of a component is calculated by using a dedicated computer's industrial drawing software. It shall be given by the manufacturer or reported in the inspection document.

G.3.2 Experimental method

The wetted volume or capacity (V_c) of a hollow component can be measured experimentally by the following procedure:

- a) Make sure that the inside of the test component is dry.
- b) Select a suitable opening for filling that accesses all other passages. Seal all other openings.
- c) Prepare a volume of test liquid (V_1), known to within 1 %, of about 1,3 times the presumed wetted volume of the component. The test liquid should be compatible with the materials of the component and its kinematic viscosity should preferably be less than 5 mm²/s at test temperature. It has been

found practical to weigh this volume in a measuring cylinder, after establishing the tare weight of the latter, and then to divide its mass by its specific gravity at test temperature.

- d) Carefully fill the component with test liquid, making sure not to trap any air. To remove any air introduced, move the component gently in suitable directions so that every empty zone of it is filled with liquid. Adjustment of the filling volume can be facilitated by using a syringe, as it can conveniently dispense small volumes and be emptied completely.
- e) Determine the volume (V_2) remaining in the measuring cylinder of the liquid in c).
- f) Calculate the volume (V_c) that was needed to fill the component using Formula G.1:

$$V_c = V_1 - V_2 \quad (G.1)$$

G.4 Determination of wetted surface area of a component

G.4.1 Calculation method

The wetted surface area of a component can be calculated by using industrial drawing software.

G.4.2 Approximate sphere concept

G.4.2.1 Equivalent sphere concept

If the wetted volume of the component is known, e.g. by experimental method, its wetted surface area can be estimated by considering this volume to be spherical and then calculating a surface area of the sphere using the basic relationship given in Formulae G.2 and G.3:

$$V_c = \pi d^3/6 \rightarrow d = (6 V_c/\pi)^{1/3} \quad (G.2)$$

$$A_s = \pi d^2 \quad (G.3)$$

where

V_c is the actual wetted volume;

d is the diameter of the equivalent sphere;

A_s is the surface area of the equivalent sphere.

Finally, because a sphere always has the absolute minimum surface area for an enclosed volume, an adjustment factor is added as the last step in calculating an approximate equivalent area, as given in Formula (G.4):

$$A_e = 1,2 A_s \quad (G.4)$$

where

A_e is the approximate equivalent area;

A_s is the calculated spherical area.

G.4.2.2 Experimental approximation

G.4.2.2.1 Determine the external wetted surface area of components that are surrounded by the system liquid as follows:

- a) Seal any internal passages.
- b) Submerge the test item.
- c) Measure the displaced volume of liquid.
- d) Calculate the approximate equivalent area in accordance with [G.4.2.1](#).

G.4.2.2.2 Determine the internal wetted surface area of components that enclose the system liquid as follows:

- a) Determine the wetted volume in accordance with [G.3](#).
- b) Calculate the approximate equivalent area in accordance with [G.4.2.1](#).

G.4.2.2.3 Determine both the external and internal wetted surfaces of components that both enclose the system liquid and are surrounded by the system liquid as follows:

- a) Calculate the approximate equivalent area for the external wetted surfaces in accordance with [G.4.2.2.1](#).
- b) Calculate the approximate equivalent area for internal wetted surfaces in accordance with [G.4.2.2.2](#).
- c) Calculate the total approximate equivalent area by adding the results from [G.4.2.2.3](#) a) and b).

G.4.3 Ratio of wetted volume to wetted surface area

If the wetted volume of the component (V_C) and the ratio of the hydraulic system volume to its wetted surface area (V_S/A_S) are known, ISO TR 10686 can be used to relate the cleanliness of a system to the cleanliness of the components that make up the system.

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