TECHNICAL REPORT

ISO/TR 10686

First edition
2013-07-01

Hydraulic fluid power — Method to relate the cleanliness of a hydraulic system to the cleanliness of the components and hydraulic fluid that make up the system

Transmissions hydrauliques — Méthode de relation entre propreté d'un système hydraulique et propreté des composants et du fluide hydraulique qui composent le système

Reference number
ISO/TR 10686:2013(E)

Contents

Page

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. 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. 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.

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

Introduction

The initial cleanliness level of a hydraulic system can affect its performance and useful life. Unless removed, particulate contaminants present after manufacture and assembly of a system can circulate through the system and cause damage to the system's components. To reduce the probability of such damage, the fluids and the internal surfaces of the hydraulic fluid power system and of its components should be cleaned to a specified level.

The final cleanliness level of the complete system can be theoretically predicted as the sum of the particulate contamination brought in by both the components that make up the system and the filling fluid.

As a reciprocal, the required cleanliness level of each individual component and of the filling fluid can be predicted from the required cleanliness level of the final system. This Technical Report explains the theoretical basis for such predictions.

Hydraulic fluid power — Method to relate the cleanliness of a hydraulic system to the cleanliness of the components and hydraulic fluid that make up the system

1 Scope

This Technical Report describes methods that can be used to:

— relate the cleanliness of a hydraulic system to the cleanliness of its components and the hydraulic fluid belonging to the system;

— estimate the final cleanliness level of an assembled hydraulic system filled with the hydraulic fluid, upon its release from the manufacturing area. The estimation of the final cleanliness level is based on the cleanliness level of each component in the system and on the cleanliness level of the filling fluid;

— calculate and manage cleanliness requirements of components and subassemblies that make up a system and of the fluid filling it so as to achieve a required cleanliness level (RCL) for the final system.

These methods can apply whatever the particle size considered and can also be used for other types than hydraulic fluid power.

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 5598, *Fluid power systems and components — Vocabulary*

3 Terms and definitions

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

3.1
wetted surface area
A
surface area of the component or system that is exposed to the system liquid in normal operation, as agreed between parties

Note 1 to entry: Subscripts C or S are added to the symbol *A* when it refers to the wetted surface area of, respectively, a component or a system.

EXAMPLE Consider a hydraulic gear pump with two gears (see Figure 1). The wetted surface area can be calculated as the sum of the internal surfaces of the pump body (two plates and one flange with two ports) plus the external surface of the two gears.

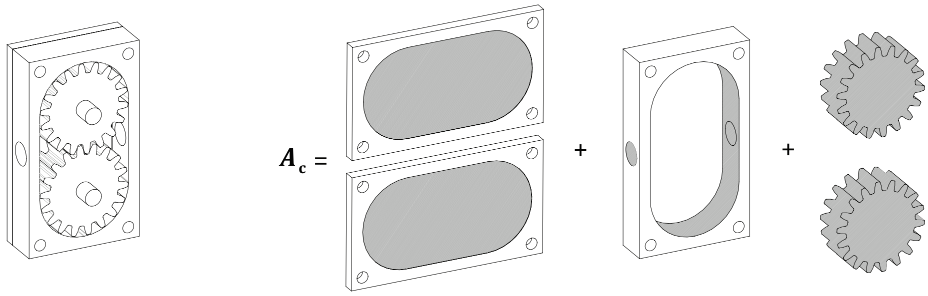


Figure 1 — Wetted surface of an external gear hydraulic pump

3.2
wetted volume
contained volume
V
volume of a component or system in which the system liquid is to be found in end-use operating conditions, as agreed between parties

Note 1 to entry: Subscripts C or S are added to the symbol *V* when it refers to the wetted volume of, respectively, a component or a system.

EXAMPLE Consider a hydraulic gear pump with two gears (see Figure 2). The wetted volume can be calculated as the volume of the body minus the volume of the two gears or measured as the filling volume of the complete pump.

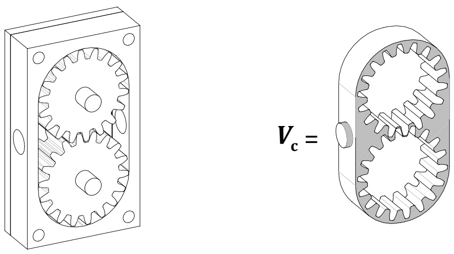


Figure 2 — Wetted volume of an external gear hydraulic pump

4 Symbols and units

The symbols and units related to the cleanliness of fluids, systems and components used in this Technical Report are given in Table 1.

Table 1 — Symbols and units

Symbol	Description or explanation	Unit
N_A	Number of particles of a given size introduced during assembly	number of particles
N_C	Number of particles of a given size in a component	number of particles
N_{Ci}	Number of particles of a given size in component *i*	number of particles
N_S	Number of particles of a given size in an empty system (without fluid)	number of particles
N_F	Number of particles of a given size in a fluid used to fill system	number of particles
N_{SF}	Number of particles of a given size in a system filled with system fluid	number of particles
N_X	Number of particles of a given size in an item *X*	number of particles

a If the relevant particle sizes are those covered in ISO 4406 [i.e. 4 µm(c), 6 µm(c), 14 µm(c) for automatic counting, 5 µm or 15 µm for microscopic counting], the cleanliness level can be expressed using the code system specified in ISO 4406.

Table 1 *(continued)*

Symbol	Description or explanation	Unit
A_C	Wetted surface area of a component	cm^2
A_S	Wetted surface area of an empty system (without fluid)	cm^2
V_C	Wetted volume of a component	cm^3 or ml
V_{Ci}	Wetted volume of component i	cm^3 or ml
V_S	Wetted volume of an empty system (without fluid)	cm^3 or ml
V_F	Volume of fluid used to fill system	cm^3 or ml
V_{SF}	Wetted volume of a system upon its release from the manufacturing area	cm^3 or ml
V_X	Wetted volume of an item	cm^3 or ml
C_C	Cleanliness level of a component – N_C / V_C	number of particles per cm^3 or ml
C_{Ci}	Cleanliness level of component i	number of particles per cm^3 or ml
C_S	Cleanliness level of an empty system (without fluid) – N_S / V_S	number of particles per cm^3 or ml
C_F	Cleanliness level of fluid used to fill system – N_F / V_F	number of particles per cm^3 or ml [a]
C_{SF}	Cleanliness level of a system upon its release from the manufacturing area – N_{SF} / V_{SF}	number of particles per cm^3 or ml

a If the relevant particle sizes are those covered in ISO 4406 [i.e. 4 µm(c), 6 µm(c), 14 µm(c) for automatic counting, 5 µm or 15 µm for microscopic counting], the cleanliness level can be expressed using the code system specified in ISO 4406.

5 Basic considerations

5.1 Particulate contamination

5.1.1 Basic principles

The physical and chemical principles that explain the presence and the behaviour of particulate contaminants in a hydraulic system are numerous and complex. This subclause covers some basic principles on which this Technical Report's approach to cleanliness is based.

5.1.2 Homogeneity of distribution of contamination in the system

In the absence of a system or flushing filter when the system is operated for the first time and stabilized, particulate contaminants are considered to be distributed homogeneously in the whole system, i.e. particulate contamination is in the fluid everywhere in the components and the system and on the wetted surfaces of the components. This assumes that all of the fluid and all the surfaces on which it flows are at the same cleanliness level.

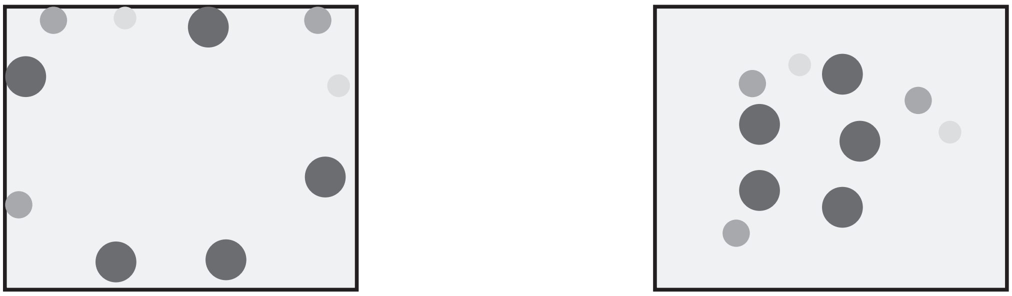
5.1.3 Actual location of contaminants in items and fluid

Particulate contaminants are either deposited on the surface area of the components or suspended in the hydraulic fluid (see Figure 3). Even if particles are deposited on the entire surface of a component, only those deposited on the wetted surface are taken into consideration because they are the only ones likely to move into the fluid and potentially to damage the system.

5.1.4 Theoretical location of contaminants in items

To apply the cleanliness prediction method described in this Technical Report, it is necessary to consider that the particulate contaminants deposited on the wetted surface areas of hollow components and assemblies are in suspension in the void volume of the items [see Figure 3 b)].

This concept applies because only particulate contaminants moving from the surface of the component into the hydraulic fluid add to the fluid contamination and become capable of damaging the system.



a) Actual situation – Contaminants on the surface **b) Cleanliness concept – Contaminants in the volume**

Figure 3 — Concept of cleanliness per unit volume

The cleanliness level of hollow components, subassemblies and systems can be compared to the cleanliness level of fluids.

5.1.5 Overall cleanliness approach

5.1.5.1 Cleanliness level of assembled components

In the majority of hydraulic circuit configurations, the following statements apply.

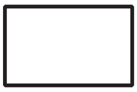
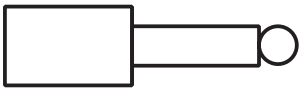
— When components are assembled in subassemblies and when subassemblies are assembled in a system, the numbers of their contaminant particles are summed and their wetted volumes are also summed.

— The cleanliness level of an empty assembled system not yet filled with fluid is the ratio of the sum of the numbers of contaminant particles in or on each component to the sum of the wetted volume of all components.

— The cleanliness level of an empty assembled system is neither the sum nor the average of the cleanliness levels of the components it is made of.

See Table 2 for an illustration of these concepts.

Table 2 — Illustration of how cleanliness levels can and cannot be used in calculations

Item	Number (N_i) of contaminant particles	Volume, V_i	Cleanliness level, C_i
		ml	N/ml
Component 1: 	5	10	5/10 = 0,5
Component 2: 	5	2	5/2 = 2,5
Component 3: 	2	1	2/1 = 2
Assembly 4: 	$N_4 = \sum N_i$ $N_4 = 12$	$V_4 = \Sigma V_i$ $V_4 = 13$	$C_4 = \sum N_i / \sum V_i$ 12/13 = 0,92
Note – $C_4 \neq C_1 + C_2 + C_3$ and $C_4 \neq (C_1 + C_2 + C_3) / 3$			

5.1.5.2 Cleanliness level of items filled with fluid

When a hollow item of volume V_X contaminated with N_X particles of a given size per ml is fully filled in with a fluid contaminated with N_F particles of the same size per ml, the resulting cleanliness level of the item filled with fluid is $(N_X + N_F) / V_F$.

5.2 System knowledge requirements

5.2.1 System structure

It is necessary to know precisely the components located upstream and downstream of the component being considered, as well as the subassembly the components are part of and the whole system the subassemblies are part of.

It is necessary to know how to manage the cleanliness of each part (i.e. make items cleaner to allow a relaxation in the cleanliness of other items), so that the overall cleanliness complies with the RCL.

5.2.2 Geometrical characteristics

5.2.2.1 Wetted volume (V_X)

The wetted volume of the item can be either measured experimentally or calculated using computerised engineering drawing tools or from the ratio V/A of the complete system. See Annex A for further details.

5.2.2.2 Wetted surface area (A_X)

The wetted surface area of the item, if required, can be calculated using computerised engineering drawing tools.

5.2.2.3 Volume-to-surface area (V/A) ratio

Some cleanliness requirements are expressed per unit surface area. To apply the cleanliness prediction method, they need being transformed to requirements per unit volume. See Annex D to do such transformation.

6 Prediction from component cleanliness to system cleanliness (the bottom-up approach)

6.1 Principles

6.1.1 It is assumed that the assembly process does not introduce any particles into the components.

NOTE It is recognized that this assumption is not true in reality. However, it is possible to estimate the contamination introduced during assembly by measuring the actual cleanliness level of the assembled components and comparing the measured number of contaminant particles to the theoretical cleanliness level calculated in accordance with this Technical Report.

6.1.2 If the contamination brought in by the assembly process is known, it can be added to the contamination brought in by each component or subassembly assembled to make the relevant item.

6.1.3 The particulate contamination of a new hydraulic system upon its release from the manufacturing area is the sum of the particles brought in by each subassembly that makes up the system and by the filling fluid.

6.1.4 The particulate contamination of a subassembly is the sum of the particles brought in by each component that makes up the subassembly.

6.1.5 Thus, if the cleanliness level of each component (i.e. the bottom) and of the fluid is known, then the final cleanliness of the system (i.e. the top) can be theoretically determined or predicted. This is the cleanliness prediction (CP) method illustrated in Figure 4.

Operating system	V_F; $N_{SF} = N_F + N_S$	$C_{SF} = (N_F + N_S) / V_F$ (N/ml)
↑		
Fluid	V_F; N_F	$C_F = N_F / V_F$ (N/ml)
↑		
System (empty)	$V_S = \Sigma V_{ci}$; $N_S = \Sigma N_{ci}$	$C_S = N_S / V_S$ (N/ml)
↑		
Components	V_C ; N_C	$C_C = N_C / V_C$ (N/ml)

Figure 4 — Relationship of cleanliness levels of components, empty system, fluid and operating system in an assembling process used in the cleanliness prediction (CP) method

6.2 Determination of the cleanliness level of a component

6.2.1 General

The cleanliness level of a component, C_C, can be expressed by a number of particles per unit wetted volume of component, that is N/ml, and can be measured or calculated from the cleanliness level of the parts it has been made of (see Annex E).

6.2.2 Measurement

Measurement is the preferred method of determining the cleanliness level of a component.

The number of particles (N_C) of a given size contaminating the components to be assembled in a system (or subassembly) is measured using an extraction method defined in ISO 18413.

If the contamination brought in the component during assembly (N_A) is known, the resulting cleanliness level of the component in N/ml is calculated using Formula (1):

$$C_C = \frac{N_C + N_A}{V_C} \qquad (1)$$

6.3 Prediction of cleanliness level of an assembled system

6.3.1 The cleanliness level of an empty assembled system, C_S, can only be predicted and calculated from the cleanliness levels of the components that comprise the system. The cleanliness level can be expressed by a number of particles (N_S) per unit volume of system (ml). This method can also be applied to the subassemblies that make up a system.

6.3.2 The system is made of n components with cleanliness levels C_i. Each component brings in N_{Ci} particles (see 7.2). The n components bring in the system N_S particles, calculated using Formula (2):

$$N_S = \sum_{i=1}^{n} N_{Ci} \qquad (2)$$

6.3.3 The cleanliness level of the empty assembled system, C_S in N/ml, whose wetted volume is V_S and is made of these n components, is calculated using Formula (3):

$$C_S = \frac{N_S}{V_S} \qquad (3)$$

NOTE The wetted volume of the system can be approximated by the sum of the wetted volumes of each component.

6.3.4 If the contamination brought in the system during assembly (N_A) is known, the resulting cleanliness level of the system, C_S in N/ml is calculated using Formula (4):

$$C_S = \frac{N_S + N_A}{V_S} \qquad (4)$$

6.4 Prediction of cleanliness level of a new system upon its release from the manufacturing area

6.4.1 The cleanliness level of a new hydraulic system upon its release from the manufacturing area can be predicted from the cleanliness levels of the empty assembled system and the filling fluid.

6.4.2 The number of particles in the empty assembled system, N_S, at the cleanliness level C_S (see 6.3) is calculated using Formula (5):

$$N_S = C_S \times V_S \qquad (5)$$

6.4.3 The cleanliness level of the filling fluid is measured using an appropriate particle counting method (e.g. microscopic counting in accordance with ISO 4407 or automatic counting in accordance with ISO 11500) and expressed as a number of particles per unit volume ($C_F = N_F / V_F$, e.g. the maximum number defined by an ISO 4406 level). The filling fluid volume, V_F, brings in the empty assembled system a number of particles N_F, which is calculated using Formula (6):

$$N_F = C_F \times V_F \qquad (6)$$

NOTE 1 The filling fluid volume V_F can be different from that of the empty system V_S, e.g. when a reservoir is partially filled.

NOTE 2 ISO 4407 and ISO 11500 can be expected to give somewhat different results. It is important to take care to use the same method whenever possible to evaluate the contamination of the system and of its constituent components.

6.4.4 The cleanliness level of a hydraulic system upon its release from the manufacturing area, C_{SF}, in N/ml, can be predicted using Formula (7):

$$C_{SF} = \frac{N_S + N_F}{V_F} \qquad (7)$$

6.5 Practical predictions

6.5.1 Assembly of components with the same cleanliness levels

Assuming the assembly process does not introduce contaminants (i.e. N_A = 0), it can be predicted that assembling n components at the same cleanliness level C_{ci} results in an empty system at the same cleanliness level (C_S = C_C). See Table 4 for an example of this practical prediction process; Table B.2 also gives a similar practical example.

Table 4 — Example of practical prediction of the cleanliness of an assembly from the cleanliness levels of components it contains

Item, *I*	**Number of contaminant particles, N_i**	**Volume, V_i**	**Cleanliness level, C_i**
		ml	***N*/ml**
Component 1: D13272EZ.EPS	10	10	10/10 = 1
Component 2: D13272FZ.EPS	2	2	2/2 = 1
Component 3: D13272GZ.EPS	1	1	1/1 = 1
Assembly 4: D13272HZ.EPS	13	13	13/13 = 1

6.5.2 Filling a system with a fluid at the same cleanliness level

The filling of an empty system at cleanliness level C_S with a fluid at the same cleanliness level (i.e. C_F = C_S and N_F/ml = N_S/ml), results in a system with twice the number of particles in the fluid volume in N/ml, as illustrated by Formula (8):

$$C_{SF} = \frac{N_S + N_F}{V_F} = 2\frac{N_F}{V_F} = 2\frac{N_S}{V_F} \qquad (8)$$

NOTE If the cleanliness level of the filling fluid is expressed in accordance with ISO 4406, the cleanliness of the hydraulic system upon its release from the manufacturing area can be predicted to be one ISO 4406 code level higher than the fluid cleanliness level, assuming the assembled but empty system is at the same cleanliness level as the fluid used to fill it. Indeed, twice as many particles in one millilitre mean one ISO 4406 code level higher.

7 Specifying the cleanliness requirements from system cleanliness level to component cleanliness level (the top-down approach)

7.1 Principle

7.1.1 The cleanliness requirement of a hydraulic system upon its release from the manufacturing area can be specified by its operating fluid cleanliness level C_{SF} in N/ml or expressed using a code in accordance with ISO 4406.

7.1.2 From the bottom-up cleanliness prediction method (see Clause 6), one knows that contamination in subassemblies and components add in their added volumes ($N_S = \Sigma N_{Ci}$, $V_S = \Sigma V_{Ci}$, $C_S = N_S / C_S$) and that empty system contamination and filling fluid contamination add ($N_{SF} = N_S + N_F$) in the same volume (V_F). Because this equation ($N_{SF} = N_S + N_F$) has a large number of solutions, the user can either specify the same requirements or manage and weigh the requirements depending on technical and/or economic issues.

7.2 Specification of identical requirements

7.2.1 The cleanliness requirements for both the empty system and the filling fluid are equal to half the cleanliness level specified for the complete system, i.e. $C_S = C_F = (C_{SF} / 2)$ in N/ml and $N_S / V_S = N_F / V_F = (N_{SF} / 2\ V_{SF})$.

NOTE If the cleanliness level is expressed using a code or classification based on a geometrical progression of 2 (such as ISO 4406), then it is helpful if the required cleanliness levels of the empty system and filling fluid is one code level smaller. A hydraulic system upon its release from the manufacturing area with a cleanliness level of 18/16/13 in accordance with ISO 4406 can be achieved by filling an empty system at a cleanliness level of ISO 17/15/12 with a fluid at a cleanliness level of ISO 17/15/12.

7.2.2 From the principle stated in 6.5.1, the cleanliness requirement for the empty assembled system becomes, without any change, the cleanliness requirement on all its subassemblies and components they are made of, i.e. $C_S = C_C = (C_{SF} / 2)$ in N/ml. See Table B.2 for an example of practical application.

7.3 Specification of different requirements

7.3.1 Because achieving a given cleanliness requirement might not be as economically or technically feasible for fluid and for all components that make up a system, the cleanliness prediction method allows the management of individual requirements while still complying with the final operating system cleanliness requirement.

7.3.2 To manage these requirements, the computerised cleanliness prediction (CP) method described in Annex B can be applied, provided the software allows variation in either the cleanliness level (number of particles per unit volume of item) or the ISO 4406 code for all items. See Annex B for an example of practical application.

NOTE 1 The reliability of first-start operation of an assembled system depends on the sensitivity of the constituent components to particulate contamination. In many cases, the more complex a component is (i.e. the smaller its V/A ratio), the more sensitive it is to contamination.

NOTE 2 Because, at first-start operation, the volume of fluid filling every component is entirely transferred into the component downstream, it is important to ensure that a component that has an higher contamination level does not exist upstream from a contamination-sensitive component without an adequate filter between them.

8 Relationship between cleanliness levels per unit volume and cleanliness levels per unit surface area

8.1 *V*/*A* ratio

All systems, subassemblies and components have a wetted volume, and the required cleanliness levels of such components is expressed in terms of *N*/ml, therefore the cleanliness prediction (CP) method specified in Clauses 6 and 7 can be applied to them.

However, it is important that care is taken in interpreting data because, as shown in Table B.1, a system is generally much simpler than some components. Its *V*/*A* ratio can be much higher than that of complex and sensitive components (e.g. pumps or valves).

8.2 Impact of surface cleanliness level on fluid cleanliness level

As explained in Figure 1, the particulate contaminants in components are likely to be transferred to the fluid filling the component and then to move to the downstream component at the first-start operation. The impact of contaminated surfaces on the cleanliness level of the fluid filling two components with a different *V*/*A* ratio is illustrated in Annex C.

Annex A
(informative)

Determination of geometrical characteristics of components

A.1 Determination of the wetted surface area A_c

Whenever possible, the wetted surface area of a component is calculated using computerised engineering drawing tools. If this is impossible, calculations can be done using existing components of the same shape with known A_c. Otherwise the contained volume can be used.

A.2 Determination of the wetted (contained) volume V_c

A.2.1 Calculation method

If the computerised engineering drawing tools available provide for such calculation, the wetted volume (V_C) can be calculated by electronic means.

A.2.2 Experimental method

A.2.2.1 Ensure that the inside of the component is dry.

A.2.2.2 Close all ports and openings except one, or more if necessary, to allow the component to be completely filled.

A.2.2.3 Prepare a volume (V_1) of test fluid of approximately 1,3 times the predicted contained volume of the component, and place the test fluid in a suitable container.

NOTE 1 It is important that the test fluid is compatible with the materials of the component and has a viscosity of less than 5 mm^2/s.

NOTE 2 It has proven to be practical to weigh this volume in a container that has been previously tared, and to calculate the volume by dividing its mass by its density.

A.2.2.4 Carefully fill the component with test fluid. Avoid trapping air by gently moving it as necessary so that its interior fills up with the test fluid.

A.2.2.5 Determine the volume (V_2) remaining in the container.

A.2.2.6 Determine the wetted volume (V_C) using Formula (A.1):

$$V_C = V_1 - V_2 \tag{A.1}$$

Annex B
(informative)

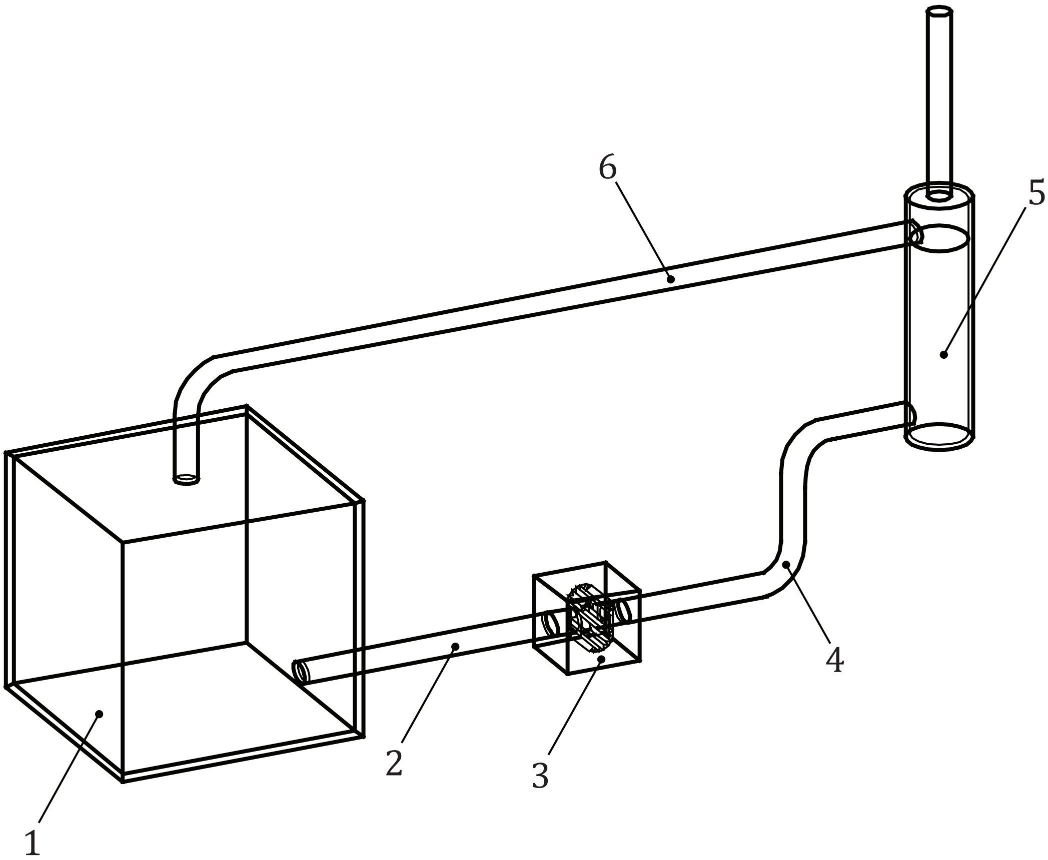
Example of calculation of the cleanliness of an assembled system from the cleanliness of individual components

B.1 Introduction

The principle of the cleanliness prediction method (CP method) allows drawing offices and designers of hydraulic systems to develop and use their own software to simulate various cleanliness levels of components, subassemblies, filling fluid and complete systems. If cleanliness levels of components that comprise the system are known, the CP method and application software allows predicting resulting cleanliness level of assembled system. The CP method can be used to theoretically quantify the effect of assembling dirtier or cleaner components and/or filling the system with a dirtier or cleaner fluid on the cleanliness level of the assembled system. This annex illustrates such a software program that uses spreadsheets.

B.2 System description

The simple example system consists of six components (see Figure B.1), the geometrical characteristics of which are given in Table B.1 below.



Key

1	reservoir
2, 4 and 6	tubes
3	gear pump
5	cylinder

Figure B.1 — Simplified hydraulic circuit

Table B.1 — Geometric characteristics of the hydraulic components and assembled system in Figure B.1

Component		Wetted Volume *V* cm³	Wetted Surface area *A* cm²	Ratio *V*/*A*
Reservoir	(1)	885	553	1,6
Tubes	(2)	5,3	26,6	0,2
	(4)	8,5	42,3	0,2
	(6)	17,2	85,9	0,2
Pump	(3)	1,8	31,5	0,05
Cylinder	(5)	31,2	55,0	0,56
Assembled system		949	794	1,19
Filling fluid		684	-	-

B.3 Particulate cleanliness level simulation

The combination of the volume of components and fluid and their cleanliness levels allow either the prediction of the cleanliness of the assembled system (values of *N* per component are introduced and cleanliness levels are automatically calculated) or the management of cleanliness levels to obtain a given final result (the cleanliness levels are introduced and the values of *N* per component are automatically calculated)

B.3.1 Software description

The calculation sheet consists of:

— as many rows as items considered (from the simplest to the most complex), the assembled system, the filling fluid and the hydraulic system upon its release from the manufacturing area;

— column 1 identifying the above items;

— column 2 reporting the numbers of particles per item considered. The number of particles in a component and fluid are measured. The number of particles in subassemblies and empty system is sum of the number of particles in each component. The number of particles in a hydraulic system upon its release from the manufacturing area is the sum of the number of particles in the empty system and the filling fluid;

— column 3 reporting the wetted volume of the components, sub-assemblies, system and filling fluid. The wetted volume of the hydraulic system upon its release from the manufacturing area is the same as that of filling fluid;

— column 4 reporting the cleanliness level per item, determined by comparing the number of particles per millilitre to a table defining a component cleanliness code, and the cleanliness level of the fluid, expressed in accordance with ISO 4406.

B.3.2 Mode of operation

B.3.2.1 Fill in column 1 except for the rows for subassemblies, the empty system and the system upon its release from the manufacturing area. Report in column 3 the volume of each item. The software calculates the cleanliness level for each item and for the system.

B.3.2.2 If required, hypothetical component cleanliness levels can be introduced in column 4 to quantify their impact on the operating system cleanliness.

B.3.3 Examples

B.3.3.1 Table B.2 shows an example of an application in which the cleanliness levels of all of the items that make up the system are identical.

Table B.2 — Example of calculation of the cleanliness of an assembled system

Components		*N* particles > *X* µm per component	Volume ml	*N* particles > *X* µm per ml	Cleanliness level C_X
Reservoir	(1)	44,3	885	5	9
Tubes	(2)	0,3	5,3	5	9
	(4)	0,4	8,5	5	9
	(6)	0,9	17,2	5	9
Pump	(3)	0,1	1,78	5	9
Cylinder	(5)	1,6	31,2	5	9
Assembled system		47	949	5	9
Filling fluid		34	684	5	9
Total system		82	684	12	10

NOTE For the example, the level C_X is determined from the numbers of particles of ISO 4406.

B.3.3.2 Tables B.3 and B.4 show examples of how, by changing the required cleanliness level of one of the components (including filling fluid) of an assembled system, one can manage the relative cleanliness of a system's components while complying with the required cleanliness level of the system upon its release from the manufacturing area.

Table B.3 — Example of an application in which a system is filled with an "ultraclean" fluid

Components		*N* particles > *X* µm per component	Volume ml	*N* particles > *X* µm per ml	Cleanliness level C_X
Reservoir	(1)	22,1	885	3	8
Tubes	(2)	0,3	5,3	5	9
	(4)	0,4	8,5	5	9
	(6)	1,7	17,2	10	10
Pump	(3)	0,7	1,78	40	12
Cylinder	(5)	0,8	31,2	3	8
Assembled system		26	949	3	9
Filling fluid		0	684	0	2
Total system		26	684	4	9

Table B.4 — Example of an application in which the assembly is made up of easy-to-clean and "dirty" components

Components		*N* particles > *X* µm per component	Volume ml	*N* particles > *X* µm per ml	Cleanliness level C_x
Reservoir	(1)	0,4	885	0	2
Tubes	(2)	0,1	5,3	3	8
	(4)	0,9	8,5	10	10
	(6)	1,7	17,2	10	10
Pump	(3)	23,1	1,78	1 300	17
Cylinder	(5)	1,6	31,2	5	9
Assembled system		28	948,98	3	9
Filling fluid		4	684	1	6
Total system		32	684	5	9

Annex C
(informative)

Impact of surface cleanliness level on fluid cleanliness level

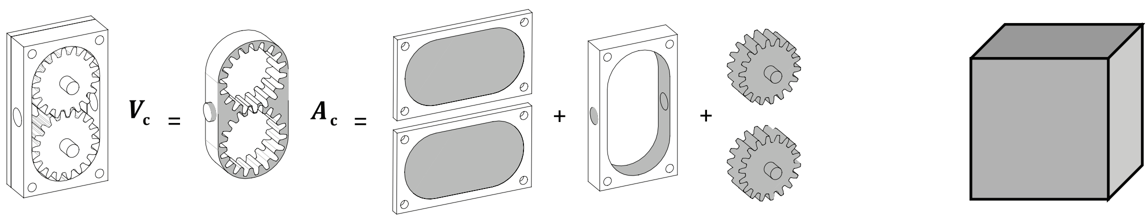
C.1 Introduction

This annex explains how initial cleanliness level of components, subassemblies and systems has an impact on the cleanliness of the fluid filling a new system at the very first time of its operation.

The example is based on two components of the simple system described in B.1: the reservoir and the external gear pump. It assumes that both are fully filled with an ultraclean fluid, i.e. one without any particulate contaminants.

C.2 Calculation

C.2.1 Data



	Pump	Reservoir
Volume:	V_P = 1,8 ml	V_R = 885 ml
Surface area:	A_P = 31,5 cm^2	A_R = 553 cm^2
Volume to area ratio:	V/A = 0,05	V/A = 1,6

Figure C.1 — Illustration of an external gear pump and a reservoir

C.2.2 Results of same surface cleanliness level

C.2.2.1 If surface cleanliness levels of the reservoir and the pump are equal, then N_R / A_R = N_P / A_P. For the purposes of this example, assume that this cleanliness level is 500 particles/cm^2.

NOTE The surface cleanliness of different components is effectively the same when they are washed together in the same washing machine.

C.2.2.2 Calculate the number of particles in the two components.

Reservoir: N_R = 500 × 553 = 276 500 particles

Pump: N_P = 500 × 31,5 = 15 750 particles

C.2.2.3 Imagine that the two components are filled in with an ultraclean fluid ($N_F = 0$) and that the contaminant particles move from the surface into the liquid (see Figure C.1 for an illustration of the concept of the cleanliness prediction method), and calculate the resulting fluid cleanliness level.

Reservoir: $C_R = N_R / V_R = 276\ 500 / 885 = 312{,}4$ particles/ml

Pump: $C_P = N_P / V_P = 15\ 750 / 1{,}8 = 8\ 750$ particles/ml

From the point of view of the fluid, the pump contains about 28 times (8 750/312,4) more particles/ml than the reservoir.

C.2.3 Results of same volume cleanliness level

C.2.3.1 If volume cleanliness levels of the reservoir and the pump are equal, then $N_R/V_R = N_P/V_P$. For the purposes of this example, assume that this cleanliness level is 320 particles/ml (or cm^3).

C.2.3.2 Calculate the number of particles in the two components:

Reservoir: $N_R = 320 \times 884 = 282\ 880$ particles

Pump: $N_P = 320 \times 1{,}8 = 576$ particles

C.2.3.3 Imagine that these contaminants are stuck on the wetted surfaces of the two components, and calculate their resulting surface cleanliness level:

Reservoir: $C_R = N_R / A_R = 282\ 880/553 = 511{,}5$ particles/cm^2

Pump: $C_P = N_P / A_P = 576/31{,}5 = 18$ particles/cm^2

The wetted surface of the reservoir contains about 28 times more particles per cm^2 (511/18) than the wetted surface of the pump.

C.3 Practical consequences

C.3.1 Same surface cleanliness level

A practical consequence of specifying the same surface cleanliness levels is that when first starting the system, the fluid leaving the reservoir would be at an ISO 4406 code level of 15 whereas the fluid leaving the pump would be at an ISO 4406 code level 20, i.e. five ISO 4406 code levels higher. If the component downstream the pump is sensitive to contamination and not protected by a filter, it will likely be damaged at first operation of the assembled system. However, a relatively high contaminant concentration exiting the pump lasts only for a fraction of 1 s as the in-built dirt is flushed out.

C.3.2 Same volume cleanliness level

A practical consequence of specifying the same volume cleanliness level is that to make a hydraulic system upon its release from the manufacturing area at a given cleanliness level, all components need to be at the same volume cleanliness level and thus at surface cleanliness levels in the ratio of their volume to area. As a result, more geometrically complex components need to be cleaned much more carefully and intensively than simple ones.

C.3.3 Cleanliness level management

If the required surface cleanliness level is difficult to achieve for technical or economical reasons, the computerised cleanliness prediction (CP) method described in Annex B is a practical tool to manage such requirements and to predict the theoretical impact of assembling more contaminated components (that is with higher contamination levels) than the final assembled system cleanliness level.

Annex D
(informative)

Relating volume to surface area

D.1 Volume-to-surface area (*V*/*A*) ratios (geometry factors)

The geometry of a hydraulic system can be characterized by its *G* factor, which is the ratio of its wetted volume (V_S) to its wetted surface area (A_S), that is: $G = V_S / A_S$

The geometry of a component can be characterized by its *G'* factor, which is the ratio of its wetted volume (V_C) to its wetted surface area (A_C): $G' = V_C / A_C$

The more complex the item, the smaller *V*/*A* is. Table D.1 shows typical values for various hydraulic components.

These values are used to calculate the wetted surface of a part or component when *G* or *G'* and the volume of the component it is part of are known. Reciprocally, they are used to transform a cleanliness statement reported per surface area into a cleanliness statement for a volume.

Table D.1 — Typical values of *V*/*A* for various hydraulic components

Hydraulic component	Typical value of *V*/*A*
Reservoir	1 to 5
Pipe	0,2
Cylinder	0,5 to 0,6
Pump	0,001 to 0,05
Valve	0,001
Complete filter	0,05 to 2
Complete system	0,2 to 4

D.2 From surface to volume

To transform a cleanliness level per unit wetted surface area (N/cm^2 or equivalent) to a cleanliness level per unit wetted volume (*N*/ml), it is necessary to know the *V*/*A* ratio (ml/cm^2) of either the component or the subassembly or the system it is part of. In this case, $(N/\text{ml}) = (N/\text{cm}^2) / (V/A)$.

D.3 From volume to surface

To transform a cleanliness level per unit wetted volume (*N*/ml) to a cleanliness level per unit wetted surface area (N/cm^2), it is necessary to know the *V*/*A* (ml/cm^2) of either the component or the subassembly or the system it is part of. In this case, $(N/\text{cm}^2) = (N/\text{ml}) \times (V/A)$.

Annex E
(informative)

Relating the cleanliness of parts to the cleanliness of components

E.1 Introduction

Clauses 6 and 7 of this Technical Report explain how to relate the cleanliness level of several components to that of a complete system, in the bottom-up way to make theoretical prediction and in the top-down way to specify individual requirements based on a global one.

All consideration referred to in Clauses 6 and 7 can be extended from components to parts, so as to cover the whole need of industry.

This annex explains how to move from a component to all the parts it is made of and vice versa. Since some parts do not have any wetted volume but only a wetted surface (e.g. gears and plates of the pump), a simple relationship is proposed to shift from the wetted volume of a component to its wetted surface area.

E.2 Basic considerations

Table E.1 covers data relating to parts.

Table E.1 — Symbols and units

Symbol	Description or explanation	Unit
N_P	Number of particles of a given size in and/or on a part	number of particles
N_{Pi}	Number of particles of a given size in and/or on part *i*	number of particles
A_P	Wetted surface area of a part	cm^2
A_{PT}	Total surface area of a part	cm^2
V_P	Wetted volume of a part	cm^3 or ml
C_P	Cleanliness level of a part – N_P / V_P	number of particles per cm^3 or ml

E.3 Prediction of cleanliness of a component (bottom-up approach)

E.3.1 General

The contamination of a component is the sum of the particles brought in by each part that makes up the component.

E.3.2 Determination of cleanliness level of parts

E.3.2.1 General

The cleanliness level of parts to be assembled to make a component, C_P, can be either measured or calculated and can be expressed as a number of particles per part (N_P).

E.3.2.2 Measurement

Measurement is the preferred method of determining the cleanliness level of a part. The number of particles (N_P) of a given size range contaminating the parts to be assembled can be measured using an appropriate and validated extraction method. See ISO 18413 for practical details.

If the extraction has been performed on the whole surface area (A_{PT}) of the part, the number of particles (N_P) on the wetted surface area (A_P) can be calculated using Formula (E.1):

$$N_P = N_P{'} \times \frac{A_P}{A_{PT}} \tag{E.1}$$

E.3.2.3 Calculation

If the parts are supplied with their cleanliness level (C_P in N/ml or N/cm^2) and if the relevant geometrical characteristic [wetted volume (V_P) or wetted surface area (A_P)] is known, the number (N_P) of particles they brought in the components can be calculated using either Formula (E.2) or Formula (E.3).

$$N_P = C_P \times V_P \tag{E.2}$$

$$N_P = C_P \times A_P \tag{E.3}$$

E.3.3 Prediction

E.3.3.1 The cleanliness level of a component can be measured in accordance with 6.2.2.

E.3.3.2 The cleanliness level of a component (C_C) can also be predicted (calculated) from the cleanliness level of each part it is made of. Each part (Pi) brings in the component N_{Pi} particles. The number of particles in the component made of n parts is calculated using Formula (E.4):

$$N_C = \sum_{i=i}^{n} N_{Pi} \tag{E.4}$$

E.3.3.3 If the wetted volume of the component is V_C, then its cleanliness level, C_C, in N/ml is calculated using Formula (E.5):

$$C_C = \frac{N_C}{V_C} = \frac{\left(\sum N_{Pi}\right)}{V_C} \tag{E.5}$$

E.4 Specification of cleanliness requirements for parts from cleanliness requirement for the component they are assembled to make

E.4.1 Hollow parts

When parts making a component have their own wetted volume, cleanliness requirements on them are expressed in N/ml at the same level as the one specified for the component.

E.4.2 Solid parts

E.4.2.1 To apply a required cleanliness level expressed in N/ml to a solid part (that is, one without a wetted volume), it is necessary to know the geometrical parameter V_C / A_C (or G') of the component it is part of.

E.4.2.2 To transform a required volume cleanliness level in N/ml into a required surface cleanliness level in N/cm^2, multiply the required volume cleanliness level by V_C / A_C (or G').

E.4.2.3 If the V_C / A_C ratio of the component is not known, the wetted surface area of all pieces (A_{Pi}) that make up the component ($A_C = \Sigma A_{Pi}$) has to be known. In this case, calculate the total number of particles in the component N_C by multiplying C_C (in N/ml) by V_C (in ml), and divide N_C by the wetted surface area of the component $C_C = N_C / A_C$ (in N/cm^2). Then assuming an identical surface density of contaminants, require the same level on the part $C_P = N_P / A_P = C_C = N_C / A_C$ in N/cm^2. See Figure E.1.

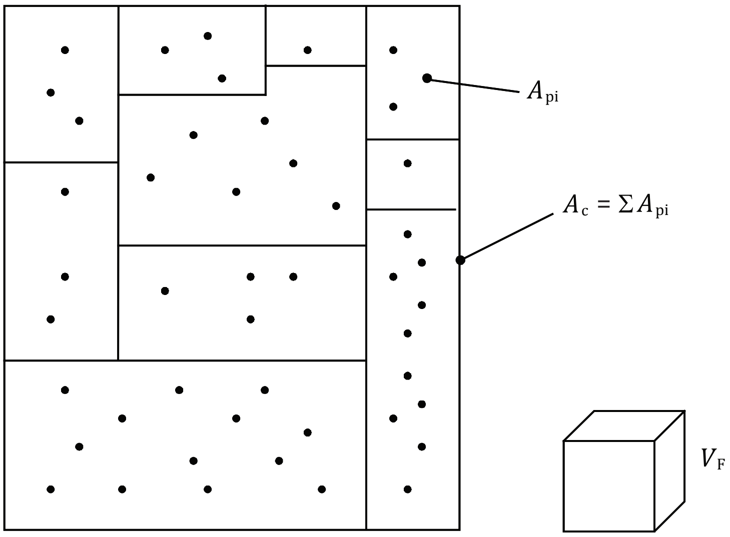


Figure E.1 — Relation between surface contamination and wetting fluid volume

E.4.2.4 In the absence of component geometry data (i.e. no V_C / A_C values are available), the geometry factor of the system V_S / A_S can be used. If the actual ratio V_S / A_S is not known, the G factor [i.e. the ratio of the volume of fluid filling the system in normal operation (V_f) to its wetted surface area (A_S)] can be used. Then a required cleanliness level expressed as the number of particles per unit volume (N/ml), such as an ISO 4406 code level, can be transformed into a required cleanliness level expressed as a number of particles per unit surface area (N/cm^2) by multiplying it by the G factor, as illustrated in Formula (E.6):

$$C_P = (C_{SF} - 1) \times G \quad \text{(E.6)}$$

where

C_P is the required cleanliness level of the part, expressed in N/cm^2;

C_{SF} is the required cleanliness level of the system upon its release from the manufacturing area expressed in accordance with ISO 4406;

G is the ratio of V_F/A_S.

E.4.2.5 It is important to take care in interpreting data because, as shown in 5.2.2.3, a system is generally much simpler than some components. Its V/A ratio can be much higher than that of complex and sensitive components (e.g. pumps or valves). This is illustrated by actual values reported in Table B.1 in Annex B.

Bibliography

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

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

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

[4] ISO 18413, *Hydraulic fluid power — Cleanliness of parts and components — Inspection document and principles related to contaminant collection, analysis and data reporting*

ICS 23.100.01

Price based on 24 pages