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

Transmissions hydrauliques — Méthode de détermination du niveau de propreté requis (NPR) d'un système

Reference number
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Foreword

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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).

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

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

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

Introduction

In hydraulic fluid power systems, power is transmitted through a liquid under pressure within a closed circuit. The liquid is both a lubricant and power-transmitting medium. The presence of solid particulate contamination interferes with the ability of the hydraulic liquid to lubricate and causes wear to the components. The extent of this form of contamination has a direct bearing on the performance and reliability of the system and needs to be controlled to levels that are considered appropriate for the system concerned. This level is called the required cleanliness level (RCL) and the level for an individual system depends upon the contaminant sensitivity of the system and the level of reliability required by the user. It therefore varies from application to application and within common system types.

In the past, the selection of the RCL was arbitrary and based on either the system designer's past experience or on third-party recommendations that were based upon their experience. Rarely did the selection reflect current fluid cleanliness requirements. Furthermore, as the selection was subjective, there was not any consistency in the RCL recommended by the various parties involved in the selection. The end result was that the user of the RCL would be confused and select an incorrect RCL. This fact was recognised by the British Fluid Power Association (BFPA) in 1999[1], and it developed a method for selecting an RCL which was based upon the requirements of an individual system and user (see the Bibliography). The rationale behind the development of this method is given in Annex A. This has since been adopted as Norwegian national standard NS 2085[2].

The emphasis on fluid cleanliness has made the RCL an important parameter in the management of cleanliness in hydraulic systems. The RCL sets the standard for cleanliness throughout the manufacturing process, through the assembly and commissioning stages, and in service. It also is instrumental in ensuring that the correct filtration level is achieved in the operating system. The RCL calculated by this method is used in ISO/TR 15640[3] to assist in the selection of filters.

This document has been developed to provide a uniform and consistent procedure for selecting the RCL for a particular system. It takes the user of this procedure through a series of conditions that best describe the system for which the RCL is required and the RCL is selected on this basis.

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

1 Scope

This document specifies a method of determining the required cleanliness level of a hydraulic system, that is, the most appropriate fluid cleanliness level for an operating hydraulic system based upon the individual requirements of that system.

It is applicable to systems where the level of fluid cleanliness is expressed in accordance with ISO 4406, although conversion to other contamination coding systems is possible.

It is applicable to both high and low pressure fluid power systems and also lubrication systems.

It does not include the effects of soft deformable particles that can be generated by thermal decomposition of the hydraulic fluid.

2 Normative references

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

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

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

3 Terms and definitions

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

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

- ISO Online browsing platform: available at www.iso.org/obp
- IEC Electropedia: available at www.electropedia.org

3.1
contamination code
set of numbers used as a shorthand method for describing the particle size distribution of contaminants in hydraulic fluid

[SOURCE: ISO 5598:2008, 3.2.129]

Note 1 to entry: ISO 4406 contamination codes are used throughout this document.

3.2
contaminant sensitivity
extent to which a component is adversely affected by the presence of particulate contamination

3.3
duty cycle
characteristic of a hydraulic system which defines the operational pressure level and the rate of change in pressure

3.4
field contamination monitor
instrument that automatically evaluates the general level of fluid cleanliness, usually by either the filter blockage technique or the light blockage technique

3.5
off-line contamination analysis
analysis of a fluid sample by an instrument that is not directly connected to the hydraulic system

[SOURCE: ISO 5598:2008, 3.1.128]

3.6
on-line contamination analysis
analysis performed on fluid supplied directly to the instrument from a major flow line in the hydraulic system

[SOURCE: ISO 5598:2008, 3.2.480]

Note 1 to entry: The instrument can either be permanently connected to the flow line or connected prior to analysis.

3.7
particle size
characteristic dimension of a particle, that defines the magnitude of the particle in terms of a physically measurable dimension related to the analysis technique used, such as the longest dimension or the equivalent spherical diameter

3.8
qualitative data
data that have less precision or accuracy than data obtained using quantitative methods and which is usually expressed in codes rather than actual numbers

3.9
required cleanliness level
RCL
hydraulic fluid cleanliness level required for a system or process

Note 1 to entry: For the purposes of this document, this is expressed in accordance with ISO 4406.

3.10
working pressure range
range of pressures between the limits within which a system or sub-system is intended to operate in steady-state operating conditions

[SOURCE: ISO 5598:2008, 3.2.780]

4 Principle of the method

The user of this document systematically examines six operational characteristics or requirements and selects the condition that best describes that system or the user's requirements. A weighting is assigned to each selected condition, and this is summated into a system weighting. This system weighting is then used to select the RCL. The chart linking the RCL with the system weighting has been developed from practical examples and is given in Figure 1.

NOTE In practice, the RCL is initially obtained by the system flushing process, and then maintained by the system filtration.

5 Selection of the RCL

5.1 General

Each of the six operational parameters defined in 5.3 to 5.8 are subdivided into different levels, and a relative weighting is given to reflect their impact on either the particle generation rate of the component or the effect that the particulate can have on it. To assist the user of this document, the various categories are illustrated with practical examples. The impact of the parameter is also explained.

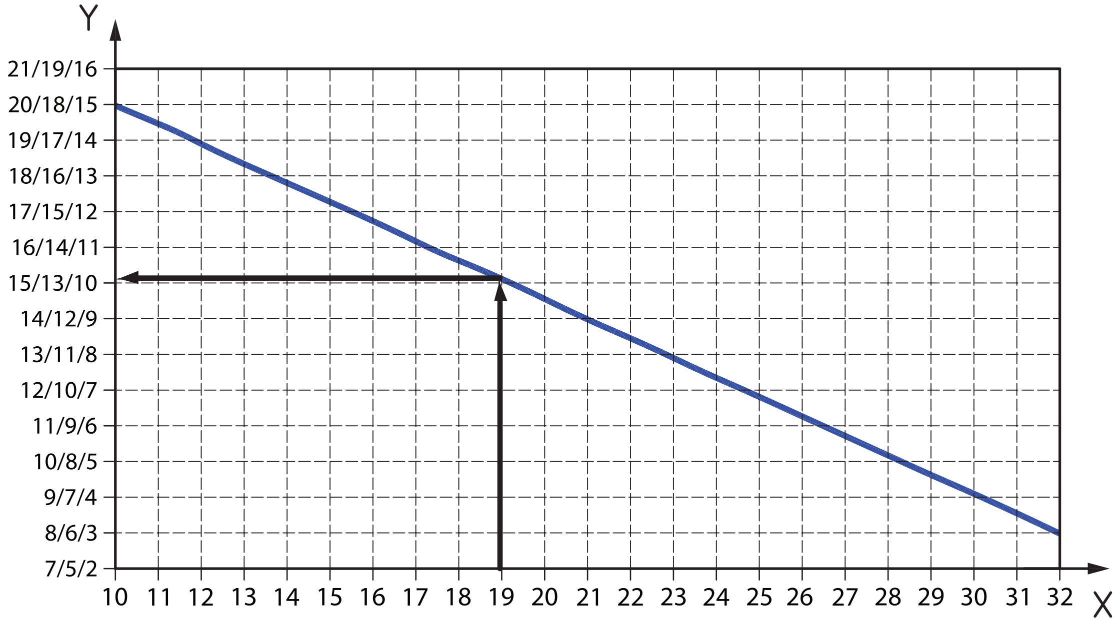
5.2 Procedure

a) Start at 5.3, and select from Table 1 the operational conditions that best describe the system whose RCL is being determined. Record that weighting on a suitable pro forma sheet; an example is given in Annex B.

b) Repeat the process stated in 5.2 a) for 5.4 through to 5.8, and sum all weightings recorded. If the sum of all weightings is <10, use as the corresponding weighting 10. If the sum of all weightings is >32, use 32 as the corresponding weighting.

c) Use Figure 1 to locate the corresponding weighting on the x-axis and draw a vertical line upwards to intersect the grade line.

d) Draw a horizontal line leftwards to intersect an ISO 4406 code on the y-axis; this code is the RCL. A worked example is given in Annex C.



Key

X total weighting

Y maximum ISO 4406 code

Figure 1 — Relationship of total weighting and ISO 4406 codes used to derive the required cleanliness level (RCL)

The ISO 4406 codes stated assume a fixed particle size distribution which might or might not be duplicated in service. For example:

— at the cleaner levels/lower scale numbers [less than ISO 4406 scale number 10 at 6 µm(c)], the difference in scale numbers between both 4 µm(c) and 6 µm(c) and also 6 µm(c) and 14 µm(c) can be greater than stated as the numbers of particles at the higher sizes approach zero.

— at the dirtier levels/higher scale numbers [greater than ISO 4406 scale number 17 at 6 µm(c)], the difference in scale numbers between 4 µm(c) and 6 µm(c) can be 3 or more ISO 4406 scale numbers due to limited capture of smaller particles by the system filters.

In all cases, the ISO scale number at 6 µm(c) shall be taken as the reference.

The grade line has been drawn using data obtained from the on-line analysis of systems as this method of analysis excludes environmental contamination introduced when the sample is collected in sample bottles for off-line analysis (see Annex D). As the use of sample bottles and subsequent off- line analysis can introduce relatively large amounts of particulate contamination, this process is considered unsuitable for cleanliness levels better than ISO 4406 Code 14/12/9.

5.3 Weightings for working pressure and duty cycle

The normal working pressure and duty cycle, which reflects the severity of change, both in magnitude and frequency of the pressure experienced in the system, shall be taken into account in accordance with the weighting specified in Table 1.

Table 1 — Weightings for working pressure and duty cycle

Duty cycle		**Working pressure**				
Level	**Description**	**≤ 6 MPa (≤ 60 bar)**	**> 6 MPa (> 60 bar)** **≤ 16 MPa (≤ 160 bar)**	**> 16 MPa (> 160 bar)** **≤ 25 MPa (≤ 250 bar)**	**> 25 MPa (> 250 bar)** **≤ 40 MPa (≤ 400 bar)**	**> 40 MPa (> 400 bar)**
Light	Continuous duty with little variation in working pressure	1	1	2	3	4
Medium	Moderate variations in working pressure	2	3	4	5	6
Heavy	Large variations in working pressure from zero to maximum	3	4	5	6	7
Severe	Large variations in working pressure from zero to maximum, with high frequency pressure transients (for example, pressure traces seen in power presses and punching machines)	4	5	6	7	8

5.4 Weightings for component contaminant sensitivity

The sensitivity of components to solid particulate contaminant shall be taken into account in accordance with the weighting specified in Table 2.

Table 2 — Weightings for component contaminant sensitivity

Sensitivity level	Example components	Weighting
Minimal	Ram pumps	1
Below average	Low performance gear pumps, manual valves, poppet valves	2
Average	Vane pumps, electro-hydraulic spool valves, high performance gear pumps	3
Above average	Piston pumps, proportional control valves	4
High	Servo-valves in industrial applications, high pressure proportional control valves	6
Very high	High performance servo-valves	8

5.5 Weightings for system life expectancy

The expected life of the system shall be taken into account in accordance with the weighting specified in Table 3.

Table 3 — Weightings for system life expectancy

System life expectancy (h)		Weighting
≥ 0	≤ 1 000	0
> 1 000	≤ 5 000	1
> 5 000	≤ 10 000	2
> 10 000	≤ 20 000	3
> 20 000	≤ 40 000	4
> 40 000	—	5

5.6 Weightings for total cost of component replacement

The total cost of component replacement shall be taken into account in accordance with the weighting specified in Table 4.

Table 4 — Weightings for total cost of component replacement

Total cost of component replacement	Examples	Weighting
Low	Manifold-mounted valves, inexpensive pumps	1
Average	Line-mounted and modular valves	2
High	Cylinders, proportional control valves	3
Very high	Large piston pumps; large high-torque, low-speed motors, high performance servo components	4

5.7 Weightings for cost of downtime

The cost of downtime shall be taken into account in accordance with the weighting specified in Table 5.

Table 5 — Weightings for cost of downtime

Cost of downtime	Examples	Weighting
Low	Equipment that is not critical to production or operation	1
Average	Equipment in plant with small to medium volume production	2
High	Equipment in plant with high volume production	3
Very high	Equipment with very high downtime costs, e.g. certain steel mill equipment	4

5.8 Weightings for risk

Hydraulic systems should be designed with safety in mind, and the presence of particulate contamination in a system can interfere with the operation and function of components; this can affect the risk of additional hazards. It shall be appreciated that cleaner levels of fluids alone do not necessarily provide the required safety.

Risk levels shall be taken into account in accordance with the weighting specified in Table 6.

Table 6 — Weightings for risk

Risk level	Description	Weighting
Low	Where failure is unlikely to cause a hazard	1
Average	Where failure is likely to cause a hazard	3
High	Where failure is likely cause significant hazard (for example, mine-winding gear braking systems, leisure rides)	6

6 Identification statement (reference to this document)

Use the following statement in test reports, catalogues and sales literature when electing to comply with the requirements of this document:

“Required cleanliness level (RCL) of a system selected in accordance with ISO 12669, Hydraulic fluid power — Method for determining the required cleanliness level (RCL) of a system.”

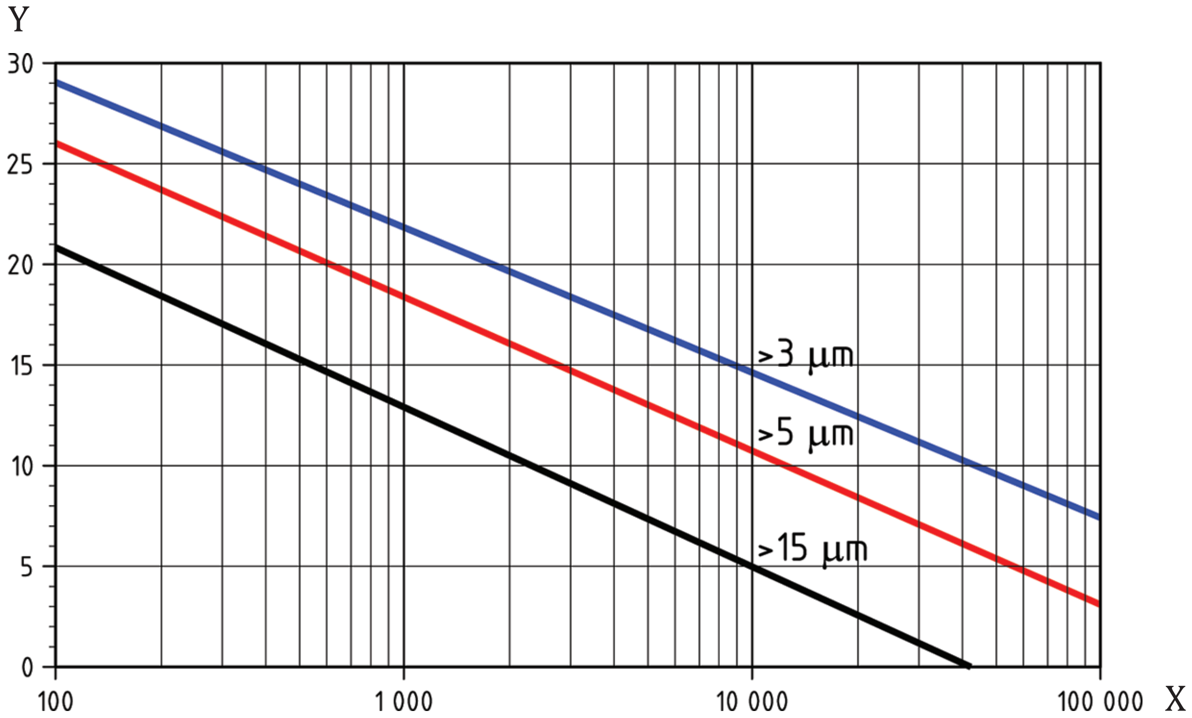
Annex A
(informative)

Options for selecting the RCL for a hydraulic system

A.1 General

The adverse effect that the presence of particulate contamination ("dirt") has on the performance and reliability of hydraulic systems has been recognised for a long time but it was not until 1984 that this relationship was quantified when the UK Department of Trade and Industry (DTI) published the results of a three-year research programme (see Reference [4]). This relationship is seen in Figure A.1 where the trend lines linking the ISO 4406 codes at 3 µm, 5 µm and 15 µm to the mean time between failures are plotted.

NOTE The data represented in Figure A.1 were obtained using an automatic particle counter calibrated to the now obsolete ISO 4402. The 5 µm size is similar to 6 µm(c), and the 15 µm size is similar to 14 µm(c).



Key

X mean time between failures (hours)

Y ISO 4406 code

Source: UK Department of Trade and Industry (DTI)

Figure A.1 — Relationship between ISO 4406 codes and reliability

This study showed that the level of dirt in the hydraulic fluid was the most important factor governing the reliability to the hydraulic system. Today, this factor is accepted and users and designers alike are setting maximum levels of contamination in order to improve reliability. There are five options, described in A.2 to A.6, available to the designer or user for deciding the most appropriate fluid cleanliness level for the system.

A.2 Option 1 — Component manufacturers' recommendations

In this option, the manufacturers of the components are contacted for their recommendations, but because each component has a different sensitivity to contaminant, different RCL are suggested and results can be confusing. Furthermore, the perception of what is "reliable" varies from person to person as well as between manufacturers, so further differences in RCL are likely. It is more usual to select the most sensitive component in the system and contact this manufacturer for his recommendations and this should reduce the range of RCL recommended. Even with this approach there is no guarantee that the most appropriate RCL is selected, because the recommendations for a specific system type could be based upon historical experience and might not account for today's needs.

All component manufacturers know the proportionate effect that increased dirt level has on the performance of their components and issue maximum permissible contamination levels. They state that operating components on fluids which are cleaner than those stated increases component life. However, the diversity of hydraulic systems in terms of pressure, duty cycles, environments, lubrication required, contaminant types, etc., makes it almost impossible to predict the components service life over and above that which can be reasonably expected. Furthermore, without the benefits of significant research material and the existence of standard contaminant sensitivity tests, manufacturers who publish recommendations that are cleaner than competitors' recommendations might be viewed as having a more contaminant sensitive product.

A.3 Option 2 — Experience of system designer or others

Here, the RCL is selected based on the designer's experience with similar equipment or with guidance from other operators of similar equipment; in most cases, this information is supplied by a filter manufacturer who has access to such information for bench marking. Again the problem with this approach is that the information is probably out of date because it relates to an earlier design which might be more tolerant to contaminant than the later model, where improved performance and reliability is required. The filter manufacturer should be best placed to give more up-to-date information on RCL because they should keep up with developments within the industry, but again the most suitable RCL is likely to vary amongst filter manufacturers.

A.4 Option 3 — Independent recommendations

These include Trade Associations and research studies and again this data is historic. There has been little research into the effect of dirt on reliability since the UK's DTI study in 1984 and hence little new data for learned bodies to use for the basis of recommendations.

A.5 Option 4 — Laboratory component contaminant sensitivity testing

This concept was originally developed in the 1970's at the Fluid Power Research Centre of Oklahoma State University and it linked the life of the component under test, with both the levels of contamination and filtration, It gained favour at a time when companies were striving to produce contaminant tolerant components and systems, but laboratory contaminant sensitivity testing of components proved to be costly and the data obtained using an artificial and abrasive contaminant was questioned. After the publication of the UK's DTI Survey report, the emphasis changed to improving the design and management of systems to remove contamination and maintain cleanliness as this was more cost effective. As a result, development of a standard contaminant sensitivity test for components ceased in the mid-1980s and there is little public information available.

A.6 Option 5 — Comprehensive method in ISO 12669

The BFPA TC6 committee analysed the above methods in 1998 and concluded that there was likely to be a considerable amount of variation in the RCL given by these methods for identical systems and requirements. Furthermore, as the majority were based upon historic data, it was likely that the resulting RCL would not satisfy the requirements of modern systems and current expectations of reliability. BFPA decided to develop a method that would provide a more consistent and detailed approach to calculating the RCL which would take into account not only operational aspects like pressure, duty cycle, relative sensitivity to contaminant but also economic factors like the life and reliability required by the user and the costs of breakdown of breakdown, in terms of both replacement costs and the cost to the operator. The method was incorporated into the BFPA P5 guidelines published in 1999[5] and forms the basis of this document. Norwegian standard NS 20184[6] was also developed from BFPA P5.

Annex B
(informative)

Example of a pro forma worksheet

Weightings for working pressure and duty cycle							
Duty cycle		**Working pressure**					**Actual**
Duty cycle	**Examples**	**≤ 6 MPa (≤ 60 bar)**	**> 6 MPa (> 60 bar) ≤ 16 MPa (≤ 160 bar)**	**> 16 MPa (> 160 bar) ≤ 25 MPa (≤ 250 bar)**	**> 25 MPa (> 250 bar) ≤ 40 MPa (≤ 400 bar)**	**> 40 MPa (> 400 bar)**	
Light	Continuous duty	1	1	2	3	4	**4**
Medium	Moderate variations in working pressure	2	3	**4**	5	6	
Heavy	Variations from zero to maximum working pressure	3	4	5	6	7	
Severe	Zero to maximum working pressure with high frequency transients	4	5	6	7	8	

Weightings for component contaminant sensitivity			
Sensitivity	**Examples**	**Weighting**	**Actual**
Minimal	Ram pumps	1	**3**
Below average	Low performance gear pumps, manual valves, poppet valves	2	
Average	Vane pumps, electro-hydraulic spool valves, high performance gear pumps	3	
Above average	Piston pumps, proportional control valves	4	
High	Servo-valves in industrial applications, high	6	
Very high	High performance servo-valves	8	

Weightings for system life expectancy			
System life expectancy (h)		**Weighting**	**Actual**
	≤ 1 000	0	**2**
> 1 000	≤ 5 000	1	
> 5 000	≤ 10 000	2	
> 10 000	≤ 20 000	3	
> 20 000	≤ 40 000	4	
> 40 000		5	

Weightings for total cost of component replacement			
Replacement cost	**Examples**	**Weighting**	**Actual**
Low	Manifold mounted valves, inexpensive pumps	1	**3**
Average	Line mounted valves, modular valves	2	
High	Cylinders, proportional valves	3	
Very high	Large piston pumps, large high-torque low-speed motors, high performance servo components	4	

Weightings for cost of downtime			
Cost of downtime	**Examples**	**Weighting**	**Actual**
Low	Equipment that is not critical to production or operation	1	**1**
Average	Equipment in plant with small to medium volume production	2	
High	Equipment in plant with high volume production	3	
Very high	Equipment with very high downtime costs (for example, certain steel mill equipment)	4	

Weightings for risk levels			
Cost of downtime	**Examples**	**Weighting**	**Actual**
Low	Failure unlikely to cause hazard	1	**1**
Average	Failure can cause hazard	3	
High	Failure can cause injury	6	

Total weighting	
Sum of actual weightings	**14**

Annex C
(informative)

Worked example of the determination of the RCL for a hydraulic system

Consider a large hydraulic excavator operating within a quarry. The hydraulic system includes pressure compensated piston pumps and very large cylinders.

Table C.1 — Worked example showing how to determine the RCL

Parameter	Examples	Weighting
Working pressure and duty cycle	System operates at 25 MPa with extreme fluctuations in both flow rate and pressure in a cycle that is repeated approximately four times per minutes. Duty is considered heavy.	5
Contaminant sensitivity	Although a majority of components are considered to be of average commercial quality the pumps are of above average sensitivity.	4
Life expectancy	Annual usage is approximately 2 000 h and component life is expected to be about 4 years; therefore life expectancy is 8 000 h	2
Total cost of component replacement	Lift cylinders and variable piston pumps are quite expensive for the end user to purchase. Component costs are high.	3
Cost of downtime	Liabilities vary depending upon the specific quarry situation. High capital cost of system puts it into the high category	4
Risk	No additional weighting for safety is required	1
	Total to be used to determine RCL	**19**

Referring to Figure 1, a weighting of 19 gives an RCL of 15/13/10 in accordance with ISO 4406.

Annex D
(informative)

Effect of extraneous contamination on cleanliness data

Off-line sampling and analysis is the most frequently used method and a wide range of techniques are available for use. Off-line analysis involves extracting a representative liquid sample from the system, collecting it in either a sample bottle or suitable container, then analysing it in either an in-house or external laboratory.

As a result of these processes, errors and variability in data are introduced into the measured results, and appropriate procedures need to be adopted to limit the introduction of extraneous contamination into the sample.

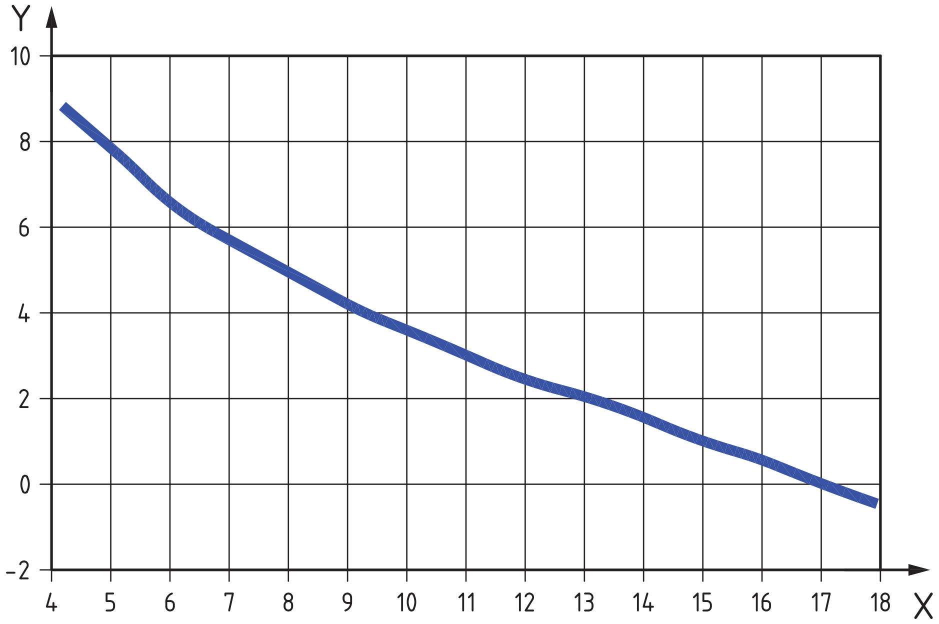
Contamination can be introduced into the sample from:

a) the sampling process;

b) the ambient environment (including the external surface of the pipe work);

c) the analysis process.

The interaction of environmental contamination on cleanliness data has been studied by numerous researchers, notably by Tampere University of Technology (TUT)[7]. This work involved the extraction of samples from 130 systems at the same time as the cleanliness level was being evaluated by on-line analysis using an automatic particle counter (APC). This data has been used to illustrate the likely errors resulting from the use of sample bottles[8] and this is shown in Figure D.1. The graph shows the error, i.e. the difference between the off-line and the on-line APC data as a function of the on-line data which are taken as the true result. The error is seen to increase as the oil gets cleaner, and it on this basis that the BFPA recommended using only on-line analysis for hydraulic fluids whose contamination level is cleaner than ISO 4406 Code 14/12/9.



Key

X	ISO 4406 code at 5 µm determined using on-line analysis
Y	difference in ISO 4406 code determined using off-line and on-line analysis

Source: Tampere University of Technology

Figure D.1 — Errors created by off-line analysis as a function of the on-line cleanliness level

Bibliography

[1] The British Fluid Power Association (BFPA).

[2] Norwegian national standard NS 2085

[3] ISO/TR 15640, *Hydraulic fluid power contamination control — General principles and guidelines for selection and application of hydraulic filters*

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