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# Hydraulic fluid power filters — Multi-pass method for evaluating filtration performance of a filter element

*Filtres pour transmissions hydrauliques — Évaluation des performances par la méthode de filtration en circuit fermé*

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## Foreword

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

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

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

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

International Standard ISO 16889 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 6, *Contamination control and hydraulic fluids*.

This first edition cancels and replaces ISO 4572:1981, of which it constitutes a technical revision.

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Annex A forms a normative part of this International Standard. Annexes B to D are for information only.

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## Introduction

In hydraulic fluid power systems, one of the functions of the hydraulic fluid is to separate and lubricate the moving parts of components. The presence of solid particulate contamination produces wear, resulting in loss of efficiency, reduced component life and subsequent unreliability.

A hydraulic filter is provided to control the number of particles circulating within the system to a level that is commensurate with the degree of sensitivity of the components to contaminant and the level of reliability required by the users.

To enable the relative performance of filters to be compared so that the most appropriate filter can be selected, test procedures should be available. The performance characteristics of a filter are a function of the element (its medium and geometry) and the housing (its general configuration and seal design).

In practice, a filter is subjected to a continuous flow of contaminant entrained in the hydraulic fluid until some specified terminal differential pressure (relief valve cracking pressure or differential pressure indicator setting) is reached.

Both the length of operating time (prior to reaching terminal pressure) and the contaminant level at any point in the system are functions of the rate of contaminant addition (ingression plus generation rates) and the performance characteristics of the filter.

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Therefore, a realistic laboratory test that establishes the relative performance of a filter should provide the test filter with a continuous supply of ingressed contaminant and allow the periodic monitoring of the filtration performance characteristics of the filter.

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The test should also provide an acceptable level of repeatability and reproducibility and a standard test contaminant [ISO medium test dust (ISO 12103-A3) in accordance with ISO 12103-1] is featured. This has been shown to have a consistent particle size distribution and is available worldwide. The filtration performance of the filter is determined by measurement of the upstream and downstream particle size distributions using automatic particle counters validated according to ISO standards.

Since it is difficult to specify, achieve and verify a cyclic flow requirement that is both realistic and consistent with the flow variations occurring in actual systems, the compromise of steady-state condition has been used for this test to enhance the repeatability and reproducibility of results.

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# Hydraulic fluid power filters — Multi-pass method for evaluating filtration performance of a filter element

## 1 Scope

**1.1** This International Standard specifies:

— a multi-pass filtration performance test with continuous contaminant injection for hydraulic fluid power filter elements;

— a procedure for determining the contaminant capacity, particulate removal and differential pressure characteristics;

— a test currently applicable to hydraulic fluid power filter elements that exhibit an average filtration ratio greater than or equal to 75 for particle sizes less than or equal to 25 µm(c), and a final reservoir gravimetric level of less than 200 mg/l;

NOTE The range of flows and the lower particle size limit that can be used in test facilities will be determined by validation.

— a test using ISO medium test dust contaminant and a test fluid according to annex A.

**1.2** This International Standard is intended to provide a test procedure that yields reproducible test data for appraising the filtration performance of a hydraulic fluid power filter element without influence of electrostatic charge.

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## 2 Normative references

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

ISO 1219-1:1991, *Fluid power systems and components — Graphic symbols and circuit diagrams — Part 1: Graphic symbols*.

ISO 2942:1994, *Hydraulic fluid power — Filter elements — Verification of fabrication integrity and determination of the first bubble point*.

ISO 3722:1976, *Hydraulic fluid power — Fluid sample containers — Qualifying and controlling cleaning methods*.

ISO 3968:1981, *Hydraulic fluid power — Filters — Evaluation of pressure drop versus flow characteristics*.

ISO 4021:1992, *Hydraulic fluid power — Particulate contamination analysis — Extraction of fluid samples from lines of an operating system*.

ISO 4405:1991, *Hydraulic fluid power —- Fluid contamination — Determination of particulate contamination by the gravimetric method*.

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ISO 5598:1985, *Fluid power systems and components — Vocabulary*.

ISO 11171:1999, *Hydraulic fluid power — Calibration of liquid automatic particle counters*.

ISO 11943:1999, *Hydraulic fluid power — On-line automatic particle-counting systems for liquids — Methods of calibration and validation*.

ISO 12103–1:1997, *Road vehicles — Test dust for filter evaluation — Part 1: Arizona test dust*.

ASTM D 4308-95, *Standard test method for electrical conductivity of liquid hydrocarbons by precision meter*.

## 3 Terms and definitions

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

**3.1**
**contaminant mass injected**
mass of specific particulate contaminant injected into the test circuit to obtain the terminal $\Delta p$

**3.2**
**differential pressure**
$\Delta p$
difference between the tested component inlet and outlet pressure as measured under the specified conditions

See Figure 1.

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**3.2.1**
**clean assembly differential pressure**
difference between the tested component inlet and outlet pressure as measured with a clean filter body containing a clean filter element

See Figure 1.

**3.2.2**
**clean element differential pressure**
differential pressure of the clean element calculated as the difference between the clean assembly $\Delta p$ and the housing

See Figure 1.

**3.2.3**
**final assembly differential pressure**
assembly differential pressure at end of test equal to sum of housing plus terminal element differential pressures

See Figure 1.

**3.2.4**
**housing differential pressure**
differential pressure of the filter body without an element

See Figure 1.


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**3.2.5**
**terminal element differential pressure**
maximum differential pressure across the filter element as designated by the manufacturer to limit useful performance

See Figure 1.

**3.3**
**rest conductivity**
electrical conductivity at the initial instant of current measurement after a d.c. voltage is impressed between electrodes

NOTE It is equal to the reciprocal of the resistance of uncharged fluid in the absence of ionic depletion or polarization.

**3.4**
**retained capacity**
mass of specific particulate contaminant effectively retained by the filter element when terminal element $\Delta p$ is reached

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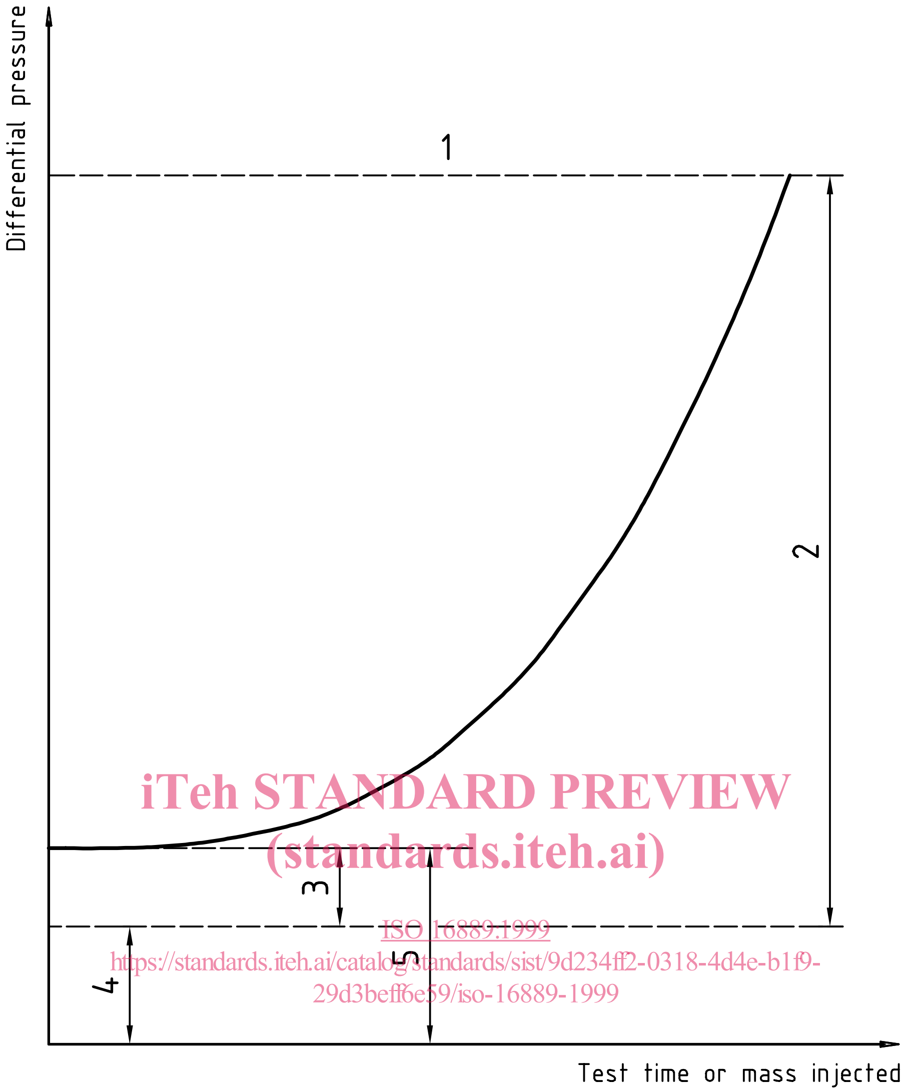


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**Key**

1 Final assembly (end of test) differential pressure
2 Terminal element differential pressure
3 Clean element differential pressure
4 Housing differential pressure
5 Clean assembly differential pressure

**Figure 1 — Differential pressure conventions for multi-pass test**

## 4 Symbols

### 4.1 Graphic symbols

Graphic symbols used are in accordance with ISO 1219-1.

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## 4.2 Quantity symbols

| Reference | Symbol | Units | Description or explanation |
|---|---|---|---|
| 4.2.1 | $\bar{A}_{\mathrm{u},x}$ | part/ml | Overall average upstream count > size $x$ |
| 4.2.2 | $\bar{A}_{\mathrm{d},x}$ | part/ml | Overall average downstream count > size $x$ |
| 4.2.3 [a] | $\beta_{x(\mathrm{c})}$ | None | Filtration ratio at particle size $x$ (ISO 11171 calibration) |
| 4.2.4 | $\beta_{x,t}$ | None | Filtration ratio at particle size $x$ and time interval $t$ |
| 4.2.5 [a] | $\bar{\beta}_{x(\mathrm{c})}$ | None | Average filtration ratio at particle size $x$ (ISO 11171 calibration) |
| 4.2.6 | $C_{\mathrm{R}}$ | g | Retained capacity |
| 4.2.7 | $G_{\mathrm{b}}$ | mg/l | Average base upstream gravimetric level |
| 4.2.8 | $G_{\mathrm{b}}'$ | mg/l | Desired base upstream gravimetric level |
| 4.2.9 | $G_{\mathrm{i}}$ | mg/l | Average injection gravimetric level |
| 4.2.10 | $G_{\mathrm{i}}'$ | mg/l | Desired injection gravimetric level |
| 4.2.11 | $G_{80}$ | mg/l | Test reservoir gravimetric level at 80 % assembly $\Delta p$ |
| 4.2.12 | $M$ | g | Mass of contaminant needed for injection |
| 4.2.13 | $M_{\mathrm{e}}$ | g | Estimated filter element capacity (mass injected) |
| 4.2.14 | $M_{\mathrm{I}}$ | g | Contaminant mass injected |
| 4.2.15 | $M_{p}$ | g | Contaminant mass injected at element differential pressure $\Delta p$ |
| 4.2.16 | $n$ | none | Number of counts in specific time period |
| 4.2.17 | $N_{\mathrm{u},x,i}$ | part/ml | Number of upstream particles > size $x$ at count $i$ |
| 4.2.18 | $N_{\mathrm{d},x,i}$ | part/ml | Number of downstream particles > size $x$ at count $i$ |
| 4.2.19 | $\bar{N}_{\mathrm{u},x,t}$ | part/ml | Average upstream count > size $x$ at time interval $t$ |
| 4.2.20 | $\bar{N}_{\mathrm{d},x,t}$ | part/ml | Average downstream count > size $x$ at time interval $t$ |
| 4.2.21 | $p$ | Pa, kPa or bar | Pressure |
| 4.2.22 | $\Delta p$ | Pa, kPa or bar | Differential pressure |
| 4.2.23 | $q$ | l/min | Test flow rate |
| 4.2.24 | $q_{\mathrm{d}}$ | l/min | Discarded downstream sample flow rate |
| 4.2.25 | $q_{\mathrm{i}}$ | l/min | Average injection flow rate |
| 4.2.26 | $q_{\mathrm{i}}'$ | l/min | Desired injection flow rate |
| 4.2.27 | $q_{\mathrm{u}}$ | l/min | Discarded upstream sample flow rate |
| 4.2.28 | $t$ | min | Test time |
| 4.2.29 | $t'$ | min | Predicted test time |
| 4.2.30 | $t_{\mathrm{f}}$ | min | Final test time |
| 4.2.31 | $t_{p}$ | min | Test time at element differential pressure $\Delta p$ |
| 4.2.32 | $V_{\mathrm{if}}$ | l | Final measured injection system volume |
| 4.2.33 | $V_{\mathrm{ii}}$ | l | Initial measured injection system volume |
| 4.2.34 | $V_{\mathrm{min}}$ | l | Minimum required operating injection system volume |
| 4.2.35 | $V_{\mathrm{tf}}$ | l | Final measured filter test system volume |
| 4.2.36 | $V_{\mathrm{v}}$ | l | Minimum validated injection system volume |

[a] The subscript (c) signifies that the filtration ratio, $\beta_{x(\mathrm{c})}$, and the average filtration ratio, $\bar{\beta}_{x(\mathrm{c})}$, are based on this standard test method (ISO 16889) using particle counters calibrated in accordance with ISO 11171.

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## 5 General procedure

**5.1** Set up and maintain apparatus in accordance with clause 6 and clause 7.

**5.2** Validate equipment in accordance with clause 8.

**5.3** Run all tests in accordance with clauses 9, 10 and 11.

**5.4** Analyse test data in accordance with clause 12.

**5.5** Present data from clauses 10, 11 and 12 in accordance with clause 13.

## 6 Test equipment

**6.1 Suitable timer.**

**6.2 Automatic particle counter(s**), calibrated in accordance with ISO 11171.

**6.3 ISO medium test dust (ISO 12103-A3),** in accordance with ISO 12103-1, dried at 110 °C to 150 °C for not less than 1 h for quantities less than 200 g and for use in the test system, mix in the test fluid, mechanically agitate, then disperse ultrasonically with a power density of 3 000 W/m$^2$ to 10 000 W/m$^2$.

NOTE This dust is commercially available. For availability of ISO 12103-A3 test dust, contact the ISO secretariat service or national members of ISO.

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**6.4 Online counting system**, and **dilution system** if necessary, that has been validated in accordance with ISO 11943.

**6.5 Sample bottles** containing less than 20 particles per millilitre of bottle volume greater than 6 µm(c), as qualified in accordance with ISO 3722 to collect samples for gravimetric analyses.

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**6.6 Petroleum base test fluid** in accordance with annex A.

NOTE 1 The use of this carefully controlled hydraulic fluid assures greater reproducibility of results and is based upon current practices, other accepted filter standards and its world-wide availability.

NOTE 2 If an anti-static agent is added to this test fluid it may affect the test results.

**6.7 Filter performance test circuit** comprised of a "filter test system" and a "contaminant injection system".

**6.7.1 Filter test system** consisting of:

a) a reservoir, pump, fluid conditioning apparatus and instrumentation that are capable of accommodating the range of flows, pressures and volumes required by the procedure and is capable of meeting the validation requirements of clause 8;

b) a clean-up filter capable of providing an initial system contamination level as specified in Table 2;

c) a configuration that is relatively insensitive to the intended operative contaminant level;

d) a configuration that will not alter the test contaminant distribution over the anticipated test duration;

e) pressure taps in accordance with ISO 3968;

f) fluid sampling sections upstream and downstream of the test filter in accordance with ISO 4021.

NOTE For typical configurations that have proved to be satisfactory refer to annex B.

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**6.7.2 Contaminant injection system** consisting of:

a) a reservoir, pump, fluid conditioning apparatus and instrumentation that are capable of accommodating the range of flows, pressures and volumes required by the procedure and is capable of meeting the validation requirements of clause 8;

b) a configuration that is relatively insensitive to the intended operative contaminant level;

c) a configuration that will not alter the test contaminant distribution over the anticipated test duration;

d) a fluid sampling section in accordance with ISO 4021.

NOTE For typical configurations that have proven to be satisfactory, refer to annex B.

**6.8 Membranes and associated laboratory equipment** suitable for conducting the gravimetric method in accordance with ISO 4405.

## 7 Accuracy of measurements and test conditions

**7.1** Utilize and maintain instrument accuracy and test conditions within the limits given in Table 1.

**7.2** Maintain specific test parameters within the limits given in Table 2 depending on the test condition being conducted.

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**Table 1 — Instrument accuracy and test condition variation**

| Test parameter | SI Unit | Instrument accuracy (±) of reading | Allowed test condition variation (±) |
|---|---|---|---|
| Conductivity | pS/m | 10 % | — |
| Differential pressure | PA, kPa or bar | 5 % | — |
| Base upstream gravimetric | mg/l | — | 10 % |
| Flow: | | | |
| Injection flow | ml/min | 2 % | 5 % |
| Test flow | l/min | 2 % | 5 % |
| APC sensor flow | l/min | 1,5 % | 3 % [a] |
| Kinematic viscosity [b] | $mm^2/s$ | 2 % | 1 $mm^2/s$ |
| Mass | g | 0,1 mg | — |
| Temperature | °C | 1 °C | 2 °C [c] |
| Time | s | 1 s | — |
| Volume: | | | |
| Injection system | l | 2 % | — |
| Filter test system | l | 2 % | 5 % |

a Sensor flow variation to be included in the overall 10 % allowed between sensors.

b 1 $mm^2/s$ = 1 cSt (centistoke).

c Or as required to guarantee the viscosity tolerance.

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**Table 2 — Test condition values**

| Filter test condition | Condition 1 | Condition 2 | Condition 3 |
|---|---|---|---|
| Initial contamination level for filter test systems: | Less than 1 % of the minimum level specified in Table 3 measured at the minimum particle size to be counted. | | |
| Initial contamination level for injection system: | Less than 1 % of injection gravimetric level. | | |
| Base upstream gravimetric level, mg/l [a] | 3 ± 0,3 | 10 ± 1,0 | 15 ± 1,5 |
| Recommended particle counting sizes [b] | Minimum of five sizes selected to cover the presumed filter performance range from $\beta$ = 2 to $\beta$ = 1 000. Typical sizes are: (4, 5, 6, 7, 8, 10, 12, 14, 20, 25, 30) µm(c). | | |
| Sampling and counting method | Online automatic particle counting | | |

[a] When comparing test results between two filters, the base upstream gravimetric level should be the same.

[b] Particle sizes where betas are low ($\beta$ = 2, 10...) may be unobtainable for fine filters and particle sizes where betas are high ($\beta$ = ..., 200, 1 000) may be unobtainable for coarser filters.

## 8 Filter performance test circuit validation procedures

NOTE These validation procedures reveal the effectiveness of the filter performance test circuit to maintain contaminant entrainment and/or prevent contaminant size modification.

### 8.1 Validation of filter test system

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**8.1.1** Validate at the minimum flow at which the filter test system will be operated. Install a conduit in place of filter housing during validation.

**8.1.2** Adjust the total fluid volume of the filter test system (exclusive of the clean-up filter circuit) such that it is numerically within the range of one-fourth (25 %) to one-half (50 %) of the minimum volume flow per minute value, with a minimum of 5 l.

NOTE 1 It is recommended that the system be validated with a fluid volume numerically equal to one-half (50 %) of the minimum test volume flow per minute value for flow rates less than or equal to 60 l/min, or one-fourth (25 %) of the minimum test volume flow per value for flow rates greater than 60 l/min.

NOTE 2 This is the volume to flow ratio required by the filter test procedure (see 10.3.4).

**8.1.3** Contaminate the system fluid for each test condition (1, 2, or 3) to be used to the base upstream gravimetric level as shown in Table 2 using ISO 12103-A3 test dust.

**8.1.4** Verify that the flow rate through each particle counting sensor is equal to the value used for the particle counter calibration within the limits of Table 1.

**8.1.5** Circulate the fluid in the test system for 1 h, conducting continuous online automatic particle counts from the upstream sampling section for a period of 60 min.

Sample flow from this section shall not be interrupted for the duration of the validation.

**8.1.6** Record cumulative online particle counts at equal time intervals not to exceed 1 min for the duration of the 60 min test at the particle sizes shown in Table 2.

**8.1.7** Accept the validation test only if:

a) the particle count obtained for a given size at each sample interval does not deviate more than 15 % from the average particle count from all sample intervals for that size;

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b) the average of all cumulative particle counts per millilitre are within the range of acceptable counts shown in Table 3.

**8.1.8** Validate the online particle counting system, and dilution systems if used, in accordance with ISO 11943.

**Table 3 — Acceptable cumulative particle count per millilitre**

| Particle size | Test condition 1 (3 mg/l) | | Test condition 2 (10 mg/l) | | Test condition 3 (15 mg/l) | |
|---|---|---|---|---|---|---|
| µm(c) | min. | max. | min. | max. | min. | max. |
| 1 | 104 000 | 128 000 | 348 000 | 426 000 | 522 000 | 639 000 |
| 2 | 26 100 | 31 900 | 86 900 | 106 000 | 130 000 | 159 000 |
| 3 | 10 800 | 13 200 | 36 000 | 44 000 | 54 000 | 66 000 |
| 4 | 5 870 | 7 190 | 19 600 | 24 000 | 29 400 | 35 900 |
| 5 | 3 590 | 4 390 | 12 000 | 14 600 | 17 900 | 22 000 |
| 6 | 2 300 | 2 830 | 7 690 | 9 420 | 11 500 | 14 100 |
| 7 | 1 510 | 1 860 | 5 050 | 6 190 | 7 570 | 9 290 |
| 8 | 1 010 | 1 250 | 3 380 | 4 160 | 5 080 | 6 230 |
| 10 | 489 | 609 | 1 630 | 2 030 | 2 460 | 3 030 |
| 12 | 265 | 335 | 888 | 1 110 | 1 340 | 1 660 |
| 14 | 160 | 205 | 536 | 681 | 810 | 1 020 |
| 20 | 46 | 64 | 155 | 211 | 237 | 312 |
| 25 | 16 | 27 | 56 | 86 | 87 | 126 |
| 30 | 6 | 12 | 21 | 40 | 34 | 58 |
| 40 | 1,1 | 4,5 | 4,4 | 14,2 | 7,9 | 20 |
| 50 | 0,15 | 2,4 | 1,0 | 7,6 | 2,4 | 11 |

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## 8.2 Validation of contaminant injection system

**8.2.1** Validate the contaminant injection system at the maximum gravimetric level, maximum injection system volume, minimum injection flow rate, and for a length of time required to deplete the complete usable volume.

**8.2.2** Prepare the contaminant injection system to contain the required amount of test contaminant and required fluid volume consistent with the configuration of that system.

NOTE All ancillary procedures utilized in preparation of the contaminant injection system become part of the validation procedure. Alteration of these procedures will require revalidation of the system.

**8.2.3** Add dust and circulate for a minimum of 15 min.

**8.2.4** Initiate injection flow from the contaminant injection system, collecting this flow externally from the system. Obtain initial sample at this point and measure the injection flow rate.

**8.2.5** Maintain the injection flow rate within ± 5 % of the desired injection flow rate.

**8.2.6** Obtain samples of the injection flow and measure the injection flow rate at (30, 60, 90 and 120) min or at least four equal intervals depending upon the depletion rate of the system.

**8.2.7** Analyse each sample from 8.2.6 gravimetrically in accordance with ISO 4405.

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