INTERNATIONAL STANDARD

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Diesel engines — Cleanliness assessment of fuel injection equipment

Moteurs diesels — Évaluation de la propreté de l'équipement d'injection

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Contents

Page

Annexes

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 12345 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 7, *Injection equipment and filters for use on road vehicles.*

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

Introduction

Modern fuel injection systems contain many closely controlled clearances and rely on the fuel-flowing characteristics of small orifices; thus they require the close control of sources of contamination in order to maintain the operational performance demanded of them throughout their design life. To this end, such systems are designed with integral fuel-filtration equipment, which reduces the amount of potentially damaging debris that could enter the system from external sources.

However, contamination of the fuel injection system can also occur internally, from system use or wear, from equipment servicing, or as a result of the original supplier's manufacturing and assembly processes. The focus of this International Standard is on the latter source of contamination, and is thus concerned with the assessment of the cleanliness of the fuel injection equipment as originally supplied to the engine manufacturer.

Fuel injection systems comprise a number of components. Traditional systems contain low-pressure elements (fuel tank, pipe-work, filters, lift pump, etc.), a fuel injection pump, high-pressure pipes and fuel injectors, located within the engine cylinder head.

During the preparation of this International Standard, the importance of care in the handling and measurement of contamination samples was clearly recognized. Moreover, the low levels of contaminant experienced with fuel injection equipment makes this a particularly difficult task. For this International Standard to be used meaningfully — as an indicator of component cleanliness and a driver towards higher quality standards — extreme attention to detail is required of the user. Verification requirements for the test equipment used are therefore emphasized, in detail.

It is not always clear what level and type of cleanliness would be beneficial for improved performance and life on a cost-effective basis. The actual quantitative levels can only be set in relation to other parameters, agreed between manufacturer, supplier and user. This International Standard provides a set of procedures for evaluating the cleanliness of diesel fuel injection equipment and a framework for common measurement and reporting.

Work on cleanliness assessment continues within ISO/TC 22/SC 7 and among other groups of experts, and could result in an amendment of this International Standard in the near future. Items under consideration are

— cleanliness procedures specifically applicable to common rail systems, and

— improvement of the reporting scheme of the cleanliness level.

Diesel engines — Cleanliness assessment of fuel injection equipment

1 Scope

This International Standard specifies cleanliness assessment procedures for evaluating the amount of debris found within the constituent parts of a fuel injection system for diesel engines that could lead to a reduction in the system's operational effectiveness. It is mainly concerned with new equipment not yet fitted to a diesel engine, and is therefore aimed primarily at engine and fuel injection equipment manufacturers.

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

ISO 4006:1991, *Measurement of fluid flow in closed conduits — Vocabulary and symbols*

ISO 4008-1, *Road vehicles — Fuel injection pump testing — Part 1: Dynamic conditions*

ISO 4020:2001, *Road vehicles — Fuel filters for diesel engines — Test methods*

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

ISO 4407:2002, *Hydraulic fluid power — Fluid contamination — Determination of particulate contamination by the counting method using an optical microscope*

ISO 4113, *Road vehicles — Calibration fluid for diesel injection equipment*

ISO 4788:1980, *Laboratory glassware — Graduated measuring cylinders*

ISO 7440-1, *Road vehicles — Fuel injection equipment testing — Part 1: Calibrating nozzle and holder assemblies*

ISO 7876-1, *Fuel injection equipment — Vocabulary — Part 1: Fuel injection pumps*

ISO 7876-2, *Fuel injection equipment — Vocabulary — Part 2: Fuel injectors*

ISO 7876-3, *Fuel injection equipment — Vocabulary — Part 3: Unit injectors*

ISO 7876-4, *Fuel injection equipment — Vocabulary — Part 4: High-pressure pipes and end-connections*

ISO 7967-7:1998, *Reciprocating internal combustion engines — Vocabulary of components and systems — Part 7: Governing systems*

ISO 8535-1, *Compression-ignition engines — Steel tubes for high-pressure fuel injection pipes — Part 1: Requirements for seamless cold-drawn single-wall tubes*

ISO 8535-2, *Compression-ignition engines — Steel tubes for high-pressure fuel injection pipes — Part 2: Requirements for composite tubes*

ISO 8984-1, *Diesel engines — Testing of fuel injectors — Part 1: Hand-lever-operated testing and setting apparatus*

ISO 11171:1999, *Hydraulic fluid power — Calibration of automatic particle counters for liquids*

ISO 11500:1997, *Hydraulic fluid power — Determination of particulate contamination by automatic counting using the light extinction principle*

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

ISO 18413:—[1)], *Hydraulic fluid power — Cleanliness of parts and components — Inspection document and principles related to contaminant collection, analysis and data reporting*

SAE J1549:1988, *Diesel fuel injection pump — Validation of calibrating nozzle holder assemblies*

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 4006, ISO 7876-1 to ISO 7876-4, ISO 7967-7 and the following apply.

3.1
fuel injection equipment cleanliness code
FIECC
three-figure code representing the distribution of particles by size found during cleanliness testing of fuel-injection equipment

3.2
average cleanliness level
ACL
average level for cleanliness measured in gravimetric or particle count terms over at least five consecutive readings

3.3
required cleanliness level
RCL
required level for cleanliness of components or products under test, measured in terms of gravimetric or particle count

1) To be published.

3.4
Reynolds number
Re
dimensionless parameter expressing the ratio between the inertia and viscous forces in a flowing fluid, given by the formula

$$Re = \frac{U \times l}{\nu}$$

where

U is the mean axial fluid velocity across the defined area, expressed in millimetres per second

l is the characteristic dimension of the system over which the flow occurs, expressed in millimetres [for pipes $l = d$ (pipe bore diameter)]

ν is the kinematic viscosity of the fluid, expressed in square millimetres per second [centistokes]

3.5
scale number
number used to represent the range of particle numbers greater than a specific size measured on a component or assembly

4 Test apparatus

A typical test equipment set-up recommended for measuring fuel-injection equipment cleanliness is described in annex A. What follows are details of specific apparatus that may be used.

4.1 Pressure source, taking different forms for different tests, as follows.

4.1.1 Fuel injection pump test bench, a single cylinder inline pump as specified in SAE J1549 and a test bench as specified in ISO 4008-1.

4.1.2 Hand-lever-operated testing and setting apparatus, a testing apparatus as specified in ISO 8984-1.

4.1.3 High-pressure pulsating flow rig, a pressure source capable of achieving

a) a flow rate that will generate a turbulent flow in the pipes ($Re >$ 4 000) for a period of 30 s $\pm$ 1 s, while pulsating the flow between zero and this value at a frequency of 0,2 Hz to 1 Hz, followed by

b) a flush at 1,4 MPa $\pm$ 0,1 MPa constant pressure for 15 s $\pm$ 1 s.

4.1.4 Verification low-pressure pump, a plunger or diaphragm-type pump having a flow rate of approximately twice the rated value for the component under test at a pressure of at least 2 MPa.

The verification low-pressure pump shall be cleaned to an ACL in accordance with annex B and carefully stored with proper cover in a clean environment.

4.1.5 Verification high-pressure pipe assembly, for testing of high-pressure pipes with open ends, having a flow rate capable of generating a Reynolds number in the pipes of $Re >$ 4 000. A pressure capability of 3 MPa $\pm$ 0,1 MPa is considered suitable.

The verification high-pressure delivery pump shall be cleaned to an ACL in accordance with annex B and carefully stored with proper cover in a clean environment.

4.2 Verification high-pressure pipe assembly, 600 mm long, of either

— tube ISO 8535-1 S-2-6-2 1 P 0 (see ISO 8535-1), or

— tube ISO 8535-2 CA-2-6-2 1 P 0 (see ISO 8535-2), and having a M12 × 1,5 threaded end connection at one end and a M14 × 1,5 threaded end connection at the other.

Stainless steel tubing should be used because of its resistance to rust and corrosion contamination. The verification high-pressure pipe assembly shall be cleaned to the ACL in accordance with annex B and carefully stored with proper cover in a clean environment.

4.3 Verification test injector, in accordance with ISO 7440-1, fitted with an orifice plate of orifice diameter 2,5 mm.

The inlet edge filter shall be removed, while the pintle end may be removed to improve particle passage. The nozzle opening pressure shall be set to $20{,}7^{+0{,}3}_{-0}$ MPa.

4.4 Collecting vessel, which may be necessary for collecting test fluid downstream from the tested equipment at a flow rate different from that passing through the particle counter, the contamination monitor or the membrane filter.

The collecting vessel may be used for storing test fluid before transfer of fluid samples to the laboratory for analysis. A cylindrical stainless steel or glass reservoir with conical bottom should be used for facilitating further particle collection.

4.5 Equipment for contamination measurement, involving the application of three specific techniques for evaluating the level of contamination:

— gravimetric analysis;

— microscopic examination;

— automatic measurement using either an automatic particle counter (APC) or field contamination monitor (see annex C).

Each requires the following specific laboratory apparatus.

4.5.1 Gravimetric analysis apparatus, consisting of the following.

4.5.1.1 Non-ventilated drying oven, capable of maintaining a temperature of 80 °C ± 2 °C.

4.5.1.2 Filter holder, comprising

— funnel of 300 ml capacity with suitably calibrated volumetric graduations (e.g. 25 ml ± 2 ml),

— suitable cover for the funnel (e.g. petri dish),

— clamping device,

— suitable base to support the membrane filter, and

— a means of dissipating any static electricity generated during the filtering process.

4.5.1.3 Vacuum flask, suitable for the filter holder and of capacity enabling it to hold the entire volume of sample liquid without refilling.

4.5.1.4 Vacuum device able to generate a vacuum of 86,6 kPa (gauge).

4.5.1.5 Solvent dispenser (syringe), a pressurized vessel that discharges solvent through an in-line filter membrane with a pore size of not greater than 1 µm.

4.5.1.6 Tweezers, flat-bladed (non-serrated, blunt tips), and of stainless steel.

4.5.1.7 Graduated cylinders, for measuring out the volume of test liquid, to an accuracy that should be in accordance with ISO 4788. Alternatively, a sample bottle calibrated with suitable volumetric graduations may be used, in which case the accuracy of graduation should be ± 2 %.

4.5.1.8 Sample bottles, of 250 ml nominal capacity, preferably flat-bottomed and wide-mouthed, with a screw cap containing a suitable internal polymeric seal.

4.5.1.9 Plastic film, 0,05 mm thick $\times$ 50 mm $\times$ 50 mm, placed between the sample bottle cap and neck if the cap does not have an internal seal. The film shall be compatible with both the cleaning and sample liquids.

4.5.1.10 Filter membranes, 47 mm in diameter, white, without grids, and compatible with the fluid to be analysed and with the rinsing chemicals. Reference membranes shall have a 0,8 µm pore size. Any other pore size used shall be stated.

4.5.1.11 Petri dishes, of glass and 150 mm diameter.

4.5.1.12 Analytical balance, of 0,05 mg accuracy.

4.5.1.13 Alpha-ray ioniser, to be used to prevent collection of dust during the weighing operation, placed under the balance scale incorporating the filter and projecting from beneath it.

4.5.1.14 Air dryer.

4.5.2 Microscopic analysis apparatus, consisting of the following.

4.5.2.1 Membrane preparation equipment, as specified in 4.5.1.1 to 4.5.1.9.

4.5.2.2 Filter membrane, compatible with the sample liquid and any solvents or chemicals used in the processes. Normally, the membrane shall be of 47 mm diameter, white, with grids (each grid square width side 3,08 mm $\pm$ 0,05 mm and equal to 1 % of the effective filtration area), and with a pore size $<$ 1,5 µm, used for manual counting down to 2 µm. A 47 mm diameter white, membrane without grids and with a pore size of $<$ 1,5 µm should be used for image analysis. Membranes of different diameters may be used.

4.5.2.3 Microscope glass base slides and microscope glass cover slips, for transmitted-light method only, of a dimension greater than the diameter of the membrane filter. The thickness of the cover slip should be approximately 0,25 mm.

4.5.2.4 Membrane holder, made of plastic or equivalent, with lid, for retaining membrane (incident-light method only).

4.5.2.5 Microscope, manual and with a range of objective lenses which, in combination with the ocular lenses, are able to resolve particles down to 2 µm, and which is fitted with

— fine and coarse focus control,

— through-the-lens lighting for the incident light method or a bottom-lighting source for the transmitted light method, or both,

— a mechanical stage so that the effective filtration area of the membrane can be scanned,

— provision on the mechanical stage for securely holding the membrane holder or glass slide, and

— an ocular micrometer of which the smallest division shall not subtend a distance larger than the smallest particle to be counted at a particular magnification, with suitable graduations.

For counting with transmitted light, the projector microscope with suitable screen, over-eyepiece mirror and rotating super-stage is preferred.

For image analysis, it is preferable to have a stabilized lighting source controlled by the imaging software, so that illumination fluctuations are eliminated and automatic correction is made for any intensity drift in the light source.

For accurate characterization of particles using the incident light method, combination light as provided by an additional oblique lighting source could be required (see 5.4).

See Table 1 for nominal magnification and optical combinations.

4.5.2.6 External lamp, of variable intensity, for when oblique illumination of the specimen stage is required.

4.5.2.7 Stage micrometer, graduated in 0,1 m and 0,01 m divisions, calibrated to national standards.

Table 1 — Nominal magnifications and optical combinations

Magnification ×			Suggested minimum particle size µm
Nominal	Ocular lens	Objective lens	
50	10	5	20
100	10	10	10
200	10	20	5
500	10	50	2

4.5.2.8 Tally counter, with sufficient sections to accumulate numbers of particles and fields counted.

4.5.3 Automatic measurement apparatus, which should be capable of reporting analyses in accordance with the fuel injection equipment cleanliness code (FIECC) (see clause 7) (see annex C for recommended instruments), comprising the following.

4.5.3.1 APC, operating on the light extinction principle in accordance with ISO 11500, calibrated in accordance with ISO 11171. The sensor shall be chosen and set such that it can count the particle at least greater than 15 µm, 100 µm and 200 µm.

4.5.3.2 APC, operating on the filter blockage technique.

4.6 Test fluid, as follows, depending on the test being conducted (see 5.3.2, 5.4.2, 5.5.2.2, 5.5.3.2, 5.6.2, 5.7.2).

4.6.1 Calibration fluid, test oil in accordance with ISO 4113, pre-filtered on a 0,8 µm cartridge filter.

4.6.2 Solvent, aliphatic hydrocarbon, pre-filtered using a 0,8 µm, single-membrane nylon filter, which

shall

— not leave any residue when vaporized, as residuals can influence the weighing results,

— shall have a minimum flash point of 38 °C, in order to fulfil normal working environment safety aspects,

— shall not have any aromatic components that could enter the atmosphere when vaporized, and

— shall have a boiling point not higher than 200 °C.

4.7 Clean-up filter, cartridge filter with a filtration rating suited to the cleanliness level required for the test (see annex B).

4.8 Pressure gauge, capable of measuring the system operating pressure, which is dependent on the system under test (see 5.3, 5.4, 5.5, 5.6 and 5.7).

4.9 Thermometer, for measurement of test fluid temperatures between 20 °C and 80 °C with an accuracy of ± 1 °C.

5 Procedure

5.1 General

This International Standard covers the following components of the fuel injection equipment:

— fuel injection pumps (see 5.3);

— fuel injectors (see 5.4);

— high-pressure fuel injection pipes (see 5.5);

— low-pressure systems (see 5.6);

— unit injectors (see 5.7).

Each of these, in turn, is treated with respect to three procedural areas:

— equipment set-up and verification;

— test procedure;

— measurement.

Optional test procedures are also specified for some components.

5.2 Contaminant removal validation procedure

As the cleanliness of a component is the total amount of contaminants deposited in or on it, and because these are extremely difficult to remove, every contaminant removal procedure shall be validated using the following procedure.

a) Repeat several times on the same component the rinsing protocol to be validated, using a separate clean container for each sample collected.

b) At each rinsing, carefully measure the rinsing fluid volume and precisely measure the parameter of interest (e.g. gravimetric, number of particles).

c) Divide the result for the last sample by the sum of the results for the previous samples.

d) If the calculated value is $\leqslant$ 0,10, sample collection is complete. For particle counting, this criterion applies to the total number of particles greater than the particle size to be controlled.

e) If the calculated value is $>$ 0,10, additional rinsing is required. Repeat the rinsing protocol as many times as necessary until the last sample gives a result $\leqslant$ 0,10 of the total results of previous samples.

The particle collection process efficiency may be illustrated by drawing the cleaning curve, i.e. the cleanliness level of the component (expressed in the terms given in clause 7), as a function of the cleaning number (or volume or time). The cleaning curve should reach an asymptote (less than 10 % of the sum of the previous measurements, see Figure 1), thus validating the cleaning process.

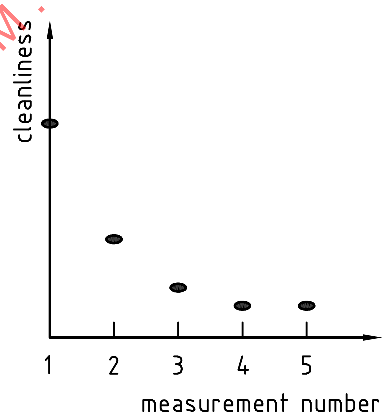

Figure 1 — Typical cleaning process validation curve

5.3 Fuel injection pumps

5.3.1 General

The procedures are similar for rotary, distributor and inline diesel fuel injection pumps. The tests to be conducted are dynamic, i.e. with the test pump running under conditions close to normal operation.

5.3.2 Equipment set-up and verification of cleanliness

a) Set up the equipment for verifying the system, described in annex A, using a pressure source as specified in 4.1.1.

NOTE This pressure source is replaced by the verification pump during testing.

b) For multi-cylinder test pumps, use either a pressure source as specified in 4.1.1 to validate every line or choose a suitable, clean, multi-cylinder pressure source to validate all lines simultaneously. If the pressure source has not been previously verified as “clean”, it may be necessary to run the pump for a period prior to verifying the system in order to ensure a high base level of cleanliness.

c) Use verification high-pressure pipe assemblies in accordance with 4.2 and a verification injector in accordance with 4.3.

d) Use a test fluid in accordance with 4.6.1, pre-filtered using a filter in accordance with 4.7, permanently fixed in the system and replaced regularly.

e) Maintain the test fluid temperature at 40 °C ± 1 °C at the pump inlet.

f) Use a clean pump that is the same as the pumps to be verified, and set it to operate the system. Verify its cleanliness in accordance with clause 6.

g) See annex B for the procedure for verifying the cleanliness of the equipment.

h) If the cleanliness criterion is not attained, repeat g) or check the clean-up filter efficiency.

5.3.3 Test procedure

a) Ensure the pump return outlet is unrestricted by valves or orifices. If not unrestricted, remove and replace it with a plain outlet.

b) Run the pump on test for a period of 10 min on full fuel delivery and at a pump speed of 200 min^{-1} below the maximum quoted full load speed; collect/count the contaminant output from all high-pressure lines.

c) Separately and similarly collect/count the contaminant output from the pump return (see annex A).

d) Measure and record the results (see 5.3.4).

e) Repeat a) to d) for the number of test samples required, as agreed between supplier and customer.

5.3.4 Measurement

a) For the high-pressure output from the pump, the number of particles at stated sizes should be recorded as well as the total weight.

b) For pump return flow, measure total weight and the longest dimension of the largest particles. This should be collected together with the high-pressure output.

c) Divide the result by the number of test samples to determine the average contamination per part.

d) Report the results (see clause 7).

5.4 Fuel injectors

5.4.1 General

The following test simulates operating conditions by use of a pressure source which equates to a fuel injection pump and which operates the injectors.

5.4.2 Equipment set-up and verification of cleanliness

a) Set up the equipment for verifying the system, described in annex A.

b) Use a pressure source in accordance with 4.1.2, and the high-pressure pipe assembly specified in 4.2.

c) Fit an injector for verification purposes (see 4.3), to be replaced by the test injectors during testing.

d) Use a test fluid specified in 4.6.2.

e) Conduct the tests using a fluid temperature of 23 °C ± 10 °C (room temperature).

f) Set up the remainder of the system such that it is as described in annex A, common across all products.

g) Operate the system in the same condition as scheduled for the test, and measure its cleanliness in accordance with clause 6.

h) Verify the cleanliness of the equipment in accordance with annex B.

i) If the cleanliness criterion is not achieved, repeat a) to g) or check the test equipment and clean-up filter.

5.4.3 Test procedure

a) Remove the system verification injector and cap the nozzle end and inlet port with clean caps.

b) Carefully fit the first injector under test in place of the calibration injector while avoiding any possible source of contamination.

c) Operate the hand-lever-operated apparatus (see 4.1.2) 50 times using a swift action to ensure injector operation on all strokes.

d) Collect the output in a suitably cleaned container (see 4.4 and ISO 3722).

e) Repeat the procedure for the number of sample tests required, as agreed between supplier and customer.

f) Remove the injector, strip and wash out the high-pressure wetted areas only, and add to the previously collected amount.

5.4.4 Washing out injectors

a) Thoroughly clean all external surfaces prior to dismantling an injector.

b) Dispense the filtered solvent as specified in 4.6.2 in accordance with 4.5.1.5 onto the required area in a jet form, so as to disturb any loose particles in a controlled manner.

c) Take great care in dismantling in order to avoid introducing/producing contaminant not relevant to this procedure.

d) Remove and wash all surfaces wetted by the high-pressure fluid; if required, wash all surfaces wetted by the low-pressure fluid separately.

e) Ensure all drillings and holes are thoroughly flushed to remove any particles.

f) Collect the contaminant in accordance with the appropriate procedures.

All tests should be carried out in a clean laboratory environment.

5.4.5 Measurement

Count the particles at stated sizes (see clause 6). The cleanliness of fuel injectors is determined by the number of particles found at the stated sizes (see clause 7).

5.5 High-pressure fuel injection pipes

5.5.1 General

Experience has shown that for removal of typical particles produced in the manufacture of these components, a turbulent flow with pulsating pressure is preferable, simulating actual operating conditions. This and two other methods may be used for checking the cleanliness of high-pressure fuel injection pipes:

— simulation method (see 5.5.2), utilizing a high-pressure supply pump;

— high-pressure flushing method (see 5.5.3);

— syringe (solvent dispenser) or hand-flush method (see 5.5.4).

Determination of the procedure to be used shall be by agreement between the fuel injection equipment supplier and customer.

5.5.2 Simulation method

5.5.2.1 General

This is the preferred method for the removal of typical tube contaminants.

5.5.2.2 Equipment set-up and verification of cleanliness

a) Set up the equipment for verifying the system, described in annex A, using a pressure source in accordance with 4.1.3.

b) Use a verification injector in accordance with 4.3 and a solvent in accordance with 4.6.2.

c) Use a verification high-pressure pipe in accordance with 4.2.

d) Circulate the test fluid through a clean-up filter until the level given in annex B is achieved. Fluid temperatures should be maintained at between 20 °C and 60 °C. The higher the temperature, the higher the particle removal efficiency.

e) Determine the flow rate required to ensure a turbulent flow in the high-pressure pipes ($Re > 4\,000$).

f) See 5.4.2, g) to i).

5.5.2.3 Test procedure

a) Remove the verification high-pressure pipe and carefully fit the first test pipe while avoiding any possible source of contamination.

b) Run the pump or pressure source to obtain a flow rate greater than the minimum calculated in 5.5.2.2, e) and allow cyclic flow variation between zero and this value at a frequency of 0,2 Hz to 1 Hz for 30 s (see 4.1.3). Remove any end restriction and reduce the pressure to a constant 1,4 MPa for a further 15 s.

c) Collect samples at the outlet of the test pipe.

d) Repeat a) to c) for the number of pipe assemblies agreed between customer and supplier.

5.5.2.4 Measurement

For each fluid sample collected, count the particle at stated sizes (see clause 6) and report fuel injection pipe cleanliness (see clause 7).

5.5.3 High-pressure flushing method

5.5.3.1 General

When the simulation method is impractical, the high-pressure flushing method should be used as a more efficient means for removal of tube contaminants.

5.5.3.2 Equipment set-up and verification of cleanliness

a) Set up the equipment for verifying the system, described in annex A, using a suitable pressure source such as that specified in 4.1.5. Use of a test injector is not required.

b) Use a verification pressure pipe as specified in 4.2 for rig verification.

c) Use a solvent as specified in 4.6.2.

d) Verify the cleanliness of the equipment in accordance with annex B.

e) Operate the system in the same condition as scheduled for the test and measure its cleanliness in accordance with clause 6.

5.5.3.3 Test procedure

a) Remove the calibration high-pressure pipe and carefully fit the first test pipe while avoiding any possible source of contamination.

b) Run the pump at a flow rate that guarantees $Re > 4\,000$ for a period of 30 s; collect all the fluid at the pipe outlet.

c) Repeat the procedure for the number of pipe assemblies agreed between customer and supplier.

5.5.3.4 Measurement

For each fluid sample collected in 5.5.3.3, b), count the particles at the stated sizes (see clause 6) and report fuel injection pipe cleanliness according to clause 7.

5.5.4 Syringe (solvent dispenser) or hand-flush method

5.5.4.1 General

If neither the simulation nor the high-pressure flushing method prove practical to the supplier or customer, by agreement the syringe (solvent dispenser) method may be used as an alternative.

5.5.4.2 Equipment set-up and verification of cleanliness

The following operation shall be performed in a contamination controlled-environment (see annex A for a typical equipment layout).

a) Set up the equipment as shown in A.3, and carefully clean it to the initial RCL (see annex B).

b) Operate the system in the same condition as scheduled for the test, but without using any tube. Use the same volume of fluid as would be used for the number of tubes to be tested, pouring it directly into the funnel of the collection vessel.

c) Measure the contaminants collected in accordance with clause 6 and refer to annex B for the criteria to be used for verification of test equipment.

5.5.4.3 Test procedure

a) Thoroughly cleanse the outer surface and unions of each tube using solvent (see 4.6.2).

b) Flush the inside of the tube using the solvent dispensed by syringe (see 4.5.1.5) and collect into either the funnel of the vacuum flask (see 4.5.1.3) or a separate collection vessel for subsequent analysis (see clause 6). Use a volume at least 10 times the volume of the tube.

c) Repeat the procedure for as many tubes as agreed between supplier and customer.

d) On completion of the flushing of all tubes, ensure that any contamination remaining on the filtration funnel (see 4.5.1.2) is removed to the filter membrane by washing down with the syringe/solvent dispenser.

5.5.4.4 Measurement

For each sample collected, count the particles at the selected sizes in accordance with clause 6 and report data in accordance with clause 7.

5.6 Low-pressure system

5.6.1 General

Cleanliness of the clean side of fuel filters is covered by ISO 4020:2001, 6.1, and so will not be dealt with in detail in this International Standard, although the procedures should be compatible.

5.6.2 Equipment set-up and verification of cleanliness

a) Maintaining a verification set-up similar to the system under test, set up the low-pressure system as for the intended installation. Use a pressure source as specified in 4.1.4, but remove the high-pressure pipe assembly (see 4.2) and test injector (see 4.3), which are not required for this test.

b) Use a test fluid as specified in 4.6.2.

c) Maintain the fluid temperature at 23 °C $\pm$ 10 °C.

d) Set up the remainder of the system so that it is as described in annex A.

e) Establish the rated flow of the system under test. Set the pressure source to achieve at least twice this flow or to ensure a maximum pressure differential of 0,02 MPa across the system. Circulate for 10 min and collect downstream fluid to measure its cleanliness according to clause 6.

f) Verify the cleanliness of the test equipment in accordance with annex B.

g) If the cleanliness criterion is not attained, repeat the procedure.

5.6.3 Test procedure

a) Carefully remove the verification low pressure system components while avoiding any possible source of contamination. Fit the first system under test.

b) Allow the test fluid to flow through the system for 10 min, and collect/measure the debris produced.

c) Where components are operated in actual use (e.g. bulbous or plunger-type lift pumps), these should be operated similarly during this test at least 50 times.

d) Repeat the procedure for as many assemblies as agreed between supplier and customer, and collect the total sample.

5.6.4 Measurement

For the total sample collected, perform the agreed analyses according to clause 6. The total weight and maximum particle size should be recorded and reported in accordance with clause 7.

5.7 Unit injectors

5.7.1 General

This is a dynamic test, and the product operates close to as it would in service.

5.7.2 Equipment set up and verification of cleanliness

a) Set up the equipment for verifying the system, described in annex A.

b) Use a test bench able to operate the unit injector under normal running conditions.

c) Fit a unit injector assembly for verification purposes.

d) Retain the verification assembly for verification of the system.

e) Use a test fluid as specified in 4.6.1, pre-filtered using a filter as specified in 4.7, permanently fixed in the system.

f) Maintain the temperature of the test fluid at the point of supply to the unit injector at 40 °C ± 10 °C.

g) Set up the remainder of the system so that it is as described in annex A, common across all products.

h) Operate the system for 10 min and collect all downstream fluid for cleanliness control.

i) Verify the cleanliness of the equipment in accordance with annex B.

j) If the cleanliness criterion is not attained, repeat h) or verify the clean-up filter efficiency.

5.7.3 Test procedure

a) Carefully remove the verification unit injector from the test bench and cap the nozzle and inlet and return ports.

b) Fit the first injector to be tested while avoiding any possible source of contamination.

c) Run the unit injector at full load and speed for 10 min, collecting the contaminant output from the nozzle; separately and similarly collect the contaminant output from the injector return outlet.

d) Repeat the procedure for a minimum of 10 assemblies, collecting the contaminant on the same filter and adding the results for all injectors separately for high-pressure and return flow.

e) Remove the test injectors, strip and wash out all internal high-pressure areas and collect contaminant along with the amount collected from the nozzles in c).

f) Similarly wash out all low pressure areas and collect contaminants along with those collected from the return flow of the assemblies (see 5.4.3).

5.7.4 Measurement

Measure the cleanliness level of each sample collected in 5.7.3, c) to f) using the appropriate method from clause 6 and reporting in accordance with clause 7. For the unit injector, count the particles at stated sizes.

6 Sample analysis

6.1 General

Samples collected downstream of the fuel injection equipment for measuring its cleanliness may be analysed using different methods depending on the type of information required. In all cases, the analysis method shall be agreed between the parties concerned and shall be validated.

6.2 Gravimetric analysis

See ISO 4405 for use of the single-membrane method, which has proven more repeatable for determining the gravimetric contamination level of fuel injection equipment.

6.3 Largest particle size

See ISO 4407 for determining by microscopy the dimension of the largest particles collected from the fuel-injection equipment under test. Particle size analysis can be either manual, using an optical microscope, or automated, using an image analyser.

NOTE The largest particle is defined as the particle with the largest maximum dimension across the particle from one side to another, independent of its orientation to the measurement device.

The pore size of the selected membrane should be commensurate with the size of the particle being monitored, to ensure the membrane is not plugged prematurely by particle sizes much smaller than the size of interest. It has been found convenient to pre-filter the contaminated test liquid through a coarse sieve and then flush the larger dirt off onto the analysis membrane.

6.4 Particle count and size

6.4.1 General

It is essential when using particle measurement devices and counting systems that the device be used and calibrated in a consistent manner. Particle measurement systems vary in the way they measure particles and hence in the end result given for the same input of particles. It can be beneficial to use one type of measurement device, depending on the typical particle shapes being encountered. Agreement should be reached between supplier and customer on the appropriate measure to be used. It is also essential that, whenever comparative cleanliness checks are made, the same measurement method be used.

6.4.2 Automatic optical particle counter (APC)

Use an APC calibrated in accordance with ISO 11171 or, if fitted on-line on the test circuit, in accordance with ISO 11943. For operating protocol and sample handling, see ISO 11500.

Exert great care in sample handling to avoid particle sedimentation.

APCs should not be used for counting particles larger than 200 µm.

6.4.3 Field contamination monitor

Use a field contamination monitor, or any other validated instrument, in accordance with the appropriate International Standard.

7 Reporting results

7.1 Gravimetric analysis

a) Totalize the weight, in milligrams, of all contaminants collected on all component (or product) samples.

b) Calculate the gravimetric ACL per component (or product), $W_{\text{ACL,C}}$, expressed in milligrams, using the following equation and rounding the result up to the next digit:

$$W_{\text{ACL,C}} = \frac{W_{\text{T}}}{n}$$

where

W_{T} is the total weight of all collected particles, in milligrams;

n is the number of components or products.

c) When wetted surface area is variable and measurable, calculate the gravimetric ACL of the wetted surface area of a component, $W_{\text{ACL,A}}$, expressed in milligrams per square metre, using the following equation and rounding the result up to the next digit:

$$W_{\text{ACL,A}} = \frac{W_{\text{T}}}{A_{\text{W}} \times n}$$

where

W_{T} is the total weight of all collected particles, in milligrams;

A_{W} is the wetted surface area of the component, in square metres;

n is the number of components or products.

Other area units, such as 1 000 cm^2, may be used provided they are agreed on by the parties involved. If the wetted area of the component is not known, but its volume is, see annex G of ISO 18413 to calculate its equivalent wetted area.

7.2 Largest particle size

This scoring system is based on the major dimension of the largest five particles found during the evaluation of the components (see 6.3). The score is obtained by assigning a code (see Table 2) to each of the five largest particles found and adding these values together to provide the overall score.

Table 2 — Allocation of largest particle score number

Score	Size Range[a] µm	Score	Size Range[a] µm
1	1 to 149	11	2 400 to 2 939
2	150 to 209	12	2 940 to 3 539
3	210 to 299	13	3 540 to 4 199
4	300 to 419	14	4 200 to 4 919
5	420 to 599	15	4 920 to 5 699
6	600 to 839	16	5 700 to 6 539
7	840 to 1 139	17	6 540 to 7 439
8	1 140 to1 499	18	7 440 to 8 399
9	1 500 to1 919	19	8 400 to 9 419
10	1 920 to 2 399	20	$>$ 9 419

[a] Largest dimension as defined in 6.3.

For example, a component could be evaluated and given a contamination score based on the major dimension of the five largest particles given in Table 3.

Table 3 — Example scores

Particle size[a] µm	Score
940	7
675	6
450	5
390	4
175	2
Total	24

[a] Largest dimension as defined in 6.3.

7.3 Fuel injection equipment cleanliness code (FIECC)

The FIECC is made up of three scale numbers, representing the number of particles above 200 µm, 100 µm and 15 µm, respectively, found in the fluid media per component or product during the cleanliness test. See Table 4 for determining the FIECC of the component from the particle size and number obtained during the test (see 6.4).

Table 4 — Allocation of scale numbers

No. of particles per component		Scale number	No. of particles per component		Scale number
More than:	Up to and including:		More than:	Up to and including:	
80 000	160 000	24	20	40	12
40 000	80 000	23	10	20	11
20 000	40 000	22	5	10	10
10 000	20 000	21	2,5	5	9
5 000	10 000	20	1,3	2,5	8
2 500	5 000	19	0,64	1,3	7
1 300	2 500	18	0,32	0,64	6
640	1 300	17	0,16	0,32	5
320	640	16	0,08	0,16	4
160	320	15	0,04	0,08	3
80	160	14	0,02	0,04	2
40	80	13	0,01	0,02	1
—	—	—	0,005	0,01	0

EXAMPLE 1 The measurement of the cleanliness of 10 pipes in accordance with 5.3 has given the following numbers of particles per component in the mentioned size range:

— 0,23 particles greater than 200 µm;

— 3,7 particles greater than 100 µm;

— 235 particles greater than 15 µm.

By comparing these numbers to the minimum and maximum numbers of Table 4, the pipe cleanliness code can be determined as:

5/9/15

EXAMPLE 2 If the cleanliness specification of an engine manufacturer requires that all delivered fuel-injection equipment be cleaner than 7/11/19, the fuel injection equipment supplier has to clean each component so that it contains the following maximums:

— 1,3 particles above 200 µm, i.e. up to 13 particles above 200 µm are permissible in every ten components produced;

— 20 particles above 100 µm, i.e. up to 200 particles above 100 µm are permissible in every ten components produced;

— 5 000 particles above 15 µm, i.e. up to 50 000 particles above 15 µm are permissible in every ten components produced.

8 Designation

8.1 Identification statement (reference to this International Standard)

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

"The procedure for assessing the cleanliness of fuel injection components conforms to ISO 12345:2002, *Diesel engines — Cleanliness assessment of fuel injection equipment.*"

8.2 Designation methods

8.2.1 Method A

The cleanliness of fuel injection equipment tested in accordance with this International Standard shall be designated using the following elements:

a) reference to this International Standard;

b) reference to one of the particle contamination methods specified in this International Standard.

Application of the FIECC (see 7.3), is identified as "Designation method A". This shall be the preferred method for designation unless otherwise agreed between customer and supplier.

EXAMPLE **ISO 12345-5/9/15**

8.2.2 Alternative methods

Additionally — or alternatively, if agreed between customer and supplier — the cleanliness level may be described using one or more of the following methods.

— Designation method B: weight, in milligrams, per component [see 7.1, b)].

— Designation method C: weight, in milligrams, per 1 000 cm^2, of the wetted surface area [see 7.1, c)].

— Designation method D: maximum particle size score (see 7.2).

When an alternative designation method is used, the appropriate reference letter shall appear as the second element of the designation [see 8.2.1, b)].

EXAMPLE 1

ISO 12345-B5

ISO 12345-C3

ISO 12345-D14

EXAMPLE 2 A two-way designation using designation method D, in addition to the preferred designation method A:

ISO 12345-5/9/15-D14

EXAMPLE 3 A three-way designation using designation methods B and C, in addition to the preferred designation method A:

ISO 12345-5/9/15-B5-C3

