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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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 × 50 mm × 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 ± 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);