INTERNATIONAL STANDARD

ISO 12345

Third edition

Diesel engines — Cleanliness assessment of fuel injection equipment

Moteurs diesels — Évaluation de propreté pour équipement d'injection de combustible

PROOF/ÉPREUVE

Reference number
ISO 12345:2021(E)

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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.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

For an explanation of 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 www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC22, *Road vehicles*, Subcommittee SC 34, *Propulsion, powertrain, and powertrain fluids*.

This third edition cancels and replaces the second edition (ISO 12345:2013), which has been technically revised.

The main changes compared to the previous edition are as follows:

— the reporting of the inspection results (Clause 7) changed from FIECC (fuel injection equipment cleanliness code, as in ISO 12345:2013) to CCC (component cleanliness code, as in ISO 16232).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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 document 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 document, the importance of care in the handling and measurement of contamination samples was clearly recognized. Moreover, the low levels of contaminant with fuel injection equipment make this a particularly difficult task. For this document to be used meaningfully - as an indicator of component cleanliness and a driver towards higher-quality standards - extreme attention to detail is recommended for the user. Therefore, verification requirements for the used test equipment are 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 the manufacturer, supplier and user. This document provides a set of procedures for evaluating the cleanliness of fuel-injection equipment and a framework for a common measurement and reporting.

Diesel engines — Cleanliness assessment of fuel injection equipment

1 Scope

This document specifies cleanliness assessment procedures for evaluating the amount of debris found within the clean side of diesel fuel injection assemblies, which could lead to a reduction in the system's operational effectiveness.

While other International Standards, e.g. ISO 16232, relate to cleanliness of components used in road vehicle fluid circuits, this document is focused on diesel fuel injection assemblies as supplied to diesel engine manufacturers or the service market.

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

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

ISO 4788, *Laboratory glassware — Graduated measuring cylinders*

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

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

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

ISO 14644-1, *Cleanrooms and associated controlled environments — Part 1: Classification of air cleanliness by particle concentration*

ISO 16232:2018, *Road vehicles — Cleanliness of components and systems*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16232 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
Reynolds number
Re
dimensionless parameter expressing the ratio between the inertia and viscous forces in a flowing fluid, given by the formula

$$R_e = \frac{U \times l}{v}$$

where,

R_e is the Reynolds number (Re);

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

l is the characteristic dimension of the system over which the flow occurs, expressed in millimetres;

[for pipes $l = d$ (pipe bore diameter)]

v is the kinematic viscosity of the fluid, expressed in square millimetres per second (centistokes).

4 Test apparatus

Typical test equipment recommended for measuring fuel-injection equipment cleanliness is described in Annex A. In 4.1 to 4.9 are details of specific apparatus that shall be used, unless a suitable alternative can be demonstrated.

4.1 Pressure source

Pressure source is test dependent as described in 4.1.1 to 4.1.7.

4.1.1 Fuel injection pump test bench

A test bench as specified in ISO 4008-1 with a single cylinder pump or one cylinder of an inline pump.

4.1.2 Hand-lever-operated testing and setting apparatus

A testing apparatus as described in ISO 8984-1.

4.1.3 High-pressure pulsating flow rig

A pressuse source capable of achieving:

a) a flow rate which will generate a turbulent flow in the pipes (Re > 4 000) for a period of 30 s ± 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 ± 0,1 MPa constant pressure for 15 s ± 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 has to be cleaned to the cleanliness level CL in accordance with Annex C. It has to be carefully stored with a proper cover in a clean environment.

4.1.5 Verification high-pressure delivery pump

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 ± 0,1 MPa is considered suitable.

The verification high-pressure delivery pump shall be cleaned to the cleanliness level CL in accordance with Annex C. It shall be carefully stored with a proper cover in a clean environment.

4.1.6 Pressure vessel

Used as pressure source. It shall be able to supply a testing pressure of at least 0,5 Mpa (= 5 bar) and to produce a turbulent flow inside the rail (recommended flow rate at least 2,5 l/min).

4.1.7 Flushing pump

Used for testing of rails with open ends, having a flow rate of at least 0,1 l/min. For this pump a pressure capability of up to 0,1 MPa ± 0,01 MPa is considered suitable.

4.2 Verification high-pressure pipe assembly

600 mm long of tube ISO 8535-1 S-2-6-2 1 P 0**,** as specified in ISO 8535-1, and suitable for the component under test.

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 cleanliness level CL in accordance with Annex C. It shall be 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 to improve the particle passage.

The nozzle opening pressure shall be set to $20{,}7\ ^{+0{,}3}_{\ \ 0}$ MPa.

4.4 Collecting vessel

It 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 fluid samples to laboratory for analysis. A cylindrical stainless steel or glass reservoir with a conical bottom should be used for facilitating further particle collection.

4.5 Verification rail

Needed to establish the cleanliness level CL for the whole rail cleanliness test apparatus.

For the verification the verification rail shall be cleaned to the blank value in accordance with Annex C and carefully stored with proper cover in a clean environment.

4.6 Equipment for contamination measurement

Involving the application of two specific techniques for evaluating the level of contamination:

— gravimetric analysis;

— microscopic examination.

Each requires the specific laboratory apparatus as given in 4.6.1 and 4.6.2.

4.6.1 Gravimetric analysis apparatus

See ISO 16232:2018, 9.2.2.

4.6.1.1 Non-ventilated drying oven

Capable of maintaining a temperature of 80 °C ± 2 °C.

4.6.1.2 Filter holder

Comprising:

- glass funnel of at least 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.

4.6.1.3 Vacuum flask

Suitable for the filter holder and of capacity enabling it to hold the entire volume of sample liquid without refilling.

4.6.1.4 Vacuum device

Able to generate a vacuum of 86,6 kPa (gauge).

4.6.1.5 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.

4.6.1.6 Tweezers

Flat-bladed (non-serrated, blunt tips), and of stainless steel.

4.6.1.7 Graduated cylinders

For measuring out the volume of test liquid, the accuracy of which shall be in accordance with ISO 4788, unless a suitable alternative can be demonstrated (with a minimum accuracy of ±2 %).

4.6.1.8 Sample bottles

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

4.6.1.9 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.

4.6.1.10 Filter membranes

Preferred 25 mm or 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 recommended pore size of between 5 µm to 8 µm. The pore size used shall be stated.

4.6.1.11 Petri dishes

Of glass and 150 mm diameter.

4.6.1.12 Analytical balance

Of at least 0,05 mg accuracy.

4.6.1.13 Alpha-ray ionizer

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.

4.6.1.14 Air dryer

4.6.1.15 Collecting vessel

A vessel with a vacuum device connecting, to be used to collect test fluid.

4.6.2 Microscopic analysis apparatus

See ISO 16232:2018, 9.2.3 and 9.3.1.

4.6.2.1 Filter membrane

Compatible with the sample liquid and any solvents or chemicals used in the processes. Normally, the membrane shall be of 25 mm or 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 <8 µm, used for manual counting down to 2 µm. A 47 mm diameter white, membrane without grids and with a pore size of <8 µm should be used for image analysis. Membranes of different diameters may be used. See also ISO 16232:2018, Clause 8.

4.7 Test fluid

Test fluids are described in the following subclauses, depending on the test being conducted.

(See 5.2.2.1, 5.2.3.1, 5.3.2, 5.4.2, 5.5.2.1, 5.5.3.1, 5.6.2.1, 5.6.3.2, 5.7.2.1, 5.7.3.1, 5.7.4.2, 5.8.2.2, 5.8.3.1, 5.8.4.2, 5.9.2.)

4.7.1 Calibration fluid

Test oil in accordance with ISO 4113, pre-filtered on a maximum of 1,0 µm cartridge filter, unless otherwise specified.

4.7.2 Solvent, aliphatic hydrocarbon

Pre-filtered using a maximum of 1,0 µm, single-membrane nylon filter, which shall:

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

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

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

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

4.7.3 Water, de-mineralised

With surface tension reduction additives (e.g. Tensides) and pre-filtered on a maximum of 1,0 µm filter.

4.8 Clean-up filter

Cartridge filter with a filtration rating suited to the cleanliness level CL required for the test (see Annex C).

4.9 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).

5 Procedure

5.1 General

All tests should be carried out in a clean laboratory environment. Failure to achieve a satisfactory blank level test of contamination could indicate unsuitable control of test conditions (see C.2). Clean room conditions according to ISO 14644-1, class 8, shall be employed as a minimum for these procedures, unless a suitable alternative can be demonstrated.

Before starting the test procedure, the outer surface of the component or assembly should be thoroughly cleaned by using a solvent such as detailed in 4.7.2.

This document covers the following components of the fuel injection equipment:

a) pumps:

   1) high-pressure supply pumps (common rail fuel injection system) (see 5.2);

   2) unit injectors (see 5.3);

   3) fuel injection pumps (see 5.4);

b) injectors:

   1) CR fuel injectors (see 5.5);

   2) fuel injectors (nozzle holder assemblies) (see 5.6);

c) pipes and rails:

   1) high-pressure fuel injection pipes (see 5.7);

   2) rails (see 5.8);

d) low-pressure systems (see 5.9).

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

— equipment set-up and verification (the verification corresponds to the qualification test and blank level requested in ISO 16232:2018, Clause 6);

— testing procedure.

In cases where more than one test procedure for a component is specified, the experience has shown that for removal of typical particles produced in the manufacture of these components, the test procedure with a turbulent flow and with pulsating pressure (simulation method) is preferred, simulating actual operating conditions.

When the simulation method is impractical, then the second test procedure should to be used as a more pragmatic means for removal of contaminants.

If neither the simulation method nor the second test procedure prove practical to the supplier or customer, by agreement a "flushing" test procedure (syringe or solvent dispenser method) may be used as an alternative.

The determination of:

— the test procedure to be used,

— as well as of the number of components to be tested,

shall be by agreement between the fuel injection equipment supplier and customer.

5.2 High-pressure supply pumps (common rail fuel injection system)

5.2.1 General

This subclause describes two test procedures for checking the cleanliness of high-pressure supply pumps:

— the preferred test is a dynamic test with the test pump running;

— if the dynamic test is not practical, a flushing test at low speed with the test pump running by hand should be used.

5.2.2 Dynamic test with the test pump running

5.2.2.1 Equipment set up and verification (qualification test and blank level) of cleanliness

a) Set up the equipment for verifying the system as shown in Figure A.1 (see A.2.2, NOTE 3), using a clean high-pressure supply pump of the same type as to be tested; the test bench shall have a separate test reservoir for the calibration fluid. Instead of a clean pump a clean dummy or a hydraulic short cut may be used.

b) The calibration fluid used should be as described in 4.7.1, pre-filtered using a filter as described in 4.8, permanently fixed in the system and replaced regularly.

c) Verify the system according to Annex C.

5.2.2.2 Test procedure

a) Replace the clean high-pressure supply pump by the pump to be tested; the pump shall be fully open (any flow regulating devices or throttling devices are not active).

b) Connect a tube to the high-pressure outlet(s) and another one to the low-pressure return flow outlet(s), both without any pressure regulation devices. Only if the pump needs a minimum system pressure for its safe operation, a pressure regulation device may be applied.

c) Run pump on test at ≥ 500 min $^{-1}$ and similarly but separately collect 1 l of test fluid at the high-pressure outlet (s) and 1 l at the low-pressure outlet.

d) Separately and similarly measure and count the contaminant output (particles) from every outlet according to Clause 6.