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Internal Combustion Engines – Exhaust Gas After-treatment – Particle Filter Systems – Testing Method

Verbrennungsmotoren – Abgasnachbehandlung – Partikelfiltersysteme – Prüfverfahren

Moteurs à combustion – Post-traitement des gaz d’échappement – Systèmes de filtres à particules – Méthode de test

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The standardization committee INB/NK 205 << Abgasnachbehandlung von Verbrennungsmotoren >> of the interdisciplinary sector is in charge of the present standard.

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Foreword

SN 277206 was developed by the “INB/NK 205 Internal Combustion Engines Exhaust Treatment Committee” of the Swiss Association for Standardisation (SAS). This committee comprised representatives from industry, trade associations, the federal administration, universities, research institutions and testing centres, as well as various technical experts. Its secretariat was managed by the SAS.

The objective of this standard is to define the methods and procedures for testing the efficiency and suitability of particle filter systems for internal combustion engines. These procedures are required for evaluating particle filter systems for heavy duty vehicles, public transport buses, construction machines and stationary equipment, as well as for cars with diesel engines.

The testing method described in this document takes the form of a component test, for the purpose of which the particle filter system (in its entirety) is regarded as a single component, for example of a utility vehicle or construction machine. It is the properties and behaviour of this component (i.e. the particle filter system) that are tested, not the emission behaviour of the vehicle or machine.

SN 277206 has mainly been developed on the basis of the former SNR 277205 and the VERT suitability test which was developed within the scope of a research project and has been in use for approximately 10 years. It describes how particle filter systems should be tested in terms of operational, physical and chemical aspects. However, it does not specify requirements relating to thresholds to be met.

In the same way as all other standards, SN 277206 is not legally binding. It is a consensus document that has the nature of a recommendation. Standards only become legally binding when they are integrated into private agreements or referred to in acts and ordinances in which their application is formally specified. This also applies to the question whether a full test with all sub-tests is to be carried out, or only certain sub-tests.

Introduction

Diesel and other internal combustion engines emit particles in their exhaust that are harmful to health. Ultrafine soot particles are of particular relevance, since they can penetrate into the lungs and are carcinogenic. Emissions of carcinogenic substances have to be minimised with the aid of the best available technology.

Today, highly effective particle filters are available which are capable of reducing the number of emitted particles by more than 99 percent. This standard describes how particle filter systems should be tested in terms of efficiency and suitability. It strongly focuses on the efficiency of particle filter systems with respect to the filtration of ultrafine particles.

The philosophy of this standard is based on the following six principles:

1. Filtration is a physical process that always observes the same principles under comparable conditions. It mainly depends on particle size and the velocity of the exhaust flows through the filter. Therefore the initial test bench procedure is focused on physical properties of the filter systems, which are basically independent of the subsequent area of application of the filter.

2. The filter systems of a given manufacturer which are based on the same filtration technology and comprise the same main components, are similarly designed and only differ from one another in terms of size, are grouped into filter “families”. With respect to functional similarity of the filter systems of one filter family, only a test of one model per family is required because the test results can be transferred to all other members of that family.

3. The evaluation of the filtration properties of a particle filter system solely relies on the filtration efficiency for ultrafine solid particles in the size range from 20 to 300 nanometer (nm), which is the most important particle fraction of health relevance. The filter evaluation is carried out using a reliable measurement procedure that delivers meaningful results. To avoid measurement-related artefacts due to condensation of semi-volatile substances, hot gas dilution is used and the measurements are limited to solid particles.

4. Filtration results obtained with a test engine can be transferred to other diesel engines if the engine and filter size are aligned with one another so that the velocity of exhaust flow through the filter (space velocity) does not exceed the level applied in the filtration test.

5. Particle filter systems can generate toxic secondary emissions, especially if catalytically active substances (e.g. catalytic filter coatings or fuel additives) are applied to support filter regeneration. This standard therefore calls for the testing of secondary emissions.

6. With respect to the later use of the particle filter system, an additional field test (endurance test) is carried out in addition to the laboratory tests. This test is performed in a typical application (e.g. filter installed in a construction machine, road vehicle, or a stationary motor) to identify weaknesses of a filter system during prolonged use under realistic conditions.

1 Scope of application

This standard applies to the testing of particle filter systems installed for the purpose of particle emission reduction in the exhaust from internal combustion engines.

Note: The focus is on testing particle filter systems for the retrofit of in-use vehicles, machinery and engines. However, parts of this standard can also be applied for testing particle filter systems for original equipment manufacturing (OEM).

2 Normative references

SN EN ISO 8178-1:1996, Reciprocating internal combustion engines -- Exhaust emission measurement -- Part 1: Test-bed measurement of gaseous and particulate exhaust emissions (ISO 8178-1:1996

SN EN ISO 8178-2:1996, Reciprocating internal combustion engines -- Exhaust emission measurement -- Part 2: Measurement of gaseous and particulate exhaust emissions at site (ISO 8178-2:1996)

SN EN ISO 8178-4:1996, Reciprocating internal combustion engines -- Exhaust emission measurement -- Part 4: Test cycles for different engine applications (ISO 8178-4:1996)

SN EN ISO 8178-6:2000, Reciprocating internal combustion engines -- Exhaust emission measurement -- Part 6: Report of measuring results and test (ISO 8178-6:2000)

ISO 11614:1999, Reciprocating internal combustion compression-ignition engines — Apparatus for measurement of the opacity and for determination of the light absorption coefficient of exhaust gas

ISO 15900:2009, Determination of particle size distribution — Differential electrical mobility analysis for aerosol particles

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

SN EN 14792:2006, Stationary source emissions - Determination of mass concentration of nitrogen oxides (NOx) - Reference method: Chemiluminescence

3 Definitions

The following definitions are applicable for this standard:

Term	**Definition**
Additive	Catalytically active substance (often an organo-metallic compound) that is added in small quantities (in the ppm range) to the motor fuel and is transformed into an active catalytic substance due to the formation of ultrafine metal oxides during combustion. As a result of the catalytic activity the ignition temperature of the accumulated soot in the filter is lowered and the chemical reaction is accelerated. Additives are regarded as *equal*, if they come from the same manufacturer, comprise the same catalytically active substances and are used in a concentration (ppm) that is not more than twice as high as the additive concentration originally specified by the manufacturer.

Coating	Covering a part of, or the complete, surface of a filter element exposed to exhaust containing a catalytically active substance. As a result of the catalytic activity the ignition temperature of the accumulated soot in the filter is lowered and the chemical reaction is accelerated. Coatings are regarded as *equal*, if they comprise the same kind and quantity (± 30 %) of catalytically active substances.
Exhaust opacity	Criterion for optical opacity of engine exhaust due to the presence of particles in the exhaust. Measured with an opacimeter indicating the opacity coefficient with the unit [m^{-1}].
Filtration efficiency	The filtration efficiency of a filter is calculated as the difference of 1 minus penetration as a number, or 100 % minus penetration as a percentage. Different filtration efficiencies are defined according to the parameter to be measured. With particle emissions this standard always relates to filtration efficiency which is based on the number of solid particles (particle number efficiency). Filtration efficiency is usually indicated as a percentage. A negative filtration efficiency indicates higher emissions after the filter system and points to secondary formation of pollutants.
Internal combustion engine	Piston engine that produces a mechanical force through the internal combustion of a fuel. Internal combustion refers to combustion within the engine's working area. In addition to diesel, petrol and fossil gases, fuels may also include combustible liquid or gaseous biogenic substances.
Mobility diameter	The mobility diameter is equivalent to the diameter of a sphere that indicates the same mobility as the observed particle (which is normally not spherical). Note: The mobility diameter is not dependent on the density of the particle.
Particle filter family	Filter systems which are based on the same filter technology, contain the same main components, are similarly designed and only differ in terms of size and geometry (e.g. radial versus axial flow), form a filter family. Note: the term "main components" is explained under "Particle filter system".
Particle filter system	System for filtering particles from engine exhaust. The main components of a particle filter system are as follows: • Filter element (filter medium) • Catalytic components (catalytic converters, coatings or additives) • Regeneration device (burner or electric ignition) Secondary components are as follows: • Electronic control unit • Additional elements (additive dosage device or injection device of additional fuel to support filter regeneration)
Particle number concentration	Number of solid particles with a mobility diameter of between 20 and 300 nm per gas volume unit in a given size class. Note: Solid particles are separated from liquid droplets by diluting the exhaust and feeding it through a pipe heated up to 573 K (300° C). This procedure is comparable to the Particle Number Emissions Measurement method in accordance with UN ECE Regulation R.83, Annex 4a, Appendix 5.

Particles	Components of the exhaust that are dispersed at 573 K (300° C) in the form of solid particles or droplets in suspension.
Penetration	Ratio of a parameter measured after the filter (i.e. in the filtered gas) versus the corresponding parameter measured before the filter (i.e. in the unfiltered gas). Alternatively, to the ratio "after the filter / before the filter", also the ratio "with filter / without filter" may be defined as penetration. Different degrees of penetration are defined according to the parameter to be measured. For particle emissions, this standard always indicates degree of penetration with respect to the particle number. Degree of penetration is usually indicated as a percentage. A penetration above 100 % indicates higher emissions after the filter, which points to the formation of secondary pollutants.
Regeneration	Combustion of soot collected and stored in the filter element. This process is initiated when the combustion temperature of the soot is reached in the filter element. Regeneration of a filter may take place continuously or intermittently. If the regeneration process is initiated via a control unit or impulse, for example in combination with the input of energy, this is referred to as active regeneration (as opposed to passive regeneration).
Secondary emissions	Emissions of pollutants that are formed as a result of particle filter use, or the concentration of which increases due to the use of a particle filter system. These pollutants may be produced in the engine during combustion or in the particle filter itself. They may take the form of gaseous compounds or particles and concern pollutants that are or are not subject to legally specified limits.
Space velocity	Ratio of exhaust flow under operating conditions (effective pressure and temperature) in the particle filter system (m^3/s) to the volume of the particle filter medium (m^3). Note: Space velocity is a chemical engineering term. It is not strictly a velocity, but has the dimension 1/time. It is equivalent to the reciprocal value of the residence time of the exhaust gas in the particle filter system.

4 Abbreviations

Abbreviation	Name in full
CO	Carbon monoxide
CPC	Condensation particle counter
FBC	Fuel-borne catalyst
HC	Hydrocarbons
NO	Nitrogen monoxide, nitric oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides

5 Testing a filter system

5.1 Overview of test procedure

The test procedure for particle filter systems consists of several separate tests, some of which only have to be carried out once, while others need to be repeated. Table 1 presents an overview of the procedure, together with a brief description of the main content of each test.

Table 1 – Overview of test procedure

Step	Nature of test	Main content of test	Section
A	Technical documentation and visual inspection	Description of technical functions of the filter system and visual inspection of the submitted model.	5.2
B	Filtration test of brand new filter	With stationary engine operation: Measurement of particle number filtration efficiency, for solid particles ranging from 20 to 300 nm.	5.3.3
C	Regeneration test	Measurement of exhaust temperature and pressure loss of filter upon initiation of filter regeneration, and of particle and gaseous emissions arising during regeneration.	5.4
D	Secondary emissions test	Measurement of toxic substances produced by the filter system.	5.5
E	Control functions test before endurance test	Testing of electronic control unit and monitoring of filter system, storage of operating parameters, issue of warnings and alarms.	5.6
F	Endurance test	Practical testing of filter system during typical use over a period of at least 1,000 operating hours.	5.7
G	Filtration test after endurance test	With stationary engine operation: Measurement of particle number filtration efficiency, for solid particles ranging from 20 to 300 nm.	5.3.4
H	Control functions test after endurance test	Same as E	5.6
I	Test report	Summary and comments on test and measurement results.	9

5.2 Technical documentation and visual inspection

A detailed technical description of the filter system must be submitted to the laboratory in advance, including information on material and structure of the filter medium, regeneration technology, type and use of catalytically active substances, monitoring of functions, thresholds relating to exhaust temperature and space velocity (or residence time) of the exhaust in the filter.

In addition, a visual inspection should be made to verify:

- That a type plate is affixed to the filter casing that indicates allocation to the particle filter family and includes the serial number of the filter.

- That the filter casing contains a closable measuring opening before the filter element.
- That the direction in which the exhaust flows through the filter is clearly marked by an arrow.
- That structural measures make it impossible to install the filter element in the reverse direction.

5.3 Filtration test

5.3.1 Introduction

Tests of the filtration properties of particle filter systems are carried out on a test bench as described in section 6.

The particle number filtration efficiency can be determined in two ways, namely with “after filter / before filter” or “with filter / without filter” measurements. Both methods are acceptable.

If the particle filter system functions with fuel additives, when the “after filter / before filter” method is used, the “before filter” measurement must be made without the addition of the additive. This ensures that any emissions of additive particles and their influence on the filtration efficiency can be recorded.

5.3.2 Filter size and size of test engine

For the filtration test, the size of the particle filter system to be tested and the test engine must be aligned to one another. At rated power of the test engine the space velocity in the filter system must attain the manufacturer’s indicated maximum permissible level with a tolerance of +/- 10 %. If necessary, for testing purposes a particle filter system of the corresponding size must be built (as a representative for the filter family to be tested), or the maximum rate of gas flow through the test engine must be restricted accordingly by limiting the engine power.

Filter size for endurance test:
Depending on the application in which the endurance test is to be performed, another filter size in the same filter family may be selected. In such cases, in the filtration test the size of the particle filter system to be tested after the endurance test can deviate from the recommended size for the test engine.

Special cases relating to filtration test after endurance test:
In certain justified cases (e.g. with very large filters which cannot be installed on the usual test engines), the filtration test after the endurance test may be carried out on the application itself in correspondingly adapted test stages.

5.3.3 Testing a brand new filter

Before a brand new filter is tested it has to be preconditioned (de-greened) in accordance with the manufacturer's instructions or by operating it at full load for at least 30 minutes. The purposes of this procedure are to eliminate low-volatile substances that originate from the manufacturing of the filter, and to stabilise the behaviour of the filter.

The filtration test has to be carried out as follows:

Status of filter	Mode of operation of test engine, Filter properties to be tested
Filter prior to regeneration	With stationary operation in accordance with stationary test cycle 5-7-3-1-5 (cf. section 7.1.2), in each test stage the following filter properties should be tested: • Particle number filtration efficiency, by particle size class (cf. section 8.2.5) or integral (cf. section 8.2.6) • Pressure loss of the filter
Filter after regeneration	With stationary operation in accordance with stationary test cycle 5-7-3-1-5 (cf. section 7.1.2), in each test stage the following filter properties should be tested: • Particle number filtration efficiency, by particle size class (cf. section 8.2.5) or integral (cf. section 8.2.6) • Pressure loss of the filter

5.3.4 Testing a filter after the endurance test

After the endurance test, the filter has to be measured in its status at time of supply.

The filtration test has to be carried out as follows:

Status of filter	Mode of operation of test engine, Filter properties to be tested
Filter in supply status	With stationary operation in accordance with stationary test cycle 5-7-3-1-5 (cf. section 7.1.2), in each test stage the following filtration properties should be tested: • Particle number filtration efficiency, by particle size class (cf. section 8.2.5) or integral (cf. section 8.2.6) • Pressure loss of the filter

5.4 Regeneration test

The regeneration test is carried out on a test bench as described in section 6.

The following tests have to be carried out:

Status of filter	Mode of operation of test engine, Filter properties to be tested
Filter in loaded status	With passive filters, regeneration is carried out in accordance with the regeneration cycle as described in section 7.3. With active filters, regeneration is carried out in accordance with the instructions of the filter manufacturer. The following should be measured at intervals of one second: • Exhaust temperature before and after filter • Pressure loss of filter • Gaseous emissions: CO, HC and NO_x after filter • Particle number, integral (cf. 8.2.6), after filter For particle and gaseous emissions, the ratio of emissions during the entire regeneration phase to the emissions during an equally long period of time without filter has to be calculated.

Note: With the regeneration test, other particle measurement methods than particle number measurements in accordance with section 8.2.6 may be used, provided it has been proven that they result in equivalent ratios of emissions.

5.5 Secondary emissions test

If the particle filter system includes catalytically active components (e.g. a catalytic coating or a catalytically active additive), a test has to be carried out concerning the occurrence of secondary emissions.

Tests for secondary emissions are carried out on a test bench as described in section 6.

5.5.1 Nitrogen dioxide (NO_2)

Status of filter	Mode of operation of test engine, Filter properties to be tested
Preconditioned filter	Measurements are carried out in stationary operation of the test engine at rated speed. The load is increased in steps of 10 % from 10 % to 100 % of the maximum engine torque. Measurements of pollutants at each load stage are carried out as soon as the exhaust temperature has settled at a stationary level. The following measurement has to be carried out at each stage: • Emissions of NO_2 and NO_x before and after the filter (or without and with filter) The results are used for calculating the NO_2/NO_x ratios.

5.5.2 Trace substances

The changes in emissions of toxic pollutants, especially carcinogenic or genotoxic substances, are to be compared with the emissions of the test engine without a particle filter system using the base fuel (i.e. fuel without additive in accordance with section 6.2.2) (reference point).

A fuel with chlorine additive is used for assessing the dioxin formation potential. The chlorine content of the base fuel (6.2.2) is raised to 10 mg/kg by adding 1.6-dichlorohexane.

If a catalytically-active fuel additive (FBC) is to be used, using the base fuel (6.2.2) a fuel is to be produced which contains the catalytically active components in double the concentration of the dosage specified by the manufacturer. The chlorine content of a part of this fuel is also raised to 10 mg/kg by adding 1.6-dichlorohexane.

Depending on the filter type, four or five configurations are required for testing for the following pollutants:

The following substances have to be measured as leading compounds for the corresponding classes of compounds (indicated in parentheses). Further substances need to be included in this list if well-founded reasons for a possible formation exist for a given particle filter system (cf. explanations in Annex B).

- 1.3-butadiene, benzene (volatile organic compounds, VOC)
- Formaldehyde, acetaldehyde (oxidised volatile organic compounds, VOCOX)
- Pyrene, fluoranthene, chrysene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indene(1,2,3-cd)pyrene (polycyclic aromatic hydrocarbons, PAH)
- 1-nitronaphthalene, 2-nitronaphthalene, 3-nitrophenanthrene, 9-nitrophenanthrene, 9-nitroanthracene, 3-nitrofluoranthene, 1-nitropyrene (nitrated polycyclic aromatic hydrocarbons, nitro-PAH)

- All 2,3,7,8-chlorinated dibenzodioxins/furanes (polychlorinated dibenzodioxins/furanes, PCDD/F)
- All catalytically active elements that occur on the filter coating or in the additive.

<table>
<tr><th>Filter type and status</th><th>Test configurations</th></tr>
<tr><td>Catalytically coated filter prior to endurance test</td><td>The stationary 8-point cycle (cf. 7.1.1) should be carried out twice in each of the following four test configurations (total measurement time per test configuration is 200 minutes).
• Reference point: engine operated with base fuel without particle filter
• Engine operated with base fuel with particle filter
• Engine operated with fuel with chlorine additive, without particle filter
• Engine operated with fuel with chlorine additive, with particle filter
For the first two test configurations, all the pollutants listed above must be recorded.
For the test configurations with fuel with chlorine additive, PCDD/F emissions must be recorded and the other pollutants may be recorded again as repeat measurements.</td></tr>
<tr><td>Filter with catalytic fuel additive (FBC)
prior to endurance test</td><td>The stationary 8-point cycle (cf. 7.1.1) should be carried out twice in each of the following five test configurations (total measurement time per test configuration is 200 minutes).
• Reference point: engine operated with base fuel without particle filter
• Engine operated with fuel with FBC, without particle filter
• Engine operated with fuel with FBC, with particle filter
• Engine operated with fuel with chlorine additive and FBC, without particle filter
• Engine operated with fuel with chlorine additive and FBC, with particle filter
For the first three test configurations, all the pollutants listed above must be recorded.
For the test configurations with fuel with chlorine additive, PCDD/F emissions must be recorded and the other pollutants may be recorded again as repeat measurements.</td></tr>
</table>

In the fuel with additive, the chlorine content and the content of catalytic additives must be determined.

The content of the same elements also has to be determined in the lubricating oil that is used.

5.6 Control functions test

The manufacturer of the electronic control unit of the particle filter system must declare the technical specifications of the unit in a separate data sheet.

The laboratory has to verify whether the following control functions and minimum requirements are secured in the manufacturer’s declaration:

- Recording of pressure loss at intervals of one second.
- Electronic storage of peak pressure loss readings at one-minute intervals, with storage capacity for at least one operating month.
- Issue of an alarm if the pressure loss (or back pressure) exceeds a given level (e.g. 200 mbar) for longer than 5 seconds. The alarm setting must be programmable in steps not exceeding 5 mbar. The alarm must be stored in a memory that cannot be overwritten and cannot be deleted.
- Issue of a warning if pressure loss (or back pressure) exceeds a given level (e.g. 150 mbar) for longer than 5 seconds. The warning setting must be programmable in steps not exceeding 5 mbar and up to a maximum of 80 % of the alarm level. The warning must be stored in a memory that cannot be overwritten and cannot be deleted.
- Issue of an alarm if a (too low) pressure loss is registered that points to damage to the filter (e.g. leak to the exterior, or fissure / rupture in the filter element). The alarm must be stored in a memory that cannot be overwritten and cannot be deleted.
- In the case of particle filter systems that operate with fuel additives, it is to verify that the additive dosage is interrupted in the event of filter damage (with simultaneous triggering of an alarm) and that an alarm is triggered if the minimum level in the additive tank is reached.

5.7 Endurance test

For an endurance test, the particle filter system is installed in a typical application on site that corresponds to its intended purpose, and is put into operation for a period of at least 1,000 hours.

The content of the test is as follows:

- Field testing of a particle filter system (sealed by the test laboratory) for a period of at least 1,000 operating hours.
- Reports concerning the use, maintenance and repairs of the engine concerned and its consumption of fuel and lubricating oil.
- Continuous data logging of exhaust temperature before the filter and pressure loss of the filter (to be carried out by the filter manufacturer or operator of the machine).
- At the beginning and end of the endurance test: measurement of the opacity of the exhaust at free acceleration by an inspector from the test laboratory.
- In the case of particle filter systems that operate with fuel additives: verification of the reliability of dosage by the manufacturer (additive and fuel consumption, data logging of additive system, etc.).

6 Test bench

6.1 Test bench set-up

For the set-up of the test bench and for carrying out test bench measurements, ISO 8178-1 applies unless this standard should stipulate to the contrary.

The test bench and test engine must be designed and dimensioned in such a manner as to ensure that the test cycles in accordance with section 8 can be properly performed and the required pollutant measurements can be carried out.

Figure 1 depicts the basic configuration of the test bench and for the collection of samples.

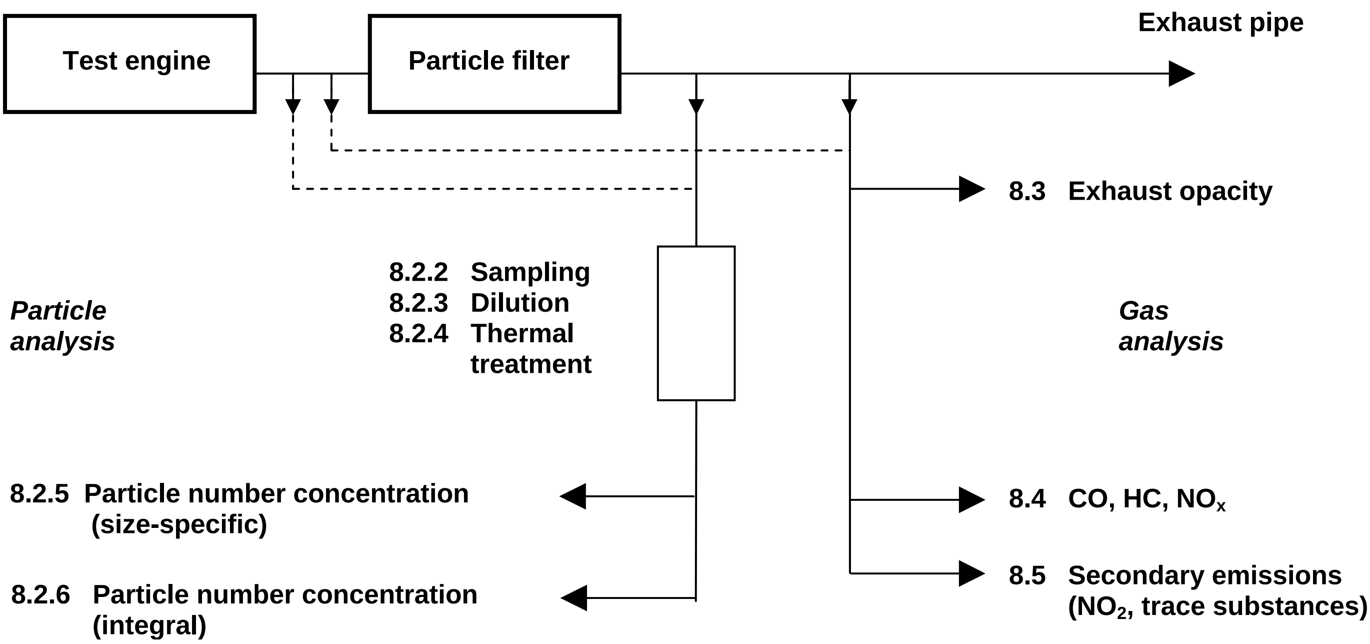

Figure 1: Basic configuration of test bench and for collection of samples

Hints for carrying out measurements

The control and monitoring parameters of the test engine should be recorded, namely:

Pressures and temperatures in the air and exhaust feeds to all main interfaces, especially directly before and after the filter to be tested; coolant temperature; lubricating oil pressure and temperature; fuel and air flow.

6.2 Test engine, fuel, lubricating oil

6.2.1 Test engine

Any 4-stroke diesel engine without exhaust gas recirculation and without exhaust after-treatment may be used as a test engine.

The engine and filter system to be tested must be matched so that, at rated power of the test engine, the space velocity of the exhaust gases in the particle filter reaches the maximum permissible level in accordance with the filter manufacturer’s specifications (cf. section 5.3.2).

6.2.2 Base fuel

The fuel used for operating the test engine must comply with standard EN 590 (Base fuel).

6.2.3 Lubricating oil

The specifications of the lubricating oil must be included in the test report.

7 Test cycles

7.1 Stationary multiple-point cycles

The stationary test cycles to be used are based on test cycle type C1 in accordance with ISO 8178-4. Either all or only some of the test stages have to be carried out, according to the details provided in sections 7.1.1 to 7.1.3. The cited test stages have to be carried out in ascending order. With respect to the terms “rated speed” and “intermediate speed”, reference is made to ISO 8178-4.

7.1.1 Stationary 8-point cycle

This test cycle corresponds to type C1 in accordance with ISO 8178-4. The duration of the full cycle is 100 minutes. The engine settings and duration of each test stage are indicated in Table 2.

Table 2: Stationary 8-point cycle

Stationary 8-point cycle	Rated speed				Intermediate speed			Idle
Test stage	1	2	3	4	5	6	7	8
Relative torque M [%]	100	75	50	10	100	75	50	0
Duration of test stage [minutes]	15	15	15	10	10	10	10	15

7.1.2 Stationary test cycle 5-7-3-1-5

This test cycle comprises test stages 5, 7, 3, 1 and 5 from type C1 in accordance with ISO 8178-4 (cf. section 7.1.1). Test stage 5 is repeated for control purposes. The required measurements must be carried out at each stage, though contrary to section 7.1.1 the duration of the test stages is based on the time requirement for carrying out the prescribed measurements.

7.2 Free acceleration

7.2.1 Conditioning of the engine

The test engine has to be run until the engine oil has reached a constant temperature.

7.2.2 Test cycle

With the engine idling, the accelerator control shall be operated quickly, but not violently, so as to obtain maximum delivery from the injection pump. This position shall be maintained until maximum engine speed is reached and the governor of the injection pump reduces the injected fuel quantity in order to stabilise the engine at cut-off speed. As soon as this speed is reached the accelerator shall be released until the engine resumes its idling speed. The engine must be allowed to idle for at least 10 seconds before the cycle may be repeated.

The brake remains coupled to the engine throughout the test. However, the stationary load should be set to zero.

For the measurement of exhaust opacity during free acceleration, the acceleration procedure described above must be repeated at least six times (cf. section 8.3).

In the case of systems for which free acceleration cannot be carried out due to the nature of their construction, the free acceleration test cycle may be substituted by a repeatable converter acceleration or load switching.

7.3 Regeneration cycle

The regeneration cycle is carried out in stationary operation at constant engine speed. Here, the filter is loaded with soot, then regeneration is triggered by gradually increasing the engine torque (cf. Figure 2).

1. The loading of the filter with soot takes place at a load that results in an exhaust temperature that is lower than the regeneration temperature. This loading procedure is maintained for four hours or until the pressure loss of the filter reaches 160 mbar.

2. To trigger regeneration, the engine torque at rated speed is increased at 10-minute intervals by 10 % of the maximum torque at rated speed up to full load.

Here the exhaust temperature before the filter is recorded when the pressure loss of the filter does not continue to increase although the loading of the filter goes on. (In this "balance point" prevails a balance between filter loading and regeneration).

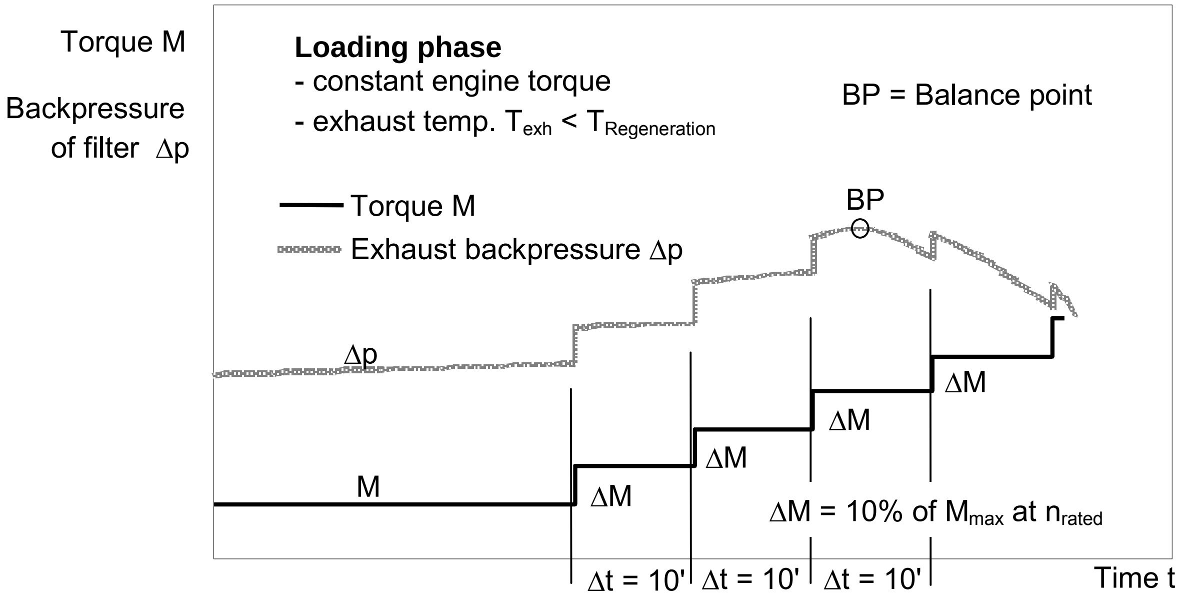

Figure 2: Regeneration cycle

8 Measurement methods

8.1 Introduction

The reliability of the measurements must be assured in that the suitability of the devices used for this purpose has been demonstrated, the devices are calibrated at appropriate intervals and thus the results are traceable to national or international standards. This requirement is fulfilled if the test laboratory concerned has been certified in accordance with ISO 17025.

ISO 8178-1 applies unless this standard should stipulate to the contrary.

8.2 Particle analysis with stationary operation

8.2.1 Introduction

The purpose of particle analysis is to determine the filtration efficiency in terms of particle number, in function of particle size. Particles are defined as the solid or liquid aerosol components at 573 K (300 ° C).

The measuring system for analysing particles comprises the following components:

- Sampling of a continuous partial flow from the exhaust
- Dilution system with sufficient degree of dilution using particle-free air, which minimises losses of particles due to coagulation, and lowers vapour pressures of volatile exhaust components to avoid condensation.
- Heater for evaporating volatile exhaust components

- Device for classifying particles in dependence on their electrical mobility diameter
- Device for measuring particle number concentration

Measurements are normally carried out in sequence with the same measuring system at both collection points (before / after the filter system) or without / with filter system.

Losses of particles occurring in the measurement system must not result in false readings. They must be sufficiently constant in terms of time, within each size category and over the full concentration range.

The residence time of the exhaust sample from entry into the probe head to measurement of particle number should be kept as short as possible, and must not exceed 10 seconds.

Note: Measurement of the penetration or filtration efficiency is a relative measurement in which two readings (before the filter / after the filter) are compared with each other. For relative measurements it is recommended to measure the two measurands one after the other (rather than at the same time) with the same device or equipment. In this way the degree of measurement uncertainty can be reduced. However, if two measurement systems are used, their compatibility must be demonstrated before each measurement.

8.2.2 Sampling

Sampling points should be located as close to the particle filter as possible, though in any case not further away than three times the diameter of the exhaust pipe.

A constant flow sample is taken from the exhaust that is representative in terms of composition.

The residence time of the exhaust sample from entry into the probe head to subsequent dilution should not exceed one second, and the flow conditions must be laminar, with a Reynolds number < 1,000.

Note 1: The sampling probe may take the form of a simple pipe. It should be affixed rectangularly to the flow direction of the exhaust and ends at a distance of between one-third and half the diameter of the exhaust pipe.

Note 2: A steel tube with an internal diameter of 8 mm is suitable for a flow of approx. 1 litre per minute.

8.2.3 Dilution

The particle number concentration has to be reduced through dilution to levels below 10^5 per cm^3. The dilution air may not contain more than 10 particles per cm^3.

The dilution factor should be selected to ensure that the particle measurement device is operated within the calibrated measurement range.

The dilution factor must remain constant throughout the measurement procedure and may not vary by more than 2 %.

The degree of uncertainty of the dilution factor must be less than 10 %.

Note: A dilution of approximately 1:1,000 is recommended for the sampling upstream of the particle filter, and approximately 1:10 downstream of the particle filter.

8.2.4 Thermal treatment of exhaust sample

The diluted exhaust sample must be heated to 573 K ± 5 K (300 ˚C ± 5 ˚C) and maintained at this temperature for at least 0.2 seconds.

Note: With an exhaust flow of 1.5 litres per minute (1 litre/min.) the residence time in a tube with an internal diameter of 6 mm (8 mm) and a length of 240 mm is around 0.27 seconds (0.72 sec.).

The thermally treated exhaust sample may be split into 2 parts, one for measuring the size-specific and the other for integral measurement.

8.2.5 Measurement of particle size distribution

The particle number concentration of the thermally treated sample must be recorded in relation to the particle size. For this purpose, the principle of electrical mobility analysis and the measurement of the particle number concentration in accordance with ISO 15900 has to be applied at least in the range between 20 and 300 nm with at least 8 logarithmic, equidistant size classes per size decade.

The degree of uncertainty of the particle size analysis must be less than 10 %. The reproducibility for measurement of the particle number concentration must be less than 10 %.

Note: The mobility diameter is used as the variable for the particle size.

8.2.6 Integral particle measurement

The particle number concentration of the thermally treated exhaust sample must be recorded as a total number concentration at least in the range between 20 and 300 nm.

The degree of uncertainty for the particle number concentration must be less than 20 %. The reproducibility for measurement of the particle number concentration must be less than 10 %.

8.3 Exhaust opacity

The exhaust opacity is measured with an opacimeter. This device determines the peak level of opacity (light intensity reduction) as the absorption coefficient of a partial exhaust flow as well as idle speed and cut-off speed of the engine during free acceleration.

The construction and basic requirements placed on an opacimeter are specified in ISO 11614.

The cycle described in section 7.2.2 must be repeated at least 6 times, in order to cleanse the exhaust system and adjust the device where necessary. The highest levels of the absorption coefficients have to be recorded for each of the sequential accelerations until constant readings are obtained. The levels that arise when the engine is idling after the accelerations are not to be taken into account. The obtained readings are regarded as constant if four successive readings are within the range of 0.25 m^{-1} and no continual decrease is observed. The absorption coefficient to be recorded is the arithmetical average of these four levels.

Note: With the latest engines and highly efficient particle filters, the sensitivity of the opacity measurement at free acceleration no longer suffices to evaluate the condition of the filter system. The opacimeter can be substituted by a device for measuring the particle number concentration. If a sudden change in particle number concentration is produced at the sampling point, the response of the instrument follows with a time delay and is attenuated according to the response time of the device. With suddenly changing particle number concentrations (e.g. during free acceleration), special attention thus has to be paid to the response time of the particle measurement device. However, validated specifications for carrying out particle number measurements under such conditions do not yet exist.

8.4 Gas analysis

ISO 8178-1 applies unless this standard should stipulate to the contrary.

With measurements on the test bench, NO, NO_2 and NO_x measurements can be carried out in accordance with EN 14792. CO, HC and NOx measurements may also be carried out with the aid of FTIR (Fourier transformation infrared spectroscopy) if equivalence with ISO 8178-1 can be demonstrated.

In an endurance test the NO_x measurement must be carried out with a measuring device that meets the requirements of the METAS guidelines on exhaust gas measuring devices for construction machines.[1]

8.5 Analysis of secondary emissions

The methods used for analysing secondary emissions must be designed in terms of detection limits and measurement uncertainties in such a manner as to ensure that an increase in emissions formed by the particle filter system by 30 % (versus emissions without the particle filter system or without the additive) can be detected.

If the raw exhaust from the test engine does not contain the respective component, the method used must be suitable to detect pollutant concentrations at levels relevant to health.

Methods for measuring secondary pollutants are listed in Annex B.

9 Test report

The results of the particle filter system test must be documented in a test report that includes:

- Details concerning the laboratory and test (name of laboratory or test centre, name of person responsible for the test, date of the test, reference number of report)
- A text section containing introductory remarks, references to special circumstances, comments on the test results
- Completed data sheets (cf. Annex D)
- Enclosures, e.g. description of testing installations, sketches, circuit diagrams, installation regulations, maintenance regulations

[1] Swiss Federal Office of Metrology (METAS): Guidelines governing exhaust gas measuring equipment for construction machinery (17 March 2000). http://www.metas.ch

Annex A
(informative)

Particle filter families

A.1 Transferability of test results

A.1.1 Filtration results (5.3)

Filters of the same filter family:
Filtration results that have been obtained from a representative of a filter family may be transferred to other particle filter systems of the same family if the systems are operated with a space velocity which is not higher than the maximum space velocity used for the filtration test (cf. 5.3.2).

Other filters from the same filter system manufacturer:
Filtration results that have been obtained from a representative of a filter family may be transferred to other filter families, if they have the identical filter medium (same material, same structure, same coating) and are operated with a space velocity which is not higher than the maximum space velocity used for the filtration test (cf. 5.3.2).

Other engine:
Filtration results that have been obtained with a test engine may be transferred to other diesel engines if the filter system is operated with a space velocity which is not higher than the maximum space velocity used for the filtration test (cf. 5.3.2).

A.1.2 Regeneration results (5.4)

Other engine in field operation:
Regeneration results that have been obtained from a representative of a filter family on a test engine may not be transferred to other diesel engines in field operation since the operating conditions (especially exhaust gas temperatures) significantly influence the processes relating to regeneration.

A.1.3 Secondary emission results (5.5)

Filters with catalytic coating, with or without DOC:
Secondary emission results that have been obtained from a representative of a filter family without DOC may be transferred to other filter families with or without DOC, if the filter medium has the same coating (cf. chapter 3).

Filters with catalytic fuel additive, with or without DOC:
Secondary emission results that have been obtained from a representative of a filter family without DOC may be transferred to other filter families with or without DOS, if the filter medium has the same coating (cf. chapter 3) and if the identical catalytic fuel additive is used in a concentration (ppm) that is not more than twice as high as the additive concentration originally specified by the manufacturer.

If other or additional catalytically active elements exist in a filter family, secondary emission results cannot be transferred.

A.1.4 Endurance test results (5.7)

Other use in field operation:
Findings concerning the performance and durability of the filter obtained from (typical) use of a representative of the filter family during the endurance test may only be transferred to other uses in the field under certain conditions, since the conditions of use (especially mechanical and thermal demands) can significantly influence the durability of a particle filter system.

A.2 Modifications to a tested particle filter family

If modifications are carried out after a representative of a given filter family has been tested, depending on the type of modification a complete new test or partial test (and in some cases, no test) may be required, depending on the specific situation. Some indications are provided below.

- A complete new test is required if the filter medium has been modified, since this concerns another, new filter family.

- A new secondary emissions test is required if the concentration of one of the catalytically active substances has been changed by more than +/- 30 %.

- A partial new test is required if secondary components of the filter system have been modified. As a rule, it is necessary to repeat the endurance test and afterwards to carry out a filtration test.

- As a rule, no new testing is required if the modification merely concerns the dimensions (size) of the filter, since the filter family itself remains the same.

Annex B
(informative)

Measurement of secondary emissions

B.1 Introduction

Depending on the method of exhaust gas treatment and the properties of the catalytically active substances, a variety of reaction products may be formed. The most important of these are toxic substances with carcinogenic, mutagenic, teratogenic or hormone-like effects.

For example, it is known that platinum-based catalytic converters increase NO_2 emissions, while those containing copper produce substantial amounts of polychlorinated dibenzodioxins and -furanes (PCDD/F) if chlorine is present. On the other hand, particle filter systems often significantly reduce emissions of polycyclic aromatic hydrocarbons (PAH), including carcinogenic ones.

The data cited in section 5.5 and in this Annex are binding for catalytic particle filter systems. Because it is not possible to list all potential secondary emissions, the catalogue of substances to be measured should be adjusted whenever reasons for a potential formation of further secondary pollutants exist.

B.2 Secondary emissions

Nitrogen dioxide (NO_2)

Nitrogen dioxide (NO_2), a toxic secondary pollutant formed in the presence of strongly oxidising catalytic converters (e.g. platinum), has to be measured in addition to nitrogen monoxide (NO). Here the analysis is carried out on the dry exhaust gas using a heated sampling line and a chemiluminescence detector (CLD) or Fourier transform infrared spectroscopy (FTIR).

Volatile organic compounds (VOC)

Benzene and 1.3-butadiene, both carcinogenic substances, have to be analysed as toxicologically relevant leading compounds for more than 100 known gaseous hydrocarbons. A proportion of the exhaust is collected in gas-tight bags. The content of each hydrocarbon is determined with a gas chromatography flame ionisation detector (GC-FID).

Oxidised volatile organic compounds (VOCOX)

Formaldehyde and acetaldehyde, both highly reactive and carcinogenic gases, have to be measured as toxicologically relevant leading compounds in the class of partially oxidised volatile hydrocarbons. A proportion of the exhaust is fed through a dinitrophenylhydrazine solution during the sampling process (chemisorption). The reactive aldehydes are converted to the corresponding hydrazones and thus stabilised. The derivatives are separated by means of liquid chromatography and the contents are measured with a UV/VIS photometer (LC-UV/VIS).

Polycyclic aromatic hydrocarbons (PAH)

As leading compounds for the PAH class of substances, at least the following carcinogenic substances have to be analysed: chrysene, benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene. In addition, the contents of pyrene and fluoranthene, which are precursor compounds for mutagenic nitro PAHs, also have to be measured. PAHs can appear both in particulate and gaseous form. A proportion of the exhaust is filtered in a multi-stage glass apparatus (dioxin train), cooled below dew point and fed through an adsorption material. The integral sample, which includes PAHs present in the gas, liquid and solid phases, is purified and fractionated by means of liquid chromatography. Separation is carried out with a gas chromatograph (GC), and quantification is achieved by means of high resolution mass spectrometry (GC-HRMS).

Nitrated polycyclic aromatic hydrocarbons (nitro-PAH)

There are numerous nitration products found in NO_x-rich diesel exhaust. As leading compounds for the nitro-PAH class of compounds, at least the mutagenic substances 3-nitrofluoroanthene and 1-nitropyrene have to be measured. In order to evaluate the nitration potential of the filter system, the following substances which are more common and thus more readily accessible for analysis are measured as representatives of other mutagenic and carcinogenic nitro-PAHs: 1-nitronaphthalene, 2-nitronaphthalene, 3-nitrophenanthrene, 9-nitrophenanthrene, and 9-nitroanthracene. Other mutagenic and carcinogenic nitro and di-nitro PAHs are also of interest, but their contents are generally lower. Nitro-PAHs are also sampled in the glass apparatus described above. Separation of individual isomers and quantification are carried out by means of GC-HRMS.

Polychlorinated dibenzodioxins / furanes (PCDD/F)

As leading compounds for the 210 PCDD/Fs, at least the 17 toxic 2,3,7,8-chlorinated PCDD/Fs and the resulting overall toxicity (TEQ or toxicity equivalent) have to be determined. The overall toxicity is deduced from the concentrations of the 17 toxic isomers and their relative toxicity (toxicity equivalence factor). PCDD/Fs are also retained in the glass apparatus described above. The integral sample is purified by means of liquid chromatography. Separation and quantification of individual isomers is achieved with gas chromatography, combined with high-resolution mass spectrometry (GC-HRMS).

Catalytically active elements (coating metals and additives)

The catalytically active elements of fuel additives and filter coatings (as specified by the manufacturer) have to be measured. The particles or particle-bound compounds are fractionated into 13 size classes from proportionally diluted exhaust using a 12-stage electric low-pressure impactor and a backup filter. The metal content of each size class is quantified using microwave digestion followed by inductively-coupled plasma mass spectrometry (ICP-MS).

B.3 Measurement methods for secondary emissions

Parameter	Sampling	Analytical method	Standard
NO_2	Heated sampling line from undiluted exhaust gas	Chemiluminescence detector (CLD) or Fourier transform infrared spectroscopy (FTIR)	EN 14792 ISO 16000 DIN EN ISO 16017
VOC	From exhaust diluted to a constant volume flow (CVS tunnel)	Gas chromatography flame ionisation detector (GC-FID)	ISO 16000 DIN EN ISO 16017
VOCOX	From exhaust diluted to a constant volume flow (CVS tunnel), chemisorption in dinitrophenylhydrazine solution	Liquid chromatography ultraviolet detector (LC-UV/VIS)	ISO 16000 DIN EN ISO 16017
PAH	Flow proportional sampling from undiluted exhaust, multiple stage glass apparatus based on the filter/condenser method (UNE-EN 1948-1)	Gas chromatography high-resolution mass spectrometry (GC-HRMS) or Liquid chromatography ultraviolet/fluorescence detector (LC-UV/fluorescence)	VDI 3874

Nitro-PAH	Flow proportional sampling from undiluted exhaust, multiple stage glass apparatus based on the filter/condenser method (UNE-EN 1948-1)	Gas chromatography high-resolution mass spectrometry (GC-HRMS)	VDI 3874
PCDD/F	Flow proportional sampling from undiluted exhaust, multiple stage glass apparatus based on the filter/condenser method (UNE-EN 1948-1)	Gas chromatography high-resolution mass spectrometry (GC-HRMS)	UNE-EN 1948
Catalytically active elements (metals)	Flow proportional sampling from undiluted exhaust, size-fractionated sampling with 12-stage electric low-pressure impactor (ELPI) plus backup filter	Microwave digestion, inductively-coupled plasma mass spectrometry (ICP-MS)	DIN EN 13890 DIN 51002-1

Annex C
(informative)

Special filter tests

C.1 Acceptance test on site

This is not a part of the overall particle filter test in the sense of section 5 of this standard, but rather is a special, separate filter test.

The aim of an acceptance test on site is to examine whether a filter from a given filter family yields the anticipated results in a specific application immediately after beginning of operation.

Here the following properties of the particle filter system have to be tested:

- Exhaust opacity with free acceleration in original engine status and after installation of the particle filter system.
- Emissions of CO, HC and NO_x at maximum engine speed and maximum configurable load of the engine, in the original engine status and after installation of the particle filter system.
- Pressure loss at maximum speed and maximum configurable load.
- Noise emissions in original engine status and after installation of the particle filter system (near-field measurement at a distance of 0.5 metres from the exhaust pipe at 45 degrees from the flow axis).

C.2 Testing attachable filters

Attachable filters are filters that can be installed reversibly for short-term use at the exhaust exit of vehicles for temporary operating phases in closed premises. As a rule they are equipped with disposal filter cartridges, and do not require either regeneration measures or electronic monitoring. In accordance with this standard, only a filtration test (5.3) applies to attachable filters.

C.3 Testing particle filter systems for original equipment manufacturing

Particle filter systems for original equipment manufacturing (OEM) can be tested in accordance with this standard.

The original equipment manufacturer of the engine, vehicle or machine is responsible for guaranteeing the regeneration behaviour and functionality of the system in long-term usage.

Test steps B, D and G (cf. 5.1) are applicable to OEM particle filter systems.

In justified cases, the filtration test may be carried out on a practice-oriented basis in appropriately adapted test stages.

Annex D
(normative)

Test report data sheets

Table D.1 — Test report: Data and description of test object

Particle filter system (complete system)				
Manufacturer of particle filter system (complete system)				
Name of particle filter family				
Name of particle filter type				
Serial number of test object				
Filter element and catalytic converter				
		Filter element	Pre-cat	Post-cat
Manufacturer of filter medium				
Name of type				
External dimensions	[mm]			
Filter volume	[dm^3]			
Active filter surface	[m^2]			
Weight	[kg]			
Material				
Porosity	[%]			
Pore size	[µm]			
Number of cells per square inch	[CPSI]			
Wall thickness	[mm]			
Maximum flow-through rate	[m^3/s]			
Maximum permissible space velocity	[s^{-1}]			

Table D.1 — Test report: Data and description of test object (continued)

Maximum operating temperature [°C]			
Storage capacity for soot/ash [g]			
Regeneration			
Regeneration procedure			
Minimum exhaust gas temperature for initiating regeneration procedure [°C]			
if catalytic coating			
	Filter element	Pre-cat	Post-cat
Manufacturer of coating			
Coating: catalytically active elements			
Wash coat: catalytically active elements			
Concentration of catalytically active elements [g/litre]			
if fuel borne catalyst (FBC)			
Manufacturer of FBC			
Name of FBC			
Catalytically active elements			
Concentration of catalytically active elements in the additive [mg/kg]			
Concentration of catalytically active elements in fuel [mg/kg]			
Dosage (additive per fuel] [ml/litre]			
Additive dosage procedure			
Name of dosage device			
Electronic control unit			
Manufacturer of control unit			
Name of control unit type			
Serial number of test object			

Table D.2 — Test report: Visual inspection and control functions test

Visual inspection (5.2)	
Description of cleaning and maintenance procedure	☐ yes ☐ no ☐ not inspected
Existence of identification plate with serial number and indication of particle filter family	☐ yes ☐ no ☐ not inspected
Measurement access upstream of filter element	☐ yes ☐ no ☐ not inspected
Flow-through direction indicated by arrow	☐ yes ☐ no ☐ not inspected
Reversal of filter element prevented through structural measures	☐ yes ☐ no ☐ not inspected
Control functions test (5.6)	
In the declaration issued by the manufacturer of the electronic control unit, control functions and minimum requirements in accordance with 5.6 are assured	☐ yes ☐ no ☐ not inspected

Table D.3 — Test report: Test engine data

Manufacturer / type	
Emission level (legal exhaust emission stage)	
Cylinder number and configuration	
Bore / stroke	[mm]
Overall displacement	[dm^3]
Compression ratio	[-]
Serial number / year of manufacture / operating hours	
Cooling medium (air, water, etc.)	
Combustion process (direct injection, pre-chamber, etc.)	
Injection system type	
Speed governor	
Supercharging	
Charge air cooling system	
Measures to reduce emissions	
Rated power / rated speed	[kW] @ [min^{-1}]
Low idle speed / high idle speed	[min^{-1}] [min^{-1}]

Test stages of motor in accordance with ISO 8178-4, test cycle C1 (corresponds to stationary 8-point cycle as per section 7.1.1)								
	Rated speed				Intermediate speed			Idle
Test stage	1	2	3	4	5	6	7	8
Speed [min^{-1}]								
Torque [Nm]								
Power output [kW]								

Table D.4 — Test report: Fuel and lubricating oil data (only if deviating from EN 590)

Base fuel (without additive)			
Type			
Manufacturer			
Properties	**Method**	**Unit**	
Density	ISO 3675	kg/litre	
Cetane number	ISO 5165	-	
Cetane index	ISO 4264	-	
Sulphur content	ISO 4260 / 8754	mg/kg	
Chlorine content		mg/kg	
Cloud point	ISO 3015	°C	
Pour point	ISO 3016	°C	
Flash point	ISO 2719	°C	
Viscosity	ISO 3104	mm^2/s	
Calorific value		MJ/kg	
Aromatic hydrocarbons	ISO 3837	% vol	
C content		% mass	
H content		% mass	
Distillation range (IBP)	ISO 3405		
10 vol %		°C	
50 vol %		°C	
90 vol %		°C	
Lubricating oil			
Manufacturer / specification			
Viscosity	[mm^2/s]		
Sulphate ash (ISO 3687)	[% mass]		
ACEA or API category			
Chlorine content	[mg/kg]		

Table D.5 — Test report: Results of filtration test (5.3)

Space velocity at rated power during filtration test (5.3.2)	[s^{-1}]	

Filtration efficiency with stationary operation of test engine

The table below must be completed for measurements before and after regeneration.

Test cycle stage	Particle size class	Particle size range [nm]	Particle number before filter [cm^{-3}]	Particle number after filter [cm^{-3}]	Penetration [%]	Filtration efficiency [%]	Pressure loss of filter [kPa]
5	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	Integral						
7	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	Integral						

Table D.5 — Test report: Results of filtration test (5.3) (continued)

Filtration efficiency in stationary operation

The table below must be completed for measurements before and after regeneration

Test cycle stage	Particle size class	Particle size range [nm]	Particle number before filter [cm^{-3}]	Particle number after filter [cm^{-3}]	Penetration [%]	Filtration efficiency [%]	Pressure loss of filter [kPa]
3	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	Integral						
1	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	Integral						

Table D.5 — Test report: Results of filtration test (5.3) (continued)

Filtration efficiency in stationary operation

The table below must be completed for measurements before and after regeneration

Test cycle stage	Particle size class	Particle size range [nm]	Particle number before filter [cm^{-3}]	Particle number after filter [cm^{-3}]	Penetration [%]	Filtration efficiency [%]	Pressure loss of filter [kPa]
5 (repeated)	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	Integral						

Table D.6 — Test report: Results of regeneration test (5.4)

Key regeneration data

Maximum pressure loss of filter during the regeneration cycle	[kPa]	
Exhaust temperature upon attaining balance point (BP)	[°C]	

Emissions during regeneration cycle

CO

Torque		Without filter	With filter	
[%]	[Nm]	CO [ppm]	CO [ppm]	K_{CO} [%]
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
Integral				

HC

Torque		Without filter	With filter	
[%]	[Nm]	HC [ppm]	HC [ppm]	K_{HC} [%]
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
Integral				

$$K_X = \frac{X_{without\,DPF} - X_{with\,DPF}}{X_{without\,DPF}}$$

K_X Reduction rate of component X

X Exhaust components (CO, HC, NO_x, PN)

Table D.6— Test report: Results of regeneration test (5.4) (continued)

Emissions during regeneration cycle

NO_x

Torque		Without filter	With filter	
[%]	[Nm]	NO_x [ppm]	NO_x [ppm]	K_{NOx} [%]
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
Integral				

PN (particle number concentration)

Torque		Without filter	With filter	
[%]	[Nm]	PN [1/cm^3]	PN [1/cm^3]	K_{PN} [%]
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
Integral				

$$K_X = \frac{X_{without\,DPF} - X_{with\,DPF}}{X_{without\,DPF}}$$

K_X Reduction rate of component X

X Exhaust components (CO, HC, NO_x, PN)

Table D.7.1 — Test report: Results of secondary emissions test

Nitrogen dioxide (5.5.1)

Torque		Measurement **before** filter (or without filter)				Measurement **after** filter (or with filter)					
at rated speed = min^{-1}		Exhaust temp.	NO_2	NO_x	NO_2/ NO_x	Exhaust temp.	NO_2	NO_x	NO_2/ NO_x	ΔNO_2	ΔNO_2/ NO_x *)
Level	M [Nm]	[°C]	[ppm]	[ppm]	[%]	[°C]	[ppm]	[ppm]	[%]	[ppm]	[%]
10 %											
20 %											
30 %											
40 %											
50 %											
60 %											
70 %											
80 %											
90 %											
100 %											

$\Delta NO_2 = NO_{2\text{ with DPF}} - NO_{2\text{ without DPF}}$

*) $\Delta NO_2/NO_{x\text{ with DPF}}$

Table D.7.2 — Test report: Results of secondary emissions test

Trace substances with catalytically coated filters (5.5.2)

- Emissions in four test configurations using base fuel and fuel with chlorine additive.
- The PCDD/F emissions have to be measured in all four test configurations.
- The other pollutants may be measured additionally, as repeat measurements (fields in the table with a grey background).
- The average change in emissions has to be calculated for each pollutant as follows.

Average change [%] = (1 - Awith/Awithout) × 100 %

Key: Awith = average from all measurements with filter (columns 3 and 5)
Awithout = average from all measurements without filter (columns 2 and 4)

Pollutant (1)	Emission without filter with base fuel (2)	Emission with filter with base fuel (3)	Emission without filter with chlorine additive (4)	Emission with filter with chlorine additive (5)	Average change [%] (6)	Increase is significant [yes/no] (7)
Benzene *						
1.3-Butadiene *						
Formaldehyde *						
Acetaldehyde *						
PAH * (total)						
Pyrene						
Fluoranthene						
Chrysene *						
Benz(a)-anthracene *						
Benzo(b)-fluoranthene *						
Benzo(k)-fluoranthene *						
Benzo(a)-pyrene *						

Pollutant (1)	Emission without filter with base fuel (2)	Emission with filter with base fuel (3)	Emission without filter with chlorine additive (4)	Emission with filter with chlorine additive (5)	Average change [%] (6)	Increase is significant [yes/no] (7)
Indene(1,2,3-cd)pyrene *						
Nitro-PAH (total)						
1-nitro-naphthalene						
2-nitro-naphthalene						
3-nitro-phenanthrene						
9-nitro-phenanthrene						
9-nitro-anthracene						
3-nitro-fluoranthene *						
1-nitropyrene *						
PCDD/F (TEQ total)						
2,3,7,8-TCDD						
1,2,3,7,8-PCDD						
1,2,3,4,7,8-HxCDD						
1,2,3,6,7,8-HxCDD						
1,2,3,7,8,9-HxCDD						
1,2,3,4,6,7,8-HpCDD						
OCDD						

Pollutant (1)	Emission without filter with base fuel (2)	Emission with filter with base fuel (3)	Emission without filter with chlorine additive (4)	Emission with filter with chlorine additive (5)	Average change [%] (6)	Increase is significant [yes/no] (7)
2,3,7,8-TCDF						
1,2,3,7,8-PCDF						
2,3,4,7,8-PCDF						
1,2,3,4,7,8-HxCDF						
1,2,3,6,7,8-HxCDF						
1,2,3,7,8,9-HxCDF						
2,3,4,6,7,8-HxCDF						
1,2,3,4,6,7,8-HpCDF						
1,2,3,4,7,8,9-HpCDF						
OCDF						

* carcinogenic or mutagenic

Table D.7.3 — Test report: Results of secondary emissions test

Metallic trace elements with catalytically coated filters (5.5.2)

- Emissions in two test configurations when using base fuel without and with filter.
- Change in emissions is to be calculated for each impactor stage as follows:

Change [%] = (1 - with/without) × 100 %

Key: with = measurement with filter (column 3)
without = measurement without filter (column 2)

- A separate test report sheet has to be completed for each chemical element of the catalytic coating.

No.	Chemical element of catalytic coating

Impactor stage (1)	Emission without filter (2)	Emission with filter (3)	Change [%] (4)	Increase is significant [yes/no] (5)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13 (Backup filter)				

Table D.7.4 — Test report: Results of secondary emissions test

Trace substances with filters with catalytic fuel additive (FBC) (5.5.2)

- Emissions in five test configurations using base fuel, fuel with FBC, and fuel with FBC and chlorine additive.
- The PCDD/F emissions have to be measured in all five test configurations.
- The other pollutants may be measured additionally, as repeat measurements (fields in the table with grey background).
- The average change in emissions has to be calculated for each pollutant as follows:

Average change [%] = (1 - Awith/Awithout) × 100 %

Key: Awith = average from all measurements with filter (columns 4 and 6)
Awithout = average from all measurements without filter (columns 2, 3 and 5)

	Chlorine content	FBC content
Fuel with FBC		
Fuel with FBC and chlorine additive		

Pollutant (1)	Emission w/o filter w/o FBC with base fuel (2)	Emission w/o filter with FBC with base fuel (3)	Emission with filter with FBC with base fuel (4)	Emission w/o filter with FBC with chlorine additive (5)	Emission with filter with FBC with chlorine additive (6)	Average change [%] (7)	Increase is significant [yes/no] (8)
Benzene *							
1,3-butadiene *							
Formaldehyde *							
Acetaldehyde *							
PAH * (total)							
Pyrene							
Fluoranthene							
Chrysene *							
Benz(a)-anthracene *							

Pollutant (1)	Emission w/o filter w/o FBC with base fuel (2)	Emission w/o filter with FBC with base fuel (3)	Emission with filter with FBC with base fuel (4)	Emission w/o filter with FBC with chlorine additive (5)	Emission with filter with FBC with chlorine additive (6)	Average change [%] (7)	Increase is significant [yes/no] (8)
Benzo(b)-fluoranthene *							
Benzo(k)-fluoranthene *							
Benzo(a)-pyrene *							
Indene(1,2,3-cd)pyrene *							
Nitro-PAH (total)							
1-nitro-naphthalene							
2-nitro-naphthalene							
3-nitro-phenanthrene							
9-nitro-phenanthrene							
9-nitro-anthracene							
3-nitro-fluoranthene *							
1-nitro-pyrene *							
PCDD/F (TEQ total)							
2,3,7,8-TCDD							
1,2,3,7,8-PCDD							
1,2,3,4,7,8-HxCDD							

Pollutant (1)	Emission w/o filter w/o FBC with base fuel (2)	Emission w/o filter with FBC with base fuel (3)	Emission with filter with FBC with base fuel (4)	Emission w/o filter with FBC with chlorine additive (5)	Emission with filter with FBC with chlorine additive (6)	Average change [%] (7)	Increase is significant [yes/no] (8)
1,2,3,6,7,8-HxCDD							
1,2,3,7,8,9-HxCDD							
1,2,3,4,6,7,8-HpCDD							
OCDD							
2,3,7,8-TCDF							
1,2,3,7,8-PCDF							
2,3,4,7,8-PCDF							
1,2,3,4,7,8-HxCDF							
1,2,3,6,7,8-HxCDF							
1,2,3,7,8,9-HxCDF							
2,3,4,6,7,8-HxCDF							
1,2,3,4,6,7,8-HpCDF							
1,2,3,4,7,8,9-HpCDF							
OCDF							

*   carcinogenic or mutagenic

Table D.7.5 — Test report: Results of secondary emissions test

Metallic trace elements with filters with catalytic fuel additive (FBC) (5.5.2)

- Emissions in three test configurations using base fuel and fuel with FBC.
- Change in emissions is to be calculated for each impactor stage as follows:

  Change [%] = (1 - with/without) × 100 %

  Key: with = measurement with filter, with FBC (column 4)
  without = measurement without filter, without FBC (column 2)

- A separate test report sheet has to be completed for each chemical element of the catalytic fuel additive.

No.	Chemical element of catalytic fuel additive

Impactor stage (1)	Emission without filter without FBC (2)	Emission without filter with FBC (3)	Emission with filter with FBC (4)	Change [%] (5)	Increase is significant [yes/no] (6)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13 (Backup filter)					

Table D.8 — Test report: Results of endurance test (5.7)

Particle filter system	
Supplier of filter system	
Filter system type / serial number	
Data logger type / serial number	
Additive dosage device type / serial number	

Type of usage	
Stationary or mobile	

System / vehicle data	
Manufacturer of system / vehicle / engine	
Name of system / vehicle / engine type	
Rated power / displacement	
Serial number (inventory number)	
Operating company / site of operation	

Table D.8 — Test report: Results of endurance test (5.7) (continued)

Measurement of pressure loss and exhaust opacity		
	At start of endurance test	**At end of endurance test**
Date		
Status of operating hours meter [hrs] or mileage indicator [km]		
Pressure loss of filter at high idle [hPa]		
Exhaust opacity **before** filter at free acceleration [m^{-1}]		
Exhaust opacity **after** filter at free acceleration [m^{-1}]		

Operating data of endurance test	
Installation of filter: date and status of operating hours [hrs] or mileage indicator [km]	
Removal of filter: date and status of operating hours [hrs] or mileage indicator [km]	
Gross usage time [hrs]	
Of which repair time [hrs]	
Effective usage time of filter system [hrs]	
Effective pressure range during endurance test [hPa]	
Effective temperature range during endurance test [°C]	