
**Reciprocating internal combustion
engines — Exhaust emission
measurement —**

**Part 3:
Test procedures for measurement of
exhaust gas smoke emissions from
compression ignition engines using a
filter type smoke meter**

*Moteurs alternatifs à combustion interne — Mesurage des émissions
de gaz d'échappement —*

*Partie 3: Définitions et méthodes de mesure de la fumée des gaz
d'échappement dans des conditions stabilisées*



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Published in Switzerland

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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/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement*.

This second edition cancels and replaces the first edition (ISO 8178-3:1994), which has been technically revised.

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

- smoke measurement by an opacimeter has been removed; this will be handled in ISO 8178-9;
- definitions of exhaust gas components related to exhaust gas smoke has been added.

This document is intended to be used in conjunction with ISO 10054.

A list of all parts in the ISO 8178 series can be found on the ISO website.

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

There exist several measurement methods to determine the components of smoke emissions. Each method is measuring special properties of smoke. Therefore, the results obtained with different methods are typically not comparable among each other.

The objective of this document is to give a guidance for measurement of soot with a filter type smoke meter, knowing about the different components of the smoke of compression ignition engines and their particular properties.

An overview of the measurement methods specified by ISO 8178-1, ISO 8178-3, ISO 8178-9 and ISO 9096 is given in [Annex B](#).

Correlation formulae to calculate the mass concentration of black carbon out of the filter smoke number (FSN) are given in [Annex C](#).

The characteristics required for filter-type-smoke meters are defined in ISO 10054.

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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 3:

Test procedures for measurement of exhaust gas smoke emissions from compression ignition engines using a filter type smoke meter

1 Scope

This document specifies a method for the measurement of smoke from exhaust gas of reciprocating internal combustion (RIC) engines at a steady state condition. The method evaluates the soot content by measurement of the blackening of a filter and derivation of black carbon mass concentration (mg/m³) from FSN. Where necessary, individual requirements may be specified for particular engine applications.

This document is applicable to RIC engines for mobile, transportable and stationary use, excluding engines for on-road transport of passengers and goods. It can be applied to engines for non-road use, e.g. for earth-moving machines, generating sets and for other applications. For engines used in machinery covered by additional requirements (e.g. occupational health and safety regulations, regulations for power plants) additional test conditions and special evaluation methods can apply.

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 10054, *Internal combustion compression-ignition engines — Measurement apparatus for smoke from engines operating under steady-state conditions — Filter-type smoke meter*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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 <http://www.electropedia.org/>

3.1

filter-type smoke meter

instrument in which a given exhaust gas volume is passed through a clean filter of a certain area and the blackness condition of this filter is subsequently used to define the *filter smoke number* (3.3)

3.2 effective filtered column length

L_F
length of the gas column actually passing through the filter, taking into account dead volume and leakage in the sampling system

Note 1 to entry: Effective filtered column length is expressed in mm.

3.3 filter smoke number FSN

standardized unit conforming to ISO 10054, expressing the smoke characteristics of an exhaust gas, represented by the degree of blackening of a clean filter caused by the *soot* (3.6) in a given column of exhaust gas passing through this filter

3.4 Bosch smoke number SN

measuring unit expressing the smoke characteristic of the exhaust gas, obtained with a Bosch smoke meter, represented by the degree of blackening of a filter, caused by the *soot* (3.6) in a given column of exhaust gas passing through this filter

Note 1 to entry: The Bosch smoke number corresponds to an *effective filtered column length* (3.2) of 405 mm, but it does not have a defined pressure and temperature as the basis.

3.5 exhaust gas smoke

visible suspension of solid and/or liquid particles in gases resulting from combustion or pyrolysis

Note 1 to entry: The exhaust gas smoke, may be black smoke, blue smoke, brown smoke or white smoke depending on the components present in the exhaust gas after the combustion or pyrolysis process. Black smoke [also referred to as "*soot*" (3.6)] is mainly due to the presence of carbon particles. Blue smoke is usually due to droplets resulting from the incomplete combustion of fuel or lubricating oil. Brown smoke is due to the presence of NO₂ in the exhaust gas. White smoke is usually due to condensed water and/or liquid fuel.

3.6 soot

all components contained in the exhaust gas and blackening a filter

Note 1 to entry: Major component of soot is *black carbon* (3.8), formed by incomplete combustion of fossil fuels, renewable fuels and biomass.

3.7 particulate matter PM

any material collected on a specified filter medium after diluting exhaust with clean filtered air to a temperature and a point as specified in ISO 8178-1

EXAMPLE *Elemental carbon* (3.9), condensed hydrocarbons and sulphates with associated water.

3.8 black carbon BC

distinct type of carbonaceous material, formed only in flames during combustion of carbon-based fuels

Note 1 to entry: It is distinguishable from other forms of carbon and carbon compounds contained in atmospheric aerosol because it has a unique combination of the following physical properties: strong absorption of light, refractory nature, insoluble and graphitic structure.

Note 2 to entry: This definition is adapted from Reference [8].

Note 3 to entry: The black carbon is reported in the following according to the details in Reference [9], Table 1.

3.9 elemental carbon EC

carbonaceous fraction of *particulate matter* (3.7) that is not removed from a filter sample heated to temperatures greater than 1 143 K (870 °C) in an inert atmosphere, excluding char

Note 1 to entry: See Reference [12], Figure 5.1.

4 Smoke measurement by a filter-type smoke meter (FSN)

4.1 Application

This method is suitable for evaluating the content of soot in exhaust gas.

4.2 Principle

A sample of exhaust gas is extracted from the exhaust pipe through a sampling line and passed through a filter of a known area. The blackening of the filter is caused by soot contained in this sampled gas column. The blackening is a measure of the content of soot in the exhaust gas and is calculated from the optical reflectance of the blackened filter relative to a clean filter according to [Formula \(1\)](#).

$$\text{FSN} = \left(1 - R'_b / R'_c\right) \times 10 \quad (1)$$

where

R'_b is the reflectometer value of the blackened filter;

R'_c is the reflectometer value of the clean filter.

For an accurate measurement of low soot concentrations a prolonged column length may be necessary. This may be obtained either by multiple operations of the instrument without changing the filter paper or — where the suction volume is controlled by a continuously working pump — by an extended operating time of the pump.

4.3 Measurement with a filter-type smoke meter

4.3.1 Installation of a filter-type smoke meter

A probe and sampling line recommended by the instrument manufacturer is to be used. The probe shall be installed in the exhaust gas pipe in a way that a representative sampling is possible and the engine operation is not affected.

If water or a reagent for an exhaust gas after treatment device is injected into the exhaust system, the probe shall be installed upstream of the point of injection.

The temperature of the exhaust sample in the sampling system is to be maintained above the dew point.

4.3.2 Engine operating conditions

A steady-state engine operation is required for the FSN method. Operating values like load, speed and exhaust gas temperature may be used to judge the steadiness of the engine. Speed and load may vary only in a small range. Declarations of the engine manufacturer shall be respected.

4.3.3 Sensitivity to fuel oil

The type of fuel which is burned during the measurement may cause sensitivities to the measurement.

4.3.4 Measurement procedure

If required a sufficient warming up time of the measurement equipment according to the manufacturer's specifications shall be maintained.

The exhaust gas sample shall be drawn into the probe and sampling line and passed through the filter with a homogeneous flow per unit area (for instance, using a piston pump or a continuous working pump). The effective gas column length (L_F) is calculated as the ratio of the effective suction volume to the blackened area of the filter. This length is indicated by the manufacturer of the instrument.

The FSN shall be given corresponding to an effective suction length of 405 mm, 25 °C (298 K) and 100 kPa.

4.4 General requirements

The measuring apparatus shall comply with ISO 10054.

4.5 Gas temperature and pressure

The FSN and carbon mass concentration (mg/m^3) measurement results shall be referenced to 25 °C (298 K) and 100 kPa using the method indicated by the instrument manufacturer. For other reference conditions refer to [Annex D](#).

5 Test report

If required, a test report according to [Annex A](#) shall be generated.

Annex A (normative)

Emission test report — Smoke test data

Table A.1 — ISO 8178 Emissions test report — FSN test data

Engine type		Instrument					
Manufacturer		Manufacturer					
Rated speed	min ⁻¹	Type and model					
Rated power	kW						
Test site		Date					
Fuel type							
Run		1	2	3	4	5	6
Ambient data							
Barometric pressure	kPa						
Intake air temperature	°C						
Intake air humidity	%						
Engine operating conditions							
Power	kW						
Speed	min ⁻¹						
Exhaust temperature at probe inlet	°C						
Exhaust pressure at probe inlet	kPa						
Temperature at instrument measuring cell	°C						
Pressure at instrument measuring cell	kPa						
Measured values							
FSN	(FSN)						
Black carbon mass concentration	mg/m ³						

Annex B **(informative)**

Overview particulate and soot measurement methods

In much of the scientific literature the terms soot, black smoke, black carbon (BC) and elemental carbon (EC) are used interchangeably, although soot, black smoke, BC and EC commonly have operational and source-based definitions, respectively, notwithstanding that reliable reference samples and aerosol standards do not exist for either one.

The filter-type smoke measurement method is used for the measurement of visible black smoke emissions. The measurement results (FSN) evaluated in accordance with this document, are different from the results obtained with the particulate-measurement methods described in ISO 8178-1 or in other standards and regulations.

There is a distinct difference between the results of this smoke measurement method and the results obtained with the measurement of opacity as described in ISO 8178-9. Whereas an opacimeter measures the fraction of light that traverses the exhaust gas, a filter type smoke meter measures the light, which is reflected by a filter blackened by exhaust gas.

Opacity based on light extinction (given by the absorption and the scattering of light) is sensitive to any kind of exhaust gas component which is absorbing and/or scattering the light passing the exhaust gas. It measures the components from the black, brown, blue and white smoke.

The FSN is sensitive to particulates which are blackening a filter and therefore it detects components which are absorbing light. These components are mainly elemental carbon.

For information about components and related measurement methods refer to [Figure B.1](#).

Components		Smoke Types		Measurement Methods	
sulfate associated water		white smoke		! ^a	! ^a
sulfates [SO ₄]	semi - volatile	blue smoke		! ^a	! ^a
organic carbon		blue smoke			
elemental carbon (EC)		black smoke			
ash fuel oil	non - volatile				
ash lube oil					
abrasion/wear					
NO ₂		brown smoke			
NO					
SO ₃		blue smoke			! ^a
SO ₂					! ^a
H ₂ O	volatile	white smoke			!
CO ₂					
CO					
O ₂					
N ₂					

Key

! contribution possible

^a Contribution can be minimized or even eliminated by use of appropriate fuel and lube oil.

NOTE Particle number and its measurement methods are not included in the figure. For more information refer to ISO 8178-1.

Figure B.1 — Exhaust components and measurement methods

Annex C (informative)

Correlation formulae

C.1 General

A number of filter type smoke meters are available. Therefore, the correlation formulae are specific for each type of instrument.

C.2 AVL Correlation formulae for the calculation of black carbon mass concentration

C.2.1 General

Calculation of BC mass concentration (mg/m³ in wet exhaust) from the FSN by means of AVL correlation formula:

Reference conditions $P_0 = 100$ kPa and $T_0 = 25$ °C.

C.2.2 Unheated conditions, $FSN \leq 8$

For measurements performed in unheated conditions (unheated instrument and unheated sampling lines) and $FSN \leq 8$, [Formula \(C.1\)](#) can be used^[11]:

$$BC = \frac{1}{0,405} \times FSN \times 4,95 \times \exp^{(0,38 \times FSN)} \quad (C.1)$$

C.2.3 Unheated conditions, $FSN > 8$

For measurements performed in unheated conditions (unheated instrument and unheated sampling lines) and $FSN > 8$, [Formula \(C.2\)](#) can be used^[11]:

$$BC = \frac{1}{0,405} \times FSN \times 4,95 \times \exp^{(0,38 \times FSN)} \times \left(1 + 10 \times \left[\frac{(FSN - 8)}{2} \right]^{10} \right) \quad (C.2)$$

C.2.4 Heated conditions, $FSN \leq 8,08$

For measurements performed with instruments operated in heated conditions (heated instrument and heated sampling lines) and $FSN \leq 8,08$, [Formula \(C.3\)](#) can be used^[11]:

$$BC = \frac{1}{0,405} \times FSN \times 5,32 \times \exp^{(0,3062 \times FSN)} \quad (C.3)$$

C.2.5 Heated conditions, $FSN > 8,08$