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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 10: Test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions

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

Partie 10: Cycles et procédures d'essai pour le mesurage sur site des émissions de fumées de gaz d'échappement des moteurs à allumage par compression fonctionnant en régime transitoire

Reference number
ISO 8178-10:2002(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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 8178 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 8178-10 was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement*.

ISO 8178 consists of the following parts, under the general title *Reciprocating internal combustion engines — Exhaust emission measurement*:

— *Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*

— *Part 2: Measurement of gaseous and particulate exhaust emissions at site*

— *Part 3: Definitions and methods of measurement of exhaust gas smoke under steady-state conditions*

— *Part 4: Test cycles for different engine applications*

— *Part 5: Test fuels*

— *Part 6: Report of measuring results and test*

— *Part 7: Engine family determination*

— *Part 8: Engine group determination*

— *Part 9: Test cycles and test procedures for test bed measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*

— *Part 10: Test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*

Annexes A, B and C form a normative part of this part of ISO 8178. Annex D is for information only.

Introduction

Throughout the world there currently exist many smoke measurement procedures in various forms. Some of these smoke measurement procedures are designed for test bed testing and may be used for certification or type-approval purposes. Others are designed for field testing and may be used in inspection and maintenance programmes. Different smoke measurement procedures exist to meet the needs of various regulatory agencies and industries. The two methods typically used are the filter smokemeter method and the opacimeter.

The objective of this part of ISO 8178 is to combine the key features of several existing smoke measurement procedures as much as is technically possible. This part of ISO 8178 is intended for the measurement of the emissions of smoke from compression ignition internal combustion engines under field conditions. It applies to engines operating under transient conditions – where the engine speed or load, or both, changes with time. It should be noted that the smoke emissions from typical well-maintained naturally-aspirated engines under transient conditions will generally be the same as the smoke emissions under steady state conditions.

Only opacimeter type smokemeters may be used for making the smoke measurements described in this part of ISO 8178. This part of ISO 8178 allows the use of either full-flow or partial-flow opacimeters. This part of ISO 8178 accounts for differences in response time between the two types of opacimeters, but does not account for any differences due to differences in temperatures at the sampling zone.

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 10: Test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions

1 Scope

This part of ISO 8178 specifies the measurement procedures and test cycles for the evaluation of smoke emissions from compression ignition engines under field conditions. This part of ISO 8178 is intended for use primarily as a support for in-use smoke testing programmes on engines that have been “certified” or “type approved” in accordance with the provisions of ISO 8178-9. ISO 8178-9 provides test procedures and test cycles for measurement of smoke from different applications of engines operating on the test bed.

Likewise, ISO 8178-4 specifies a number of different test cycles to be used in order to characterize gaseous and particulate emissions from nonroad engines. The test cycles in ISO 8178-4 were developed in recognition of the differing operating characteristics of various categories of nonroad machines.

For transient smoke test cycles, smoke testing is conducted using smokemeters that operate on the light extinction principle. The purpose of this part of ISO 8178 is to define the smoke test cycles and the methods used to measure and analyse smoke. Specifications for measurement of smoke using the light extinction principle can be found in ISO 11614. The test procedures and measurement techniques described in clauses 5 to 11 of this part of ISO 8178 are applicable to reciprocating internal combustion (RIC) engines in general. However, an engine application can only be evaluated using this part of ISO 8178 once the appropriate test cycle has been developed. Annexes A to C to this part of ISO 8178 each contains a test cycle that is relevant only for those specific applications listed in the scope of that annex. Where possible, the smoke test cycle described in the annex utilizes the engine and machine categories developed in ISO 8178-4.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 8178. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 8178 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 8178-4:1996, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 4: Test cycles for different engine applications*

ISO 8178-5, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 5: Test fuels*

ISO 8178-6, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 6: Report of measuring results and test*

ISO 8178-7, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 7: Engine family determination*

ISO 8178-8, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 8: Engine group determination*

ISO 8178-9:2000, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 9: Test cycles and test procedures for test bed measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*

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*

3 Terms and definitions

For the purposes of this part of ISO 8178 the following terms and definitions apply.

3.1
exhaust gas smoke
visible suspension of solid and/or liquid particles in gases resulting from combustion or pyrolysis

NOTE Black smoke (soot) is mainly comprised of carbon particles. Blue smoke is usually due to droplets resulting from the incomplete combustion of fuel or lubricating oil. White smoke is usually due to condensed water and/or liquid fuel. Yellow smoke is caused by NO_2.

3.2
transmittance
τ
fraction of light, transmitted from a source through a smoke-obscured path, which reaches the observer or the instrument receiver

NOTE It is expressed as a percentage.

3.3
opacity
N
fraction of light, transmitted from a source through a smoke-obscured path, which is prevented from reaching the observer or the instrument receiver ($N = 100 - \tau$).

NOTE It is expressed as a percentage.

3.4 Optical path length

3.4.1
effective optical path length
L_A
length of the smoke-obscured optical path between the opacimeter light source and the receiver, corrected as necessary for non-uniformity due to density gradients and fringe effect

NOTE 1 It is expressed in metres. 9.2 describes how to determine L_A and how to install measuring equipment, on exhaust systems that may be encountered in the field.

NOTE 2 Portions of the total light source to receiver path length which are not smoke obscured do not contribute to the effective optical path length.

3.4.2
standard effective optical path length
L_{AS}
measurement used to ensure meaningful comparisons of quoted opacity values

NOTE See 10.1.4.

3.5
light absorption coefficient
k
fundamental means of quantifying the ability of a smoke plume or smoke-containing gas sample to obscure light

NOTE By convention, the light absorption coefficient is expressed in reciprocal metres (m^{-1}). The light absorption coefficient is a function of the number of smoke particles per unit gas volume, the size distribution of the smoke particles, and the light absorption and scattering properties of the particles. In the absence of blue, white or yellow smoke or ash, the size distribution and the light absorption/scattering properties are similar for all diesel exhaust gas samples and the light absorption coefficient is primarily a function of the smoke particle density.

3.6
Beer-Lambert law
mathematical equation describing the physical relationships between the light absorption coefficient, k, the smoke parameters of transmittance, τ, and effective optical path length, L_A

NOTE Because the light absorption coefficient, k, cannot be measured directly, the Beer-Lambert law is used to calculate k, when opacity, N, or transmittance, τ, and effective optical path length, L_A, are known:

$$k = \frac{-1}{L_A} \ln \left(\frac{\tau}{100} \right) \tag{1}$$

$$k = \frac{-1}{L_A} \ln \left(1 - \frac{N}{100} \right) \tag{2}$$

3.7
opacimeter
instrument for the measurement of smoke characteristics using the optical method of transmittance

3.7.1
full-flow opacimeter
instrument in which all the exhaust gas flow passes through the smoke measuring chamber

3.7.1.1
full-flow end-of-line opacimeter
instrument that measures the opacity of the full exhaust plume as it exits the tailpipe

NOTE The light source and receiver for this type of opacimeter are located on opposite sides of the smoke plume and in close proximity to the open end of the tailpipe. When applying this type of opacimeter, the effective optical path length is a function of the tailpipe design.

3.7.1.2
full-flow in-line opacimeter
instrument that measures the opacity of the full exhaust plume within the tailpipe

NOTE The light source and receiver for this type of opacimeter are located on opposite sides of the smoke plume and in close proximity to the outer wall of the tailpipe. With this type of opacimeter the effective optical path length is dependent on the instrument.

3.7.2
partial flow opacimeter
instrument that samples a representative portion of the total exhaust flow and passes the sample through the measuring chamber.

NOTE With this type of opacimeter the effective optical path length is a function of the opacimeter design.

3.7.3 Opacimeter response time

3.7.3.1
opacimeter physical response time
t_p
difference between the times when the raw k-signal reaches 10 % and 90 % of the full deviation when the light absorption coefficient of the gas being measured is changed in less than 0,01 s

NOTE The physical response time of the partial flow opacimeter is defined by means of the sampling probe and transfer tube. Additional information on the physical response time can be found in 8.2.1 and 11.7.2 of ISO 11614:1999.

3.7.3.2
opacimeter electrical response time
t_e
difference between the times when the instrument recorder output signal or display goes from 10 % to 90 % of full scale when the opacity or light extinction coefficient is changed in less than 0,01 s

NOTE Additional information on the electrical response time can be found in 8.2.3 and 11.7.3 of ISO 11614:1999.

4 Symbols and units

For the purposes of this part of ISO 8178, the symbols and units listed in Table 1 apply.

Table 1 — Symbols and units

Symbol	Term	Unit
D	Bessel function constant	1
E	Bessel constant	1
f_a	Atmospheric factor	1
f_c	Bessel filter cut-off frequency	s^{-1}
k	Light absorption coefficient	m^{-1}
k_{corr}	Ambient condition corrected light absorption coefficient	m^{-1}
k_{obs}	Observed light absorption coefficient	m^{-1}
K	Bessel constant	1
K_S	Smoke ambient correction factor	1
L_A	Effective optical path length	m
L_{AS}	Standard effective optical path length	m
N	Opacity	%
N_A	Opacity at effective optical path length	%
N_{AS}	Opacity at standard effective optical path length	%

Table 1 *(continued)*

Symbol	Term	Unit
p_{me}	Brake effective mean pressure	kPa
p_S	Dry atmospheric pressure	kPa
P	Engine Power	kW
S_i	Instantaneous smoke value	m^{-1} or %
Δt	Time between successive smoke data (= 1/sampling rate)	s
t_{Aver}	Overall response time	s
t_e	Opacimeter electrical reponse time	s
t_F	Filter response time for Bessel function	s
t_p	Opacimeter physical response time	s
T_a	Engine intake air temperature	K
X	Desired overall response time	s
Y_i	Bessel averaged smoke value	m^{-1} or %
ρ	Dry ambient density	kg/m^3
τ	Smoke Transmittance	%
Ω	Bessel Constant	1

5 Test conditions

5.1 Ambient test conditions

5.1.1 Test condition parameter

The absolute temperature, T_a, of the engine intake air expressed in Kelvin, and the dry atmospheric pressure, p_s, expressed in kPa, shall be measured, and the parameter, f_a, shall be determined according to the provisions evaluated by equations (3) to (5).

Naturally-aspirated and mechanically-supercharged compression ignition engines, and compression ignition engines with wastegates operating:

$$f_a = \left(\frac{99}{p_s}\right) \times \left(\frac{T_a}{298}\right)^{0,7} \tag{3}$$

NOTE This equation also applies if the wastegate is operating only during sections of the test cycle. If the wastegate is not operating during any section of the test cycle, equation (4) or (5) shall be used depending on the type of charge cooling, if any.

Turbocharged compression ignition engines without charge air cooling, or with charge air cooling by air/air cooler:

$$f_a = \left(\frac{99}{p_s}\right)^{0,7} \times \left(\frac{T_a}{298}\right)^{1,2} \tag{4}$$

Turbocharged compression ignition engines with charge air to liquid charge air cooler:

$$f_a = \left(\frac{99}{p_s}\right)^{0,7} \times \left(\frac{T_a}{298}\right)^{0,7} \quad (5)$$

5.1.2 Test validation criteria — Test conditions

For a test to be recognized as valid, with respect to atmospheric conditions, the parameter f_a should be such that:

$$0,93 \leqslant f_a \leqslant 1,07 \quad (6)$$

Smoke values obtained within this range of f_a shall be corrected in accordance with the provisions given in 10.3. Results from tests conducted outside this range are not comparable to the results from ISO 8178-9.

Additional validation criteria are given in 7.3.4 (opacimeter zero drift) and annexes A to C (test cycle validation criteria).

5.2 Power

Auxiliaries necessary only for the operation of the machine shall be turned off. If they cannot be turned off, they shall be made to function at minimum power as much as is possible during the test. The following incomplete list of such auxiliaries is given as an example:

- air compressor;
- power steering pump;
- air conditioning compressor;
- pumps for hydraulic actuators;
- auxiliary electrical equipment (lights, blowers, etc.).

5.3 Engine air inlet system

The inlet air system shall be inspected for leaks, loose or missing clamps or fittings, etc. The general condition of the air system, including whether or not the air cleaner is in need of service, shall be noted.

5.4 Engine exhaust system

The exhaust system shall be inspected for leaks, loose or missing clamps or fittings, etc. The general condition of the exhaust system shall be noted.

5.5 Engines with charge air cooling

The charge air cooling system shall be inspected for leaks, loose or missing clamps or fittings, etc. The general condition of the charge air cooling system shall be noted.

6 Test fuels

Fuel characteristics influence engine smoke emissions. Smoke tests conducted in accordance with ISO 8178-9 are generally “certification” or “type approval” tests, utilizing a fuel specified in the regulation. Field tests are typically not conducted using the reference fuel. Therefore, especially for vehicles that fail the smoke test, the characteristics of the fuel used for the test shall be determined, recorded and presented with the results of the test.

Where fuels designated in ISO 8178-5 as reference fuels are used, the reference code and the analysis of the fuel shall be provided. For all other fuels, the characteristics recorded are those listed in the appropriate universal data sheets in ISO 8178-5.

The selection of the fuel for the test depends on the purpose of the test. Unless otherwise agreed by the parties the fuel shall be selected in accordance with Table 2.

Table 2 — Selection of fuel

Test purpose	Interested parties	Fuel selection
Type approval (certification)	— Certification body — Manufacturer or supplier	— Reference fuel, if one is defined — Commercial fuel if no reference fuel is defined
Inspection/maintenance test	— Manufacturer or supplier — Customer or inspector	— Commercial fuel as specified by the manufacturer [a]
Research/development	One or more of: manufacturer, research organization, fuel and lubricant supplier, etc.	To suit the purpose of the test.

[a] Customers and inspectors should note that the emission tests carried out using commercial fuel will not necessarily yield results that are comparable to those from testing with reference fuels.

The fuel used for acceptance tests should be within the range of fuel specifications allowed by the engine manufacturer, as specified in the engine manufacturer's technical literature. When a suitable reference fuel is not available, a fuel with properties very close to the reference fuel may be used. The characteristics of the fuel shall be declared.

7 Measurement equipment and accuracy

7.1 General

The equipment mentioned in 7.3 shall be used for smoke tests of engines in the field.

7.2 Test conditions

7.2.1 General

This part of ISO 8178 does not contain details of engine speed, pressure and temperature measuring equipment. Instead, only the accuracy requirements of such equipment are given in 7.4.

7.2.2 Engine speed

Measurement of engine speed is required in order to determine that the test is being run correctly. Measurement of engine speed is required to determine if the engine governor is operating correctly – in order to avoid possible damage to the engine. Incorrect low or high idle speeds may also cause the smoke to differ from those tests conducted according to the provisions of ISO 8178-9.

7.2.3 Ambient temperature

Ambient temperature (dry bulb temperature) is required in order to correct smoke for the ambient test conditions and determine if the engine complies with the standard to which it was certified according to the provisions of ISO 8178-9.

7.2.4 Dry ambient pressure

Dry ambient pressure is required in order to correct smoke and determine if the engine complies with the standard to which it was certified according to the provisions of ISO 8178-9. Dry ambient pressure is typically determined by subtracting a calculated vapour pressure from the measured wet ambient pressure (barometric pressure). Vapour pressure is typically calculated from measurement of the dew point temperature or the wet and dry bulb temperatures.

7.3 Determination of smoke

7.3.1 General

Transient smoke tests shall be conducted using opacimeter-type smokemeters. Three different types of opacimeters are allowed, in-line and end-of-line full flow opacimeters and the partial flow opacimeter. Specifications for the three types of opacimeters can be found in clause 11 of this part of ISO 8178 and in clauses 6 and 7 of ISO 11614:1999. Temperature correction has not been validated for transient tests, therefore, temperature correction of smoke results has not been included in this part of ISO 8178.

7.3.2 General specifications — Opacimeters

Smoke tests require the use of a smoke measurement and data processing system that includes three functional units. These units may be integrated into a single component or provided as a system of interconnected components. The three functional units are:

— a full-flow or a partial-flow opacimeter meeting the specifications of this clause. Detailed specifications for opacimeters can be found in clause 11 and in ISO 11614;

— a data processing unit capable of performing the functions described in 10.2 and 10.3 and in the applicable annex (A, B or C);

— a printer and/or electronic storage medium to record and output the required smoke values specified in the applicable annex (A, B or C).

7.3.3 Linearity

The linearity is the difference between the value measured by the opacimeter and the reference value of the calibrating device. The linearity shall not exceed ± 2 % opacity.

7.3.4 Zero drift

The zero drift during the lesser of a one hour period or the duration of the test shall not exceed ± 0,5 % opacity or 2 % of full scale, whichever is smaller.

7.3.5 Opacimeter display and range

For display in both opacity and light absorption coefficient the opacimeter shall have a measuring range appropriate for accurately measuring the smoke of the engine being tested. The resolution shall be at least 0,1 % of full scale.

The optical path length selected for the smoke instrument shall be suitable for the smoke levels being measured, in order to minimize errors in calibrations, measurements and calculations.

7.3.6 Instrument response time

The physical response time of the opacimeter shall not exceed 0,2 s, and the electrical response time of the opacimeter shall not exceed 0,05 s.

7.3.7 Sampling requirements for partial flow opacimeters

The sampling conditions shall conform to the requirements of 11.3 of ISO 8178-9:2000.

7.3.8 Light source

The light source shall conform to the requirements of 11.2 and 11.3 of ISO 8178-9:2000.

7.3.9 Neutral density filters

Any neutral density filters used for calibrating and checking opacimeters shall be known to an accuracy of ± 1 % opacity and the filter's nominal value shall be checked for accuracy at least yearly using a reference traceable to a national or international standard.

NOTE Neutral density filters are precision devices and can easily be damaged during use. Handling should be minimized and, when required, should be done with care to avoid scratching or soiling of the filter.

7.4 Accuracy

The calibration of all measuring instruments shall be traceable to international (national if no international standards exist) standards and comply with the requirements given in Table 3.

Table 3 — Permissible deviations of instruments for engine-related parameters

Item	Permissible deviation	Calibration intervals months
Engine speed	± 5 % of measurement	3
Ambient temperature	± 2 °C	3
Barometric pressure	± 0,5 %	3
Ambient air relative humidity	± 3 %	3

NOTE ISO 8178-1 specifies measurement of intake air temperature while this part of ISO 8178 utilizes ambient temperature. In some engine installations the difference between the two may be substantial, and should be accounted for.

8 Calibration of the opacimeter

8.1 General

The opacimeter shall be calibrated as often as necessary to fulfill the accuracy requirements of this part of ISO 8178. The calibration method that shall be used is described in 8.2.

8.2 Calibration procedure

8.2.1 Warming-up time

The opacimeter shall be warmed up and stabilized in accordance with the manufacturer's recommendations. If the opacimeter is equipped with a purge air system to prevent sooting of the instrument optics, this system should also be activated and adjusted in accordance with the manufacturer's recommendations.

8.2.2 Establishment of the linearity response

With the opacimeter in the opacity readout mode, and with no blockage of the opacimeter light beam, the readout shall be adjusted to 0,0 % ± 0,5 % opacity.

With the opacimeter in the opacity readout mode, and all light prevented from reaching the receiver, the readout shall be adjusted to 100,0 % ± 0,5 % opacity.

The linearity of the opacimeter, when used in the opacity mode, shall be checked periodically in accordance with the manufacturer's recommendations. A neutral density filter between 30 % and 60 % full scale which meets the requirements given in 7.3.9 shall be introduced to the opacimeter and the value recorded. The instrument readout shall not differ by more than ± 2 % opacity from the nominal value of the neutral density filter. Any non-linearity exceeding the above value shall be corrected prior to the test.

9 Test run

9.1 Installation of the measuring equipment

The opacimeter and sample probes, if applicable, shall be installed after the muffler or any after-treatment device, if fitted, in accordance with the installation procedures specified by the instrument manufacturer. Some exhaust systems are designed such that ambient air can enter the exhaust pipe and mix with the exhaust stream. Smoke measurement shall be made before this mixing occurs if results are to be compared to the results of ISO 8178-9. Additionally, the requirements of clause 10 of ISO 11614:1999 shall be observed, where appropriate. When a full-flow end-of-line smokemeter is used, L_A is a function of the vehicle exhaust system and the way the meter is mounted on the tailpipe. Determination of L_A for various types of exhaust pipe that may be encountered in the field is presented in 9.2. Accessibility to the exhaust system may be limited in some machines, and it may not be possible to install the instrumentation in accordance with these recommendations. In these instances smoke results may not be comparable to the results of ISO 8178-9.

Excessively windy conditions shall be avoided. Winds are considered excessive if they disturb the size, shape or location of the smoke plume in the region where the exhaust samples are drawn or where the smoke plume is measured. The effect of wind may be eliminated or reduced by locating the machine in a wind-sheltered area or by using measuring equipment designs which preclude wind effects on the smoke in the measuring or sampling zones.

No visible humidity (rain, fog or snow) shall be present in the region where exhaust samples are drawn or the smoke plume is measured. Care shall be taken to ensure that direct sunlight is not hitting the smoke plume or the receiver. Some equipment designs preclude the effects of these conditions.

9.2 Determination of effective optical path length (L_A)

9.2.1 General

Portions of the light source to receiver path length which are not smoke-obscured do not contribute to the effective optical path length. If the smokemeter light beam is located sufficiently close to the exhaust outlet (within 0,07 m), the cross-section of the smoke plume as it passes by the smokemeter is essentially the same as the tailpipe outlet along the line of orientation of the smokemeter light beam. In general, this distance should be determined by direct measurement of the tailpipe outlet. To achieve corrected smoke results that are accurate within ± 2 % opacity, determination of L_A shall be made within ± 6,0 %. (The largest error in opacity occurs at an opacity of approximately 60 %, at lower and higher values of opacity, less accurate determination of L_A can be tolerated.) For the smallest standard effective optical path length (0,038 m), ± 6 % equates to an accuracy of 0,002 m.

It is often difficult, particularly in field testing, to gain access to and obtain direct measurements of the tailpipe outlets on many machines. Therefore, the extension of the exhaust stack pipe from three to a maximum of thirty times the stack pipe diameter shall be considered if the engine manufacturer does not have any objections. Proper sealing of that joint is necessary in order to avoid exhaust dilution with air.

For many common tailpipe designs L_A can be determined with sufficient accuracy from external exhaust system dimensions which are more easily measured. The remainder of this section describes these cases and the principles and procedures that shall be adhered to in determining L_A.

9.2.2 External versus internal tailpipe dimensions

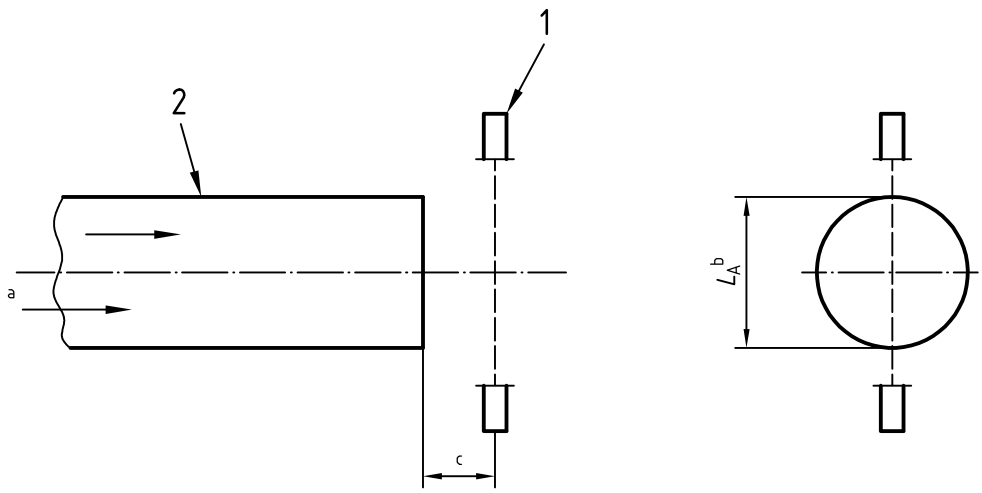
9.2.2.1 General

Most tailpipes encountered on machines are constructed from metal tubing of various standard nominal sizes. Nominal tubing sizes are based on the tubing OD whereas it is the internal dimension of the tailpipe that dictates L_A. The difference between the external and internal tailpipe dimension is twice the tubing wall thickness, which is typically small.

Use of the external tailpipe dimension as the as-measured effective optical path length results in corrected smoke values which are slightly less than the true corrected smoke values ($<$ 1 % opacity). In most cases, this small error is acceptable. However, in cases where extreme accuracy is required or where the tailpipe wall thickness is unusually large, the material thickness should be accounted for in determining L_A.

9.2.2.2 Straight circular non-bevelled tailpipes

This is the simplest tailpipe design that may be encountered and is illustrated in Figure 1. In this case, the smokemeter light beam shall be oriented such that it is perpendicular to and passes through the central axis of the smoke plume and is within 0,05 m of the tailpipe exit. If these guidelines are followed, L_A is equal to the tailpipe ID and can usually be adequately approximated by the tailpipe OD (see 9.2.2.1).



Key

1 Full flow smokemeter

2 Circular tailpipe

a Exhaust flow

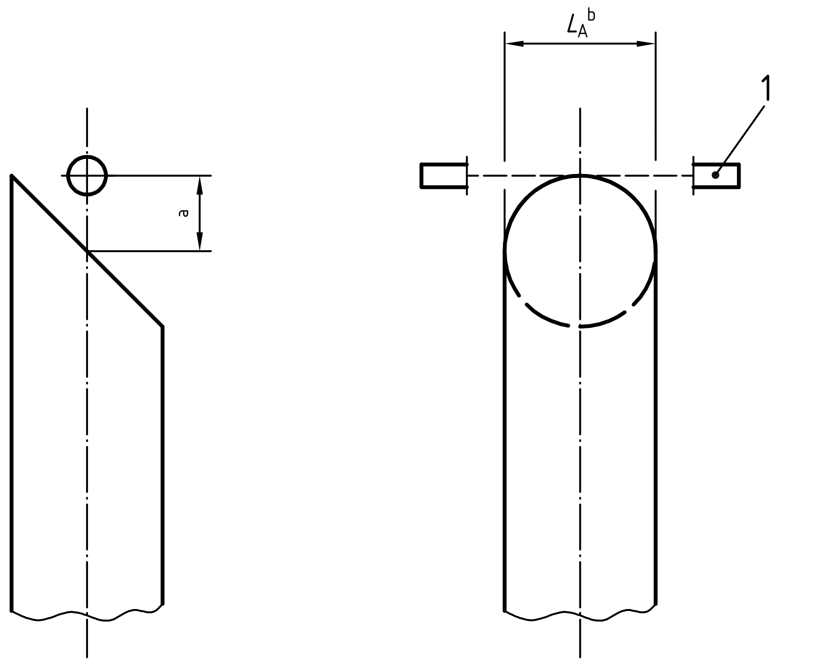
b $L_{A\infty}$ = Tailpipe inner diameter; $L_{A\infty}$ = Tailpipe outer diameter for wall thickness less than 1,5 mm

c $\leqslant$ 5 cm

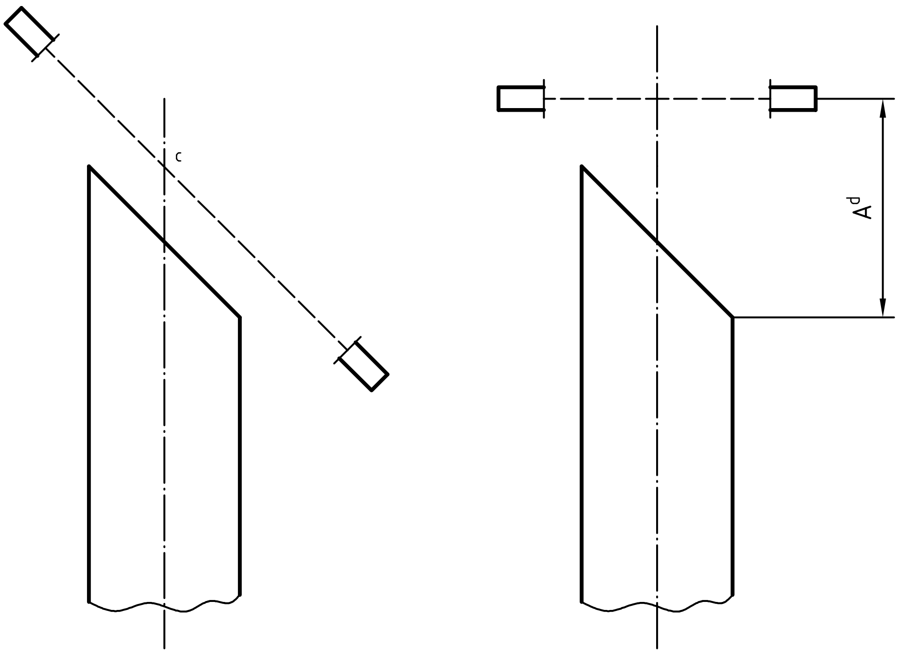
Figure 1 — Straight circular non-bevelled tailpipe

9.2.2.3 Straight circular bevelled tailpipes

A bevelled tailpipe is formed when the outlet of the tailpipe is not cut off square (perpendicular) to the axis of the exhaust flow. When this type of tailpipe is encountered, there is only one recommended smokemeter mounting orientation. The axis of the smokemeter light beam shall be perpendicular to and passing through the central axis of the smoke plume and should be parallel to the minor axis of the elliptical shape to the tailpipe exit. The smokemeter light beam shall also be within 0,05 m of the tailpipe outlet (see Figure 2). If these guidelines are followed, L_A is equal to the tailpipe ID and can usually be adequately approximated by the tailpipe OD (see 9.2.2.1).



a) Recommended smokemeter orientation



Key

1 Full flow smokemeter

[a] ⩽ 5 cm

[b] L_A = Tailpipe inner diameter; L_A = Tailpipe outer diameter for wall thickness less than 1,5 mm

[c] Light beam not perpendicular to exhaust flow

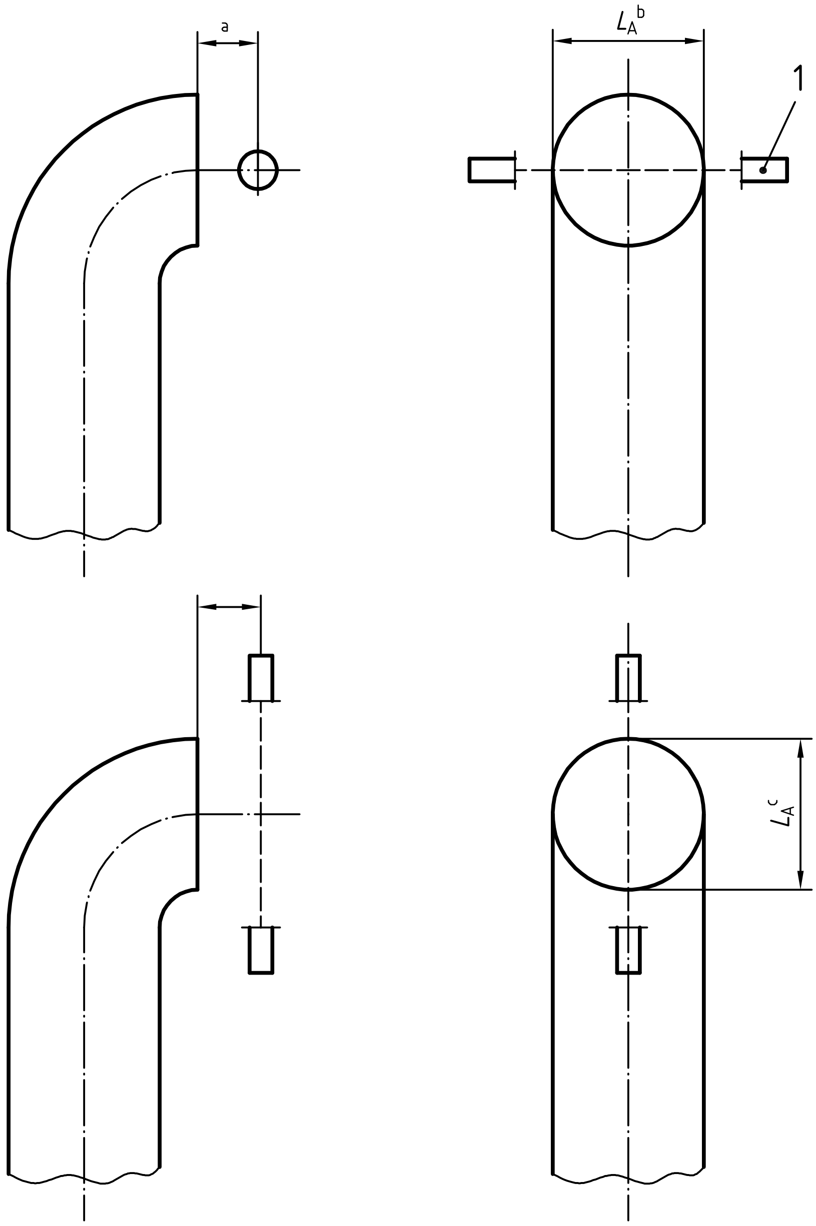
[d] “A” typically > 50 mm

b) Smokemeter orientations that are not recommended

Figure 2 — Straight circular bevelled tailpipe

9.2.2.4 Curved circular tailpipes

When the central axis of the tailpipe is curved at the approach to the exit, the tailpipe is said to be curved and the cross section of the tailpipe outlet is non-circular. To avoid erroneously low readings when this type of tailpipe is encountered, the smokemeter shall be mounted such that the axis of the smokemeter light beam is perpendicular to and passing through the central axis of the smoke plume (not necessarily the centerline of the pipe) and is parallel to the minor axis of the tailpipe exit. The smokemeter light beam shall also be within 0,05 m of the tailpipe exit (see Figure 3). If these guidelines are followed, L_A is equal to the tailpipe ID and can usually be adequately approximated by the tailpipe OD (see 9.2.2.1). Smokemeter orientations in which the smokemeter light beam is not parallel to the minor axis of the tailpipe exit may be used, but in these cases it will be necessary to determine L_A by direct measurement.



Key

1 Full flow smokemeter

a $\leqslant$ 5 cm

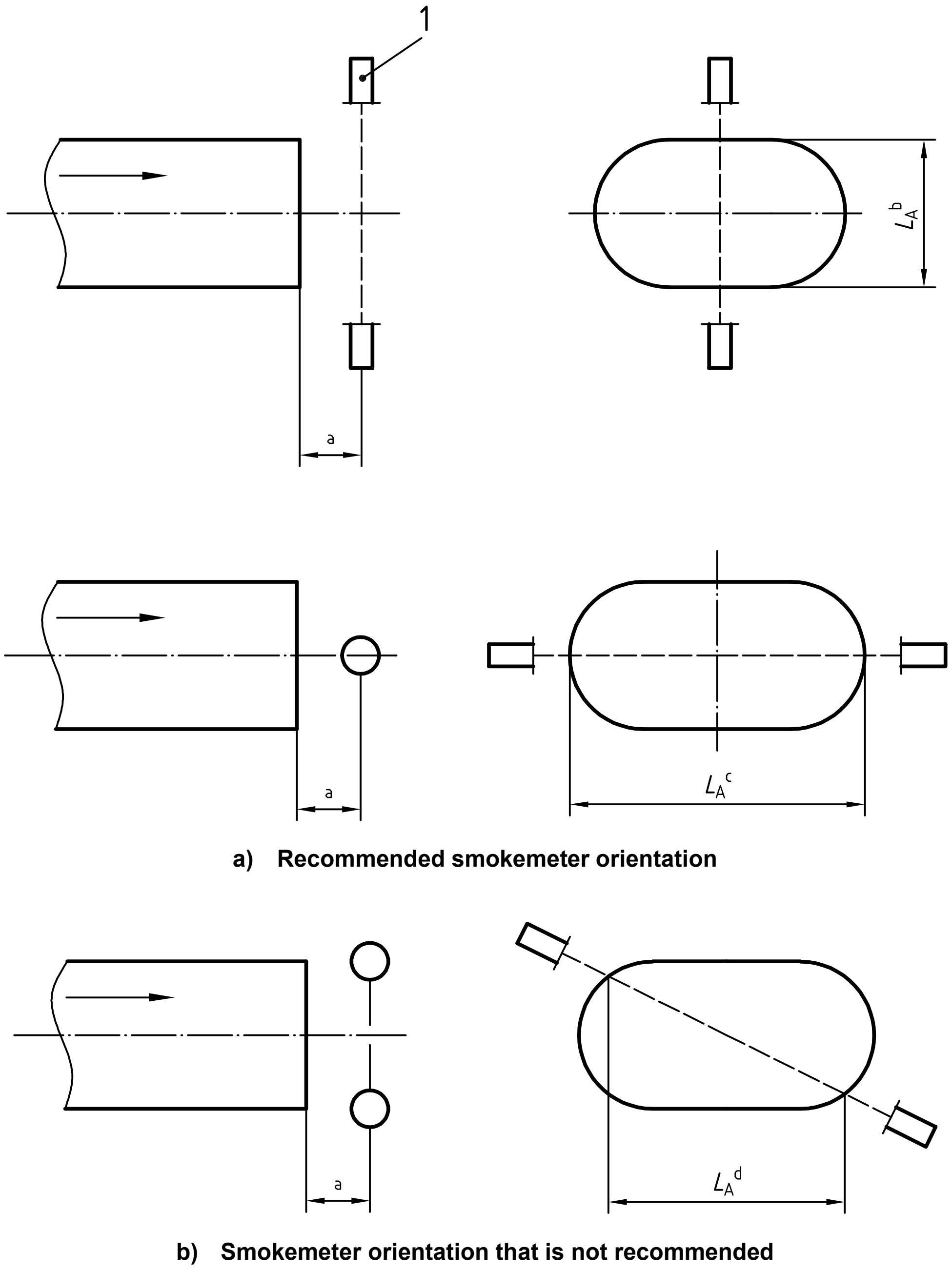
b L_A = Minor axis of outlet; L_A = Tailpipe inner diameter; L_A = Tailpipe outer diameter for wall thickness less than 1,5 mm

c L_A = Major axis of outlet; $L_A >$ Tailpipe inner diameter (to be determined by direct measurement)

Figure 3 — Curved circular tailpipe

9.2.2.5 Non-circular tailpipe

If the tailpipe cross section is non-circular, the smokemeter shall be mounted such that the smokemeter light beam is perpendicular to and passes through the central axis of the smoke plume and is within 0,05 m of the tailpipe exit. For these cases, L_A shall be determined by direct measurement. If the tailpipe cross section is an oval or an ellipse, it is recommended that the smokemeter light beam be aligned with either the major or minor axis of the tailpipe cross section in order to facilitate the measurement of L_A (see Figure 4).



Key

1 Full flow smokemeter

a ⩽ 5 cm

b L_A = Minor axis to be determined by direct measurement

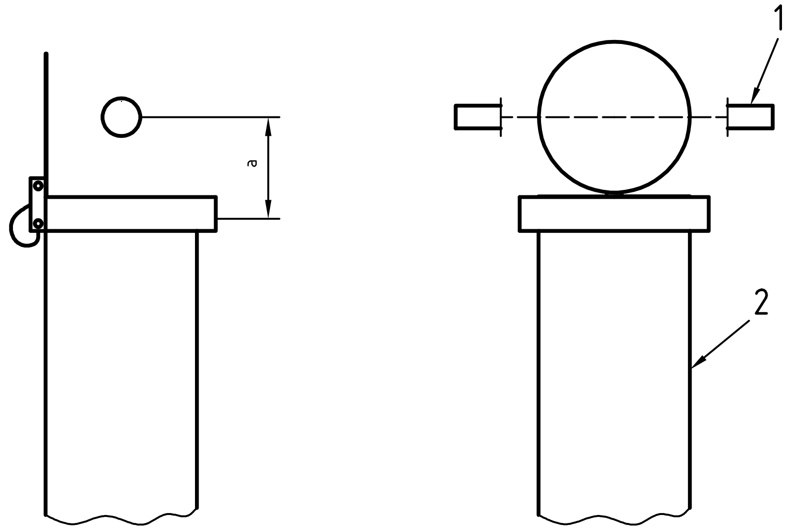
c L_A = Major axis to be determined by direct measurement

d L_A = Major or minor axis difficult to measure

Figure 4 — Non-circular tailpipe

9.2.2.6 Rain caps

Smoke measurements cannot be performed using a full-flow end-of-line smokemeter when a tailpipe rain cap is operational. If present, rain caps shall be removed or secured in the fully open position prior to smoke testing. If the smokemeter is installed without removing the rain cap, the meter shall be oriented so that the cap does not interfere with the smoke plume or block any portion of the smokemeter light beam (see Figure 5).



Key

1 Full flow smokemeter

2 Raincap secured in fully open position; smokemeter oriented so that the light beam is not interrupted by open rain cap.

a ⩽ 5 cm

Figure 5 — Rain cap

9.2.2.7 Downward directed exhaust

Some machines have horizontal exhaust systems affixed to the underside of the chassis. Typically these exhaust systems have a curved tailpipe which directs the exhaust flow down against the surface of the earth.

Care should be exercized when using a full-flow end-of-line smokemeter with machines having this type of exhaust system. In some cases, exhaust gases can “rebound” off the earth and recirculate through the smokemeter light beam causing erroneously high smoke measurements. This condition can be aggravated if dust becomes entrained in the recirculating exhaust flow.

In most cases, little can be done to prevent this condition, however, it is recommended that testing personnel attempt to observe whether recirculation is occurring when testing machines with downward directed exhaust systems. If recirculation appears to be influencing the smoke measurement, the test results shall be considered unreliable (too high) and should be used with caution.

9.3 Checking of the opacimeter

Prior to any zero and full-scale checks, the opacimeter shall be warmed up and stabilized in accordance with the instrument manufacturer's recommendations. If the opacimeter is equipped with a purge air system to prevent sooting of the meter optics, this system shall also be activated and adjusted in accordance with the manufacturer's recommendations.

The zero and full-scale checks shall be made in the opacity readout. The light absorption coefficient is thus correctly calculated based upon the measured opacity and the L_A, as submitted by the opacimeter manufacturer, when the instrument is returned to the k readout mode for testing.

With no blockage of the opacimeter light beam, the readout shall be adjusted to 0,0 % ± 0,5 % opacity. With the light being prevented from reaching the receiver, the readout shall be adjusted to 100,0 % ± 0,5 % opacity.

9.4 Test cycle

The engine shall be run on the test cycle as described in the applicable annexes A, B and C taking into account the considerations noted in annex D.

NOTE Test cycles for constant-speed off-road engines are given in ISO 8178-9.

Prior to conducting the test the following items shall be completed.

a) If the machine is equipped with a manual transmission, the transmission shall be placed in neutral and the clutch shall be released. If the machine is equipped with an automatic transmission, the transmission shall be placed in the park position, if available, or otherwise in the neutral position.

b) The machine shall be restrained from moving during testing.

c) Machine air conditioning should be turned off.

d) If the engine is equipped with an engine brake, it shall be deactiviated during testing.

e) All devices installed on the engine or machine and which alter the normal acceleration characteristics of the engine (such as lights and other accessories) shall be deactivated prior to testing.

f) All implements and attachments on the machine shall be in a safe position and, if necessary, restrained from moving.

10 Data evaluation and calculation

10.1 Data evaluation

10.1.1 General requirements — Opacimeters

The smoke shall be sampled with a minimum frequency of 20 Hz. Smoke values shall be corrected, as necessary, for opacimeter optical path length differences and smoke units (see 10.1.2, 10.1.3 and 10.1.4) and ambient test conditions (see 10.3). The smoke data shall then be processed by means of the Bessel algorithm, as described in 10.2 and the applicable annex.

10.3 specifies that the sample line length shall not affect the smoke trace. However, even though sample line length does not affect the shape of the smoke trace, it may introduce a delay between when the smoke is produced and when it is measured. The analysis of smoke traces shall account for any delay time associated with transport of smoke in the exhaust system.

The smoke values shall then be calculated as described in the applicable annex.

10.1.2 Beer-Lambert relationships

The Beer-Lambert law defines the relationship between transmittance, light absorption coefficient and effective optical path length as shown in equation (7).

$$\frac{\tau}{100} = e^{-kL_A} \qquad (7)$$

From the definitions of transmittance and opacity, the relationship between these parameters may be defined as shown in equation (8).

$$N = 100 - \tau \tag{8}$$

From equations (7) and (8) the following relationships are derived:

$$N_{AS} = 100 \times \left[1 - \left(1 - \frac{N_A}{100} \right)^{\frac{L_{AS}}{L_A}} \right] \tag{9}$$

$$k = -\frac{1}{L_A} \times \ln\left(1 - \frac{N_A}{100} \right) \tag{10}$$

10.1.3 Data conversion

Conversion from as-measured smoke values to appropriate reporting units is a two-step process. Since the basic measurement unit of all opacimeters is transmittance, the first step in all cases is to convert from transmittance, τ, to opacity at the as-measured effective optical path length, N_A, using equation (8). For most opacimeters this step is done internally and is transparent to the user.

The second step of the process is to convert from N_A to the desired reporting units as follows.

If the test results are reported in opacity units, equation (9) shall be used to convert from opacity at the as-measured effective optical path length, N_A, to opacity at the standard effective optical path length, N_{AS}.

NOTE In the event that the measured and standard effective optical path lengths are identical, N_{AS} is equal to N_A and this secondary conversion step is not required.

If the test results are reported in units of light absorption coefficient, then equation (10) shall be applied.

10.1.4 Effective optical path length input values

In order to apply equation (10), it is necessary to input the as-measured effective optical path length, L_A. To use equation (9), values shall be input both for L_A and for L_{AS}, the standard effective optical path length.

For full-flow end-of-line opacimeters, L_A is a function of the engine tailpipe design (see 9.2).

For partial flow (sampling) opacimeters and full-flow in-line opacimeters, L_A is a fixed function of the instrument measurement cell and purge air system design. Specification data supplied by the instrument manufacturer shall be used to determine the appropriate value for L_A when these types of opacimeters are used.

It may be necessary to determine L_A within 0,002 m to achieve corrected smoke results that are accurate to within ± 2 % opacity (see 9.2).

Smoke opacity readings depend on the effective optical path length of the instrument. Since limit values may be established in units of percent opacity, they shall be referred to standard effective optical path lengths (pipe diameter) at which the limit values apply. For meaningful smoke data comparisons, smoke opacity results shall be reported at the standard effective optical path lengths, L_{AS}, shown in Table 4. Smoke opacity may, however, be measured at non-standard optical path lengths. For the purposes of Table 4, engine power need not be measured. Engine power is typically available either from a label on the engine, from the owner's manual for the engine, or from information used to apply certification or type approval of the engine. In the event that engine power cannot be determined, it is not possible to evaluate the engine’s compliance with limit values that are expressed in percent opacity.

Table 4 — Standard effective optical path lengths

Engine power P kW	Standard effective optical path length L_{AS} m
$P < 37$	0,038
$37 \leqslant P < 75$	0,05
$75 \leqslant P < 130$	0,075
$130 \leqslant P < 225$	0,1
$225 \leqslant P < 450$	0,125
$P \geqslant 450$	0,15

10.2 Bessel algorithm

10.2.1 General

The Bessel algorithm shall be used to compute the average values from the instantaneous smoke readings. The algorithm is properly applied to smoke values expressed as a light absorption coefficient. However, if the smoke level is less than 40 % opacity, the algorithm may be applied to the opacity signal with negligible error. The algorithm emulates a low pass second order filter, and its use requires iterative calculations to determine the coefficients. These coefficients are a function of the response time of the opacimeter system and the sampling rate. Therefore, 10.2.2 shall be repeated whenever the system response time and/or sampling rate changes.

10.2.2 Calculation of filter response time and Bessel constants

The required Bessel filter response time, t_F, is a function of the physical and electrical response times of the opacimeter system, as defined in 3.7.3, and the desired overall response time, X, and shall be calculated using equation (11):

$$t_F = \sqrt{X^2 - \left(t_p^2 + t_e^2\right)} \qquad (11)$$

where:

t_p is the physical response time in seconds;

t_e is the electrical response time in seconds.

The above equation can be used to adjust differing opacimeters to a common response time as long as both t_p and t_e are $<< X$ (see 7.3.6) and as long as both t_p and t_e are $<<$ the duration of the transient test.

The calculations for estimating the filter cutoff frequency, f_c, are based on a step input of 0 to 1 in $< 0{,}01$ s (see annex A). The response time is defined as the time between when the Bessel output reaches 10 % (t_{10}) and when it reaches 90 % (t_{90}) of this step function. This shall be obtained by iterating on f_c until $t_{90} - t_{10} \approx t_F$. The first iteration for f_c is given by equation (12):

$$f_c = \frac{\pi}{(10 \times t_F)} \qquad (12)$$

The Bessel constants E and K shall be calculated by equations (13) and (14):

$$E = \frac{1}{1 + \Omega \times \sqrt{3 \times D} + D \times \Omega^2} \tag{13}$$

$$K = 2 \times E \times \left(D \times \Omega^2 - 1\right) - 1 \tag{14}$$

where:

D = 0,618 034;

Δt = 1/sampling rate;

Ω = 1/[tan($\pi \times \Delta t \times f_c$)]

Using the values of E and K, the Bessel-averaged response to a step input S_i shall be calculated as follows:

$$Y_i = Y_{i-1} + E \times \left(S_i + 2 \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}\right) + K \times \left(Y_{i-1} - Y_{i-2}\right) \tag{15}$$

where:

$S_{i-2} = S_{i-1} = 0$;

S_i = 1;

$Y_{i-2} = Y_{i-1} = 0$.

The times t_{10} and t_{90} shall be interpolated. The difference in time between t_{90} and t_{10} defines the reponse time t_F for that value of f_c. If this response time is not close enough to the required response time, iteration shall be continued until the actual response time is within 1 % of the required response as follows:

$$\left|\left(t_{90} - t_{10}\right) - t_F\right| = 0{,}01\ t_F \tag{16}$$

NOTE Since the application of the Bessel algorithm on filtering is a new procedure in smoke determination, an explanation of the Bessel filter, an example of the design of a Bessel algorithm, and an example of the calculation of the final smoke value is given in annex D of ISO 8178-9:2000. The constants of the Bessel algorithm only depend on the design of the opacimeter and the sampling rate of the data acquisition system. It is recommended that the opacimeter manufacturer provide the final Bessel filter constants for different sampling rates and that the customer use these constants for designing the Bessel algorithm and for calculating the smoke values.

10.2.3 Calculation of Bessel averaged smoke

Once the proper Bessel algorithm constants E and K have been calculated in accordance with 10.2.2, the Bessel algorithm shall then be applied to the instantaneous smoke trace using equation (15).

The Bessel algorithm is recursive in nature. Thus, it needs some initial input values of S_{i-1} and S_{i-2} and initial output values Y_{i-1} and Y_{i-2} to get the algorithm started. These may be assumed to be 0.

The resultant Bessel-averaged smoke values are then used to calculate the appropriate smoke values as described in the appropriate annex.

10.3 Ambient correction

10.3.1 General

Engine smoke shall be corrected for ambient conditions if in-use smoke values are to be compared to a regulated limit value. If f_a lies within a band of 0,93 to 1,07, smoke shall be corrected in accordance with equation (19). The smoke correction equation has not been confirmed for a value of f_a outside the band of 0,93 to 1,07. Smoke measurements occurring outside this range may be corrected in accordance with equation (19), but results should not be compared to ISO 8178-9.

NOTE The air density correction equations provided in this clause reflect the best fit nominal sensitivity of a sample of engines/vehicles evaluated. Some engines were more sensitive, and some were less sensitive to the air density changes than predicted by the adjustment equations. In light of this, applying the correction equations to specific engines/vehicles of unknown air density sensitivity, the adjustment equations can only be considered approximate. It is recommended that regulatory agencies adopting this procedure in enforcement programs make some allowance for the fact that the air density sensitivity of individual vehicles tested in the programme will, in general, not be known precisely and may be different than indicated by the nominal adjustment.

10.3.2 Reference conditions

The correction factor given in 10.3.3 accounts for engine intake dry air density. The reference dry air density is 1,157 5 kg/m^3 at the reference temperature of 298 K and the reference pressure of 99 kPa (see 5.1.1).

10.3.3 Ambient density smoke correction

The correction shall be applied to smoke values expressed as a light absorption coefficient or k. The correction shall be applied to the Bessel-averaged peak smoke values, and not to the raw smoke trace. Opacity values shall be converted to k using equation (10) and may then be reconverted to opacity units after making the correction. Equation (17) shall be used:

$$K_s = \frac{1}{19{,}952\ \rho^2 - 48{,}259\ \rho + 30{,}126} \tag{17}$$

$$\text{where } \rho = \frac{p_s \times 10^3}{287 \times T_a} \tag{18}$$

Using equation (17), smoke values in the annexes shall be corrected from “observed” to “corrected” values of light absorption coefficient as follows:

$$k_{corr} = K_s \times k_{obs} \tag{19}$$

10.4 Test report

The test report shall contain the data specified in ISO 8178-6.

11 Determination of smoke

11.2 and 11.3 of ISO 8178-9:2000 contain detailed descriptions of the recommended opacimeter systems. Since various configurations can produce equivalent results, exact conformance with the figures is not required. Additional components such as instruments, valves, solenoids, pumps and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

The principle of measurement is that light is transmitted through a specific length of the smoke to be measured and that proportion of the incident light which reaches a receiver is used to assess the light obscuration properties of the medium. The smoke measurement depends upon the design of the apparatus, and may be done in the exhaust pipe (full-flow in-line opacimeter), at the end of the exhaust pipe (full-flow end-of-line opacimeter) or by taking a sample from the exhaust pipe (partial-flow opacimeter). For the determination of the light absorption coefficient from the opacity signal, the optical path length of the instrument shall be supplied by the instrument manufacturer.

Annex A
(normative)

Test cycle for variable-speed off-road engines

A.1 General

The smoke cycle described in this annex consists of an acceleration from low idle to high idle. This smoke cycle is applicable to those variable speed engines that are included in the C1 cycle of ISO 8178-4:1996. The transient smoke cycle is an easy-to-perform in-use emission test that can be run on a diesel engine that is installed in a machine.

The C1 category of ISO 8178-4:1996 is for “Off-road vehicles, diesel powered off-road industrial equipment”. Typical applications for C1 engines included in the scope of this annex include, but are not limited to,

- industrial drilling rigs, compressors etc.;
- construction equipment including wheel loaders, bulldozers, crawler tractors, crawler loaders;
- truck-type loaders, off-highway trucks, hydraulic excavators etc.;
- agricultural equipment, rotary tillers;
- forestry equipment;
- self propelled agricultural vehicles (including tractors);
- material handling equipment;
- fork lift trucks;
- road maintenance equipment (motor graders, road rollers, asphalt finishers);
- snow plough equipment;
- airport supporting equipment;
- aerial lifts;
- mobile cranes.

The transient smoke test described in this annex may not be feasible on all engines in all machines. Some engine and/or machine control strategies may be present that would prevent an acceleration from slow idle to high idle. Smoke measurement from one or two cylinder engines may include a pulsation that precludes reliable measurements unless a damping volume (muffler) is employed. Special test procedures for unique applications may be used if agreed upon by the parties involved.

A.2 Terms and definitions

A.2.1
acceleration test
test consisting of accelerating the engine against its own internal inertia, flywheel and unloaded machine parasitics from low idle speed to high idle speed

A.2.1.1
free acceleration time
FAT
time, in seconds, required for the engine to go from 5 % above low idle speed to 95 % of rated speed in the free acceleration test.

NOTE For the purposes of this field test procedure, FAT may be approximated as the time required for the engine to accelerate from low idle speed to high idle speed. An approximate value for FAT should be determined during the in-field smoke test. Unusually high rotating inertias, or high parasitic loads on the engine, could cause the value of FAT from the in-use test to be greater than 9 FAT from test in accordance with ISO 8178-9:2000 annex A. In-use smoke values should not be compared to the limit value if this occurs, as the in-use smoke test has been run outside the bounds to which the engine has been certifed or type-approved.

A.2.1.2
Peak Smoke Value
PSV_s
highest 1,0 second Bessel-averaged smoke value obtained during the acceleration in A.3.5.1 e) for the in-service test (s = service)

NOTE The reported value for PSV_s is the average of the three individual accelerations of A.3.5.1 e).

A.3 Test cycle

A.3.1 General

The test consists of engine accelerations between low idle speeds and high idle speeds. Multiple accelerations are conducted to reduce variability.

A.3.2 Engine inspection

The engine shall be off, the parking brake shall be on, and all implements and attachments shall be in a safe position, in accordance with the provisions of 9.4. The engine shall be inspected for loose or missing parts, paying particular attention to the intake and exhaust system in accordance with 5.3, 5.4 and 5.5. The fuel system shall be inspected for evidence of tampering. Mal-maintenance of or tampering with the intake, exhaust or fuel system could cause the engine to fail the smoke test. Engine power, engine model (type), engine serial number and engine family shall also be determined and recorded during the inspection.

A.3.3 Check idle speeds

Low idle speed shall be checked and recorded prior to running a smoke test.

It is also recommended that the high idle speed be checked prior to running the smoke test in order to avoid engine damage during the test. The speed control level shall be moved slowly to the full-speed position while monitoring engine speed. If the engine speed exceeds the high idle speed recommended by the manufacturer, the speed control shall be immediately returned to the low idle position and the smoke test discontinued.

A.3.4 Preconditioning of the engine

The engine shall be warmed up by operating it at least 15 min under load. Alternatively, oil and coolant temperature gauges may be used to confirm that the engine is at normal operating temperatures.

NOTE A preconditioning phase should also protect the actual measurement against the influence of deposits in the exhaust system from a former test.

A.3.5 Acceleration test

A.3.5.1 General

The parking brake shall be on and all implements and attachments shall be in a safe position. All accessories shall be off. Accessories and other engine-driven equipment that cannot be turned off shall be set to absorb the minimum possible engine load. Manual transmissions shall be in "'Neutral" and automatic transmissions shall be in "Park". Smoke instrumentation shall be installed and calibrated in accordance with the provisions of 7.3 and clause 8.

The acceleration test is a procedure that accelerates the engine from low idle speed to high idle speed.

The acceleration test has the following general sequence. The sequence is graphically shown in Figure A.1.

a) The engine shall be stabilized at low idle speed for 15 s ± 5 s.

b) The speed control lever shall be moved rapidly to and held in the wide open position until the engine reaches its governed high idle (no load) speed.

c) The speed control lever shall be returned to the closed position and the engine allowed to return to its low idle speed.

d) The above sequence shall be repeated twice as practice runs in order to clean out the exhaust system.

e) After the three practice runs, the above sequence shall be repeated until three successive runs meet the stability criteria as described in A.3.5.2.

A.3.5.2 Test validation criteria — Acceleration test

The acceleration test results shall be considered valid only after the following test cycle criteria have been met.

The arithmetical difference between the highest and lowest maximum 1,0 s Bessel-averaged smoke values from the three successive acceleration tests shall not exceed 5,0 % opacity. Additional test validation criteria are given in 5.1.2 and 7.3.4.

A.3.5.3 Determination of free acceleration time (FAT)

The free acceleration time for an individual acceleration in A.3.5.1 e) is the time from when the engine speed leaves low idle speed until the engine speed reaches high idle speed. FAT shall be determined for purposes of comparison to the acceleration times used when the engine was cerftified or type approved according to the provisions of ISO 8178-9. If the in-field acceleration time is greater than nine times the free acceleration time of ISO 8178-9, then the engine should not necessarily be expected to meet the limit value.

[a] High idle

[b] Rated

[c] Idle

[d] Practice runs

[e] Actual runs

(a), (b) and (c) refer to paragraphs in A.3.5.1.

Figure A.1 — Acceleration test

A.4 Analysis of results

A.4.1 General

This clause describes how to analyse the results of the acceleration test. Many opacimeters used for this test have a smoke output signal that is an $X = 0{,}5$ s Bessel-average smoke according to the algorithm described in 10.2. For these opacimeters further signal conditioning to produce the $X = 1{,}0$ s smoke results is needed, and the value of $(t_p^2 + t_e^2)$ used in equation (11) in 10.2.2 is $0{,}5^2$. The results of raw smoke analysis, those not already processed according to the 0,5 s Bessel algorithm, shall use a $(t_p^2 + t_e^2)$ value that represents the opacimeter system.

Reported smoke values shall also be corrected for ambient conditions as described in 10.3.

A.4.2 Peak Smoke Value (PSV_s)

Values for PSV shall be calculated for each acceleration of A.3.5.1 e). These values are the maximum values of the $X = 1{,}0$ s Bessel-averaged smoke that occurs during the acceleration event. Care shall be taken to ensure that the smoke data that is analysed corresponds to the time during which the acceleration event occurs (see 10.1.1). For acceleration procedure see A.3.5.1 b). The methodology for calculating Bessel-averaged numbers can be found in 10.2. For peak smoke values, the value of X in equation (11) is 1,0 s. PSV_s is the average of the values obtained for each of the three accelerations.

A.5 Reported results

The following shall be reported: Engine power, engine type, engine family (from emissions label), engine serial number, FAT, PSV_s.

A.6 Statistical evaluation of results

The results of this test procedure are intended for use as part of an enforcement programme. It is recommended that additional tests be run prior to taking any enforcement action if the results (average PSV) are close to the legislated limit value, LL. The clause provides a recommended statistical procedure to use prior to taking any enforcement action.

a) If each value of the three values of PSV is $<$ LL: acceptable result; end of procedure

b) If each value of the three values of PSV is $>$ 1,5 LL: unacceptable result; end of procedure

c) If neither a) nor b) is true, then additional tests are recommended. At a minimum A.3.3, A.3.4 and A.3.5 should be run two additional times, generating six additional values of PSV. The acceptable/unacceptable decision should then be based upon the average of at least nine values of PSV.

Annex B
(normative)

Test cycle for marine propulsion engines

B.1 General

Marine engine operations occurs over a much more limited combination of speed and torque compared to on-road and mobile off-road engines. This is partly due to the fact that marine engines are not equipped with a shiftable gearbox and partly to the physical behaviour of the power transmission from the propeller to the water.

There are mainly two principle torque-to-speed relationships: the propeller law, defined by torque $= f(n^2)$ with a fixed propeller or water jet, and the constant-speed law (comparable to generator applications) which is applicable with a controllable-pitch propeller. These principles correspond with the E1, E2 and E3 and E5 test cycles of ISO 8178-4:1996. Therefore, the smoke during the engine load increase, for both cases (with or without speed increase), is more stable and influenced mainly by the rate of load increase. This rate is subjected to automatic limitation procedures of various kinds.

One example is the power-increase rate. For marine engines the power-increase rate is a slower rate compared to on-road or mobile off-road engines. This is partly due to the physical behaviour of the power transmission from the propeller to the water. In all such cases, the engine will be controlled by its management or control system depending on the kind of the vessel. This “standard case” is also the worst case, and is very suitable as basis for dynamic smoke measurements. Engines with various management or control settings can be combined in engine families or groups, with a worst case being tested for the complete family or group.

On board vessels, safety is always of paramount importance. Therefore, although automatic control is the general rule, an exception shall remain for emergency cases where overriding of the system is needed to reduce imminent danger. In such an emergency case there might be an increased smoke rate due to greater engine acceleration. Such increased smoke rates are not considered in this annex.

B.2 Application of the smoke test cycle

The smoke test cycle described in this annex is applicable to those engines which are included in the E1, E2, E3 and E5 cycles of ISO 8178-4:1996. The discrimination on whether to use the test cycle in this annex is the loaded acceleration time. This should be 20 s ± 5 s or be as declared by the manufacturer, taking into account the engine management or control system. Those marine propulsion engines which can be used in the application for mobile off-road engines may optionally be tested according the procedures in annex A.

Typical applications are:

E1: Diesel engines for craft less than 24 m length (derived from test cycle B).

E2: Constant-speed, heavy-duty engines for vessel propulsion without limitation in length.

E3: Propeller-law, heavy-duty engines for vessel propulsion without limitation in length.

E5: Diesel engines for craft less than 24 m length (propeller law).

This annex has been confirmed for engines with rated power up to 1 500 kW.

B.3 Terms and definitions

B.3.1 Test under transient load

B.3.1.1
for variable-speed engines
that portion of the procedure which consists of running the engine through a clearly defined cycle consisting of an acceleration mode under load, and a mode at 80 % of rated speed under load

B.3.1.2
for constant-speed engines
that portion of the procedure which consists of running the engine at rated speed through a clearly defined cycle consisting of a load-increase mode and a mode at 50 % of rated power

B.3.2 Load-increase time

B.3.2.1
for variable-speed engines
time an engine requires to accelerate from low-idle speed to 80 % of rated speed; during acceleration, the engine load being controlled so the engine torque corresponds to the transient load curve

B.3.2.2
for constant-speed engines
time an engine requires at rated speed to increase the load from no-load to 50 % of rated power

B.3.3 Transient-load curve

B.3.3.1
for variable-speed engines
propeller curve, defined by torque $= f(n^2)$, at the end point of which, the rated power is reached at the rated speed

B.3.3.2
for constant-speed engines
constant-speed curve at rated speed, at the end point of which, the rated power is reached

B.3.4
Peak Smoke Value
PSV
average of the three highest 1,0-s Bessel-averaged smoke values obtained during the test under transient load

B.4 Test cycle

B.4.1 General

During smoke measurement in the test under transient load (described in detail in B.4.2 and B.4.3), the engine load is increased as rapidly as possible, either on the propeller curve or at constant speed. The load-increase rate and, thus the load-increase time, is controlled by the engine management or control system.

This cycle is suitable for use on the test stand as well as for measurements with the engine installed in the vessel.

When engine smoke is measured on the test stand, the load-increase time can be varied within a range which covers the service conditions of an engine family or engine group which shall be defined according to ISO 8178-7 and ISO 8178-8.

B.4.2 Preconditioning of the engine

The engine shall be warmed up at rated power in accordance with the manufacturer's recommendations in order to stabilize engine operating parameters.

NOTE This preconditioning phase will also protect the current measurement against the influence of a previous test and be considered as creating reference conditions.

B.4.3 Conducting a test under transient load

B.4.3.1 General

The test under transient load shall be performed immediately following the preconditioning, as described in B.4.2.

B.4.3.2 Variable-speed engines

The test under transient load consists of accelerating the engine from low-idle speed to 80 % of rated speed against the load that is described by the function torque $= f(n^2)$. The sequence is shown graphically in Figure B.1.

B.4.3.3 Constant-speed engines

The test under transient load consists of increasing the engine load at rated speed from no-load to 50 % of the rated load. The sequence is shown graphically in Figure B.2.

Conducting a test under transient load begins with a conditioning cycle to improve repeatability of the results. The conditioning cycle is followed by three load-increase cycles. The loaded transient test sequence is described in B.4.3.4 and B.4.3.5.

B.4.3.4 Test sequence for variable-speed engines

B.4.3.4.1 Conditioning cycle

a) The engine shall be operated at the lowest possible stabilized load with the load/speed control lever in the lowest possible position at low-idle speed for 40 s ± 5 s.

b) From the low-idle speed, the load/speed control lever shall be moved:

   1) to an open position allowing the engine to reach 80 % of its rated speed in 20 ± 5 s;

   2) rapidly to, and held at, the fully-open position. The engine shall accelerate against the load on the transient load curve to 80 % of its rated speed in the time permitted by the engine management or control system.

c) 80 % of rated speed and the given load as specified in the transient load curve shall be maintained for 60 s ± 5 s.

d) The load shall be reduced and the load/speed control lever shall be returned to the low-idle position.

B.4.3.4.2 Measurement cycle

Repeat a) to d) until three consistent, consecutive results are completed.

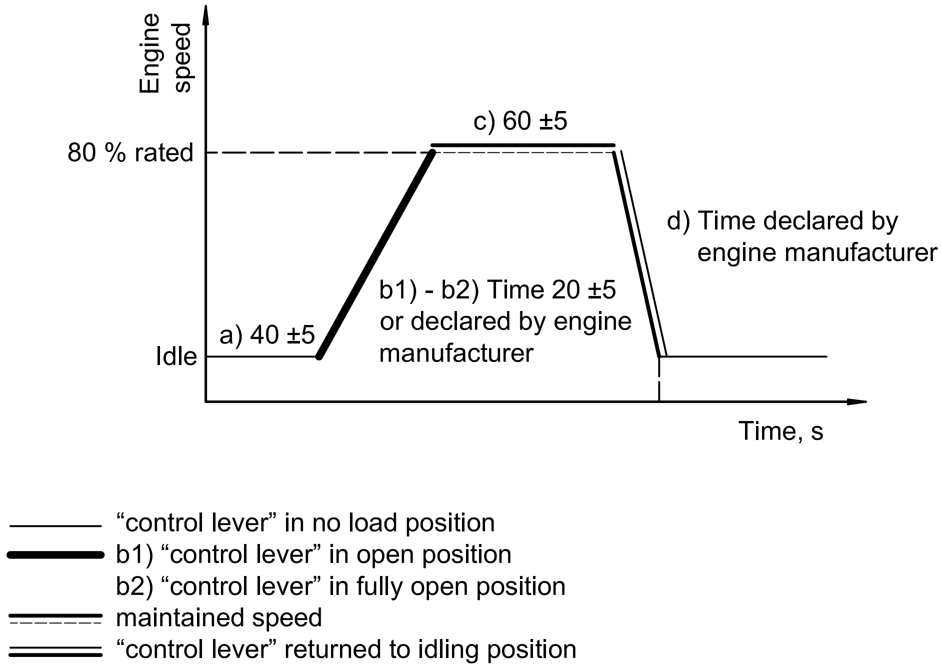


Figure B.1 — Testing under transient load — Variable-speed engines

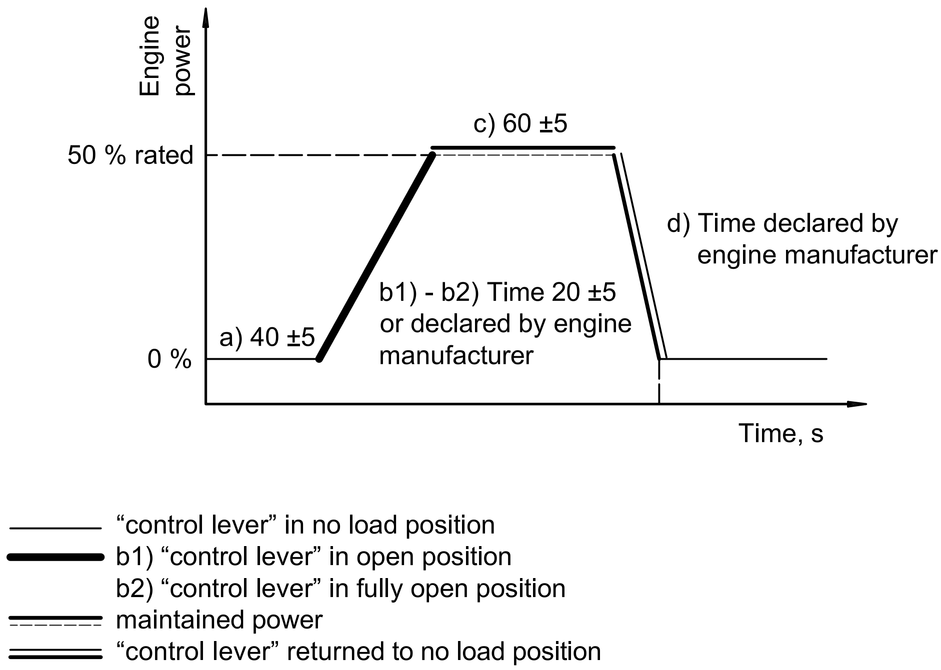


Figure B.2 — Loaded acceleration test — Constant-speed engines

B.4.3.5 Test sequence for constant-speed engines

B.4.3.5.1 Conditioning cycle

a) The engine shall be operated at the lowest possible stabilized load at rated speed for 40 s ± 5 s.

b) At rated speed, the load/speed control lever shall be moved:

   1) to an open position allowing the engine to reach 50 % of its rated load in 20 s ± 5 s;

   2) rapidly to the 50 % position and held at this position. The engine load shall increase at constant engine speed to 50 % of its rated load in the time permitted by the engine management or control system.

c) 50 % of rated power at rated speed shall be maintained for 60 s ± 5 s.

d) The load shall be reduced and the load control lever shall be returned to the no-load position at rated speed.

B.4.3.5.2 Measurement cycle

Repeat a) to d) until three consistent, consecutive results are completed.

B.4.3.6 Test validation criteria — Test under transient load

The acceleration tests results under load shall be considered valid only after the following test cycle criteria have been met.

The arithmetical difference between the highest and lowest maximum 1,0 s Bessel-averaged smoke values from the three successive acceleration tests under load shall not exceed 5,0 % opacity.

Additional test validation criteria are given in 5.1.2 and 7.3.4.

B.5 Analysis of results

B.5.1 General

This subclause describes how to analyse the results of the test under transient load. Many opacimeters used for this test have a smoke output signal that is an $X = 0{,}5$ s Bessel-averaged smoke value according to the algorithm described in 10.2. For these opacimeters, further signal conditioning is needed to produce results equivalent to the formula in which $X = 1{,}0$ s, and where the value for $(t_p^2 + t_e^2)$ used in 10.2.2, equation (11), is $0{,}5^2$. Analysis of raw smoke results, those not already processed according to the 0,5 s Bessel algorithm, shall use a value for $(t_p^2 + t_e^2)$ which represents the opacimeter system used.

B.5.2 Peak smoke value (PSV)

Determine the highest 1,0 s Bessel-averaged smoke values which occur during the three repetitions mentioned in B.4.3. Care must be taken to assure that the smoke data which are analysed correspond to the time during which the load increase occurs (see 10.1.1). PSV is the average of the three highest 1,0 s Bessel-averaged smoke values obtained during load increase.

The methodology for calculating Bessel-averaged numbers can be found in 10.2. For peak smoke values, the value of X in equation (11) is 1,0 s.

B.6 Reported results

The following smoke values shall be reported: PSV_1, PSV_2, PSV_3, plus PSV_a (average of those three). The duration for the three tests (during the load increases) shall also be reported. Time lapses a) to d) in Figures B.1 and B.2 refer to paragraphs in B.4.3.4.1 and B.4.3.5.1 respectively.

Annex C
(normative)

Test cycle for variable-speed engines type F (rail traction)

C.1 General

An acceleration test against the engine's inertial moment (no-load) is not relevant for rail-traction engines, because, to avoid locomotive wheel slip, throttle response of rail-traction engines is not as rapid as that of off-road (C1) engines. When accelerating, the throttle of rail-traction engines is not opened quickly but on a time-based load-increase rate. Engines with differing settings for the engine management or control system can be combined in engine families or groups when the worst case is tested, representative for the complete family or group.

The test will normally be carried out with the engine on a test bench with all static equipment and measurement instruments. In some cases it is possible to absorb the produced power in a static test bench installation (e.g. load bank system) without dismantling the engine from the locomotive.

C.2 Application of the test cycle

This annex C has been confirmed for engines with rated power up to 1 500 kW.

C.3 Terms and definitions

C.3.1
test under transient load
that portion of the procedure which consists of running the engine through a clearly defined cycle consisting of an acceleration mode under load, and a rated-speed, full-load mode

C.3.2
acceleration time under load
time an engine requires to accelerate from idle speed to the rated speed where, during acceleration, the engine load is controlled so the engine power lies on the acceleration load curve

NOTE The acceleration time under load is controlled by the engine management or control system.

C.3.3
acceleration load curve
natural load curve of hydraulic dynamometers that is approximately of the form torque $= f(n^2)$ and which represents actual load curves in service

NOTE In cases where the test is carried out with a generator this relation torque $= f(n^2)$ shall be used.

C.3.4
Peak Smoke Value
PSV
average of the three highest 1,0 s Bessel-averaged smoke values obtained during the acceleration modes of the tests under transient load.

C.4 Test cycle

C.4.1 General

The engine shall be tested with the management or control system that is to be used in service.

C.4.2 Preconditioning of the engine

The engine shall be warmed up at rated power in accordance with the recommendations of the manufacturer in order to stabilize the engine operating parameters.

NOTE This preconditioning phase will also protect the current measurement against the influence of a previous test and be considered as creating reference conditions.

C.4.3 Test under transient load

C.4.3.1 General

The test under transient load shall be performed immediately following the preconditioning described in C.4.2. The test under transient load is a procedure that accelerates the engine from low-idle speed against the load. The end of this load curve at rated speed shall be the rated power of the engine.

C.4.3.2 Acceleration time under transient loading

The acceleration time during this test shall be controlled by the engine management or control system and is oriented to the engine operating conditions in rail-traction service. Since the smoke emission of an engine under transient loading increases as the time for acceleration decreases, the acceptance of engines with differing acceleration times within an engine family or group will be facilitated by testing the engine which has the shortest acceleration time, as reference engine.

C.4.3.3 Conducting a test under transient load

C.4.3.3.1 General

The test under transient load begins with a conditioning cycle to improve the repeatability of the results. The conditioning cycle is followed by three acceleration cycles under transient load. The loaded acceleration is followed by full-load speed stabilization. The sequence is given in C.4.3.3.2 and C.4.3.3.3.

C.4.3.3.2 Conditioning cycle

a) The engine shall be operated at the lowest possible stabilized external load with the speed control lever in the lowest possible position (low-idle speed) for 40 s ± 5 s.

b) From idle speed, the load/speed control lever shall be moved rapidly to the full-load/speed control position to accelerate the engine against a load that will allow the engine to reach 95 % of its rated speed in a time which is permitted by the engine management or control system.

c) Within 20 s of the engine reaching 95 % of rated speed, the necessary dynamometer load shall be applied to stabilize the engine at its full-rated speed/load.

NOTE During the stabilizing time an overshoot may occur.

d) Rated speed and full-load shall be maintained for 60 s ± 5 s.

e) The load shall be reduced and the load/speed control lever shall be returned to the idle position.

C.4.3.3.3 Measurement cycle

Repeat a) to e) until three consistent, consecutive results are completed.

C.4.3.4 Test validation criteria — Test under transient load

The acceleration tests results under load shall be considered valid only after the following test cycle criteria have been met.

The arithmetical difference between the highest and lowest maximum 1,0 s Bessel-averaged smoke values from the three successive acceleration tests under load shall not exceed 5,0 % opacity. Additional test validation criteria are given in 5.1.2 and 7.3.4.

C.5 Analysis of results

C.5.1 General

This subclause describes how to analyse the results of the test under transient load. Many opacimeters used for this test have a smoke output signal that is an $X = 0{,}5$ s Bessel-averaged smoke value according to the algorithm described in 10.2. For these opacimeters, further signal conditioning is needed to produce results equivalent to the formula in which $X = 1{,}0$ s, and where the value for $(t_p^2 + t_e^2)$ used in 10.2.2, equation (11), is $0{,}5^2$. Analysis of raw smoke results, those not already processed according to the 0,5 s Bessel algorithm, should use a value for $(t_p^2 + t_e^2)$ which represents the opacimeter system used.

C.5.2 Peak smoke value (PSV)

Determine the highest 1,0 s Bessel-averaged smoke values which occur during the three repetitions of b) in C.4.3.3.2. Care must be taken to assure that the smoke data that are analysed correspond to the time during which the acceleration event occurs (see 10.1.1). PSV is the average of the three highest 1,0 s Bessel-averaged smoke values obtained during acceleration under load.

The methodology for calculating Bessel-averaged numbers can be found in 10.2. For PSV_s, the value of X in equation (11) is 1,0 s.

C.6 Reported results

The following smoke values shall be reported: PSV_1, PSV_2, PSV_3, plus PSV_a (average of those three). The duration for the three tests (during the load increases) shall also be reported.

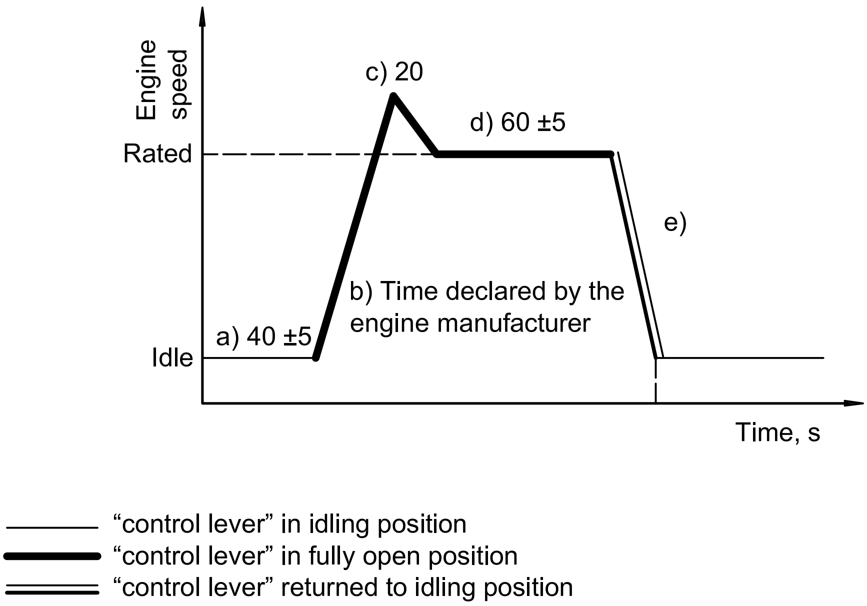


Figure C.1 — Loaded acceleration test

Time lapses a) to e) refer to lines in C.4.3.3.2.

Annex D
(informative)

Remarks on test cycles

The test procedures of ISO 8178-9 are specifically intended for the test bed measurement of an engine, including certification or type approval of the engine to a regulated limit value. It is envisioned that ISO 8178-9 tests would be run on a “parent engine” of the engine family, and that the results of the tests would be compared to the regulated limit value. The most straightforward way to apply this part of ISO 8178 is as a check for “gross emitters” – those engines whose in-use smoke levels exceed the new-engine regulated limit value by a substantial amount.

However, it is recognized that regulators may want a more discerning in-use smoke test – one that can detect if a particular in-use engine is abnormal compared to smoke values obtained during certification/type-approval. Conceptually, this could be done by comparing the in-use smoke value at the in-use acceleration time to the certification/type-approval smoke value (actual or interpolated) at the same certification/type-approval acceleration time; e.g., if the certification/type approval FAT is 1,0 s, then smoke test the values determined at FAT plus 3, 6 and 9 FAT, or 1, 3, 6 and 9 seconds. If the in-use acceleration time is 4 s, then one could determine an interpolated certification/type approval smoke value for 4 s by linearally interpolating between the 3 and 6 FAT certification/type approval smoke values. However, in order to use the certification/type-approval smoke values in this manner, various sources of smoke data variability should be assessed.

There are two types of engine variability to consider; the variability between ratings and the variability between engines of the same rating. There are typically a number of engine ratings in the family and the smoke signature will vary somewhat from one rating to the next. The results of in-use tests on one particular rating cannot be expected to correspond precisely to tests on another rating. Secondly, production tolerances lead to a different smoke level from one engine to the next, even for engines of the same rating. In order to use the results of ISO 8178-9 in the in-use inspection programme, a statistically valid sample of ISO 8178-9 results should be obtained. One should determine the variability both between ratings in a family and among different engines of the same rating in order to judge if an in-use engine is “good” or “bad”. Failure to make such a determination could jeopardize the credibility of an in-use programme. The programme should be designed so as not to fail an engine that has a smoke level higher than the particular certification test engine but still within normal production tolerances.

Finally, measurement variability should also be considered. It should be noted that the in-use measurements in accordance with the provisions of this part of ISO 8178 are likely to be less precise than test bed measurements in accordance with those of ISO 8178-9. Therefore, the limit values established for certification/type approval may be inappropriately low for an-in-use programme. Additional test data are needed to determine the appropriate offset, if any, between a test bed smoke limit and an in-use smoke limit.

It is anticipated that measuring difficulties will be experienced on engines that have only a few (one, two and perhaps three) cylinders feeding into an exhaust pipe. These few-cylinder engines will have substantial variation in exhaust pressure and flow rate, leading to reduced accuracy and increased variability.

The limitations expressed in annexes A, B and C should be respected. Smoke tests on engines outside the limitations of an annex may require a different cycle or measurement procedure. Work is in process to verify the accuracy of instruments outside the normal size range. This will be taken into account in future editions of this part of ISO 8178.

The smoke cycles described in annexes A, B and C are intended to be able to be run in the field (i.e., with the engine installed in the machine). The cycles in those annexes are intended to be closely related to the corresponding cycles in the annexes of ISO 8178-9:2000.

The test cycle described in Annex A is representative of those engines which are used in applications as described in the C-1 cycles of ISO 8178-4:1996. The scope of annex A is thus far confirmed up to a rated power output of 1 500 kW. Extension of this part of ISO 8178 to other applications is foreseen, through the development of additional annexes. Extension to other power levels (such as power plants) and other applications (such as constant speed engines, large ships or locomotives) requires serious study. Limitations to acceleration rates (due to engine size) and inclusion of other operating conditions (such as engine starting) needs further definition. Furthermore, some engines may be equipped with speed and/or load control systems that preclude the engines running the cycles described in annexes A, B and C. It should be recognized that these control systems may be present, at least in part, to provide smoke control. Special test procedures may be needed to address these circumstances.

It should be noted that an acceptable in-use smoke test may not be possible on certain machines, specifically those machines for which the free acceleration time of the engine in the machine is greater than 9 × FAT for the engine tested in accordance with ISO 8178-9.

There are a number of situations which could cause the in-use engine to fail the smoke test. The engine may be mis-applied to the machine, with an undersized intake, exhaust or cooling system that fails to meet the engine manufacturer's specifications. Furthermore, infrequent or improper maintenance could also cause the engine to fail the smoke test. Additionally, the in-use fuel could cause the engine to have high smoke levels.

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[7] Council Directive 72/306/EEC, *On the approximation of the laws of the Member States relating to the measures to be taken against the emission of pollutants from diesel engines for use in vehicles*

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