
**Road Vehicles — Aerosol separator
performance test for internal
combustion engines —**

**Part 5:
Engine fractional efficiency test
method and upstream distribution
sampling method**

*Véhicules Routiers — Norme d'essai de performance des filtres des
circuits fermés de ré-aspiration des gaz de carter moteur —*

*Partie 5: Méthode d'essai d'efficacité fractionnaire moteur et méthode
d'échantillonnage de la distribution amont*



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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).

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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 22, *Road vehicles*, Subcommittee SC 34, *Propulsion, powertrain and powertrain fluids*.

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.

A list of all parts in the ISO 17536 series can be found on the ISO website.

Introduction

Engine crankcase blowby is composed of combustion exhaust gases which have escaped to the crankcase via piston ring seals and lube oil aerosols generated by thermal and mechanical action within the engine. These gases are vented from the crankcase to prevent a build-up of high pressure. The constituents of vented engine blowby gases are recognized as an undesirable contaminant and technology for their containment is therefore evolving.

The device used to separate oil aerosols from the blowby typically releases cleaned gases to atmosphere or into the air inlet prior to the engine or turbo compressor (if present). The latter has led to the requirement for a pressure control device to isolate the engine from turbo inlet suction.

It is the purpose of this document to either define standardized and repeatable test procedures for the evaluation of blowby oil aerosol separators and filtering devices using this engine fractional efficiency test method and/or determining the size distribution of the blowby aerosol from the engine.

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Road Vehicles — Aerosol separator performance test for internal combustion engines —

Part 5:

Engine fractional efficiency test method and upstream distribution sampling method

1 Scope

This document defines standardized and repeatable test procedures by using internal combustion engines for the evaluation of blowby oil aerosol, and aerosol separators and filtering devices by specifying the engine blowby sampling procedure and engine fractional efficiency test in both open and closed crankcase ventilation systems running at steady state. Due to sampling requirements, measuring efficiency when there are transient flow conditions is not in scope.

Separator life is not evaluated in this document.

Conformance of a device to legislation is outside of the scope of this document.

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 17536-1, *Road vehicles — Aerosol separator performance test for internal combustion engines — Part 1: General*

3 Terms, definitions, and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 17536-1 and the following apply.

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1 Terms and definitions

3.1.1

fractional separation efficiency

ability of the separator to remove particles of a specified size expressed as a percentage

3.2 Abbreviated terms

PSL polystyrene latex, referring to commercially available particles of various specific sizes

4 Measurement accuracy

The measurement accuracy of this document shall be in accordance with ISO 17536-1.

5 Test materials and test conditions

5.1 Test oil and aerosol

The engine oil shall be documented for make, type, viscosity, cleanliness, and density.

The aerosol produced by the engine shall be measured using a calibrated particle size measurement device.

Mass aerosol distribution shall be displayed in Particle Size (μm) versus mass percent less than stated size.

The test conditions, engine aerosol size distribution, and fractional efficiency shall be documented. See [Annex A](#), [Figures A.1](#), [A.2](#) and [A.3](#) for a sample test reporting structure.

5.2 Absolute filter, wall flow trap and leakage

The provisions related to the absolute filter (if present), the downstream wall flow trap (if present), and leakage shall be in accordance with ISO 17536-1.

5.3 Test conditions

Flow rate for efficiency tests shall be recorded in volumetric flow. All engine efficiency tests shall be documented with actual on-engine blowby temperature, absolute pressure, and humidity.

5.4 Aerosol Sampling System

5.4.1 The design criterion for the sampling system shall be to provide a particle transport of > 95 % for 3 μm diameter particles from the sample probe inlet within the test duct to the inlet of the particle counter.

NOTE This can be verified by experimental measurement or by numerical calculation of particle transport based upon the geometry of the sampling system, the sampling flow rate, and particle deposition associated with diffusion, sedimentation, turbulent flow, and inertial forces. Aerosol Measurement: [1] is a possible reference for developing a good aerosol sampling system.

5.4.2 The use of a sampling system is allowed to optimize particle transport from the inlet probe to the particle counter. The sampling system shall meet the following criteria:

5.4.2.1 The portion of the sampling line in the duct shall block less than 25 % of the duct cross-sectional area¹⁾.

5.4.2.2 Isokinetic sampling (to within +0 to -10 %) shall be maintained on both upstream and downstream probes for nominal flow rates.

5.4.2.3 Flow through the sampling system shall be measured to within 5 % with volumetric devices (e.g., orifice plates and variable area flowmeters)²⁾.

1) Taken from: ASTM D1099-97 Standard Practice for Sampling Steam pg. 4 [3].

2) Taken from: ISO 21501-1:2009, *Determination of particle size distribution — Single particle light interaction methods — Part 1: Light scattering aerosol spectrometer* [4].

5.4.2.4 The upstream and downstream sampling systems shall be of equal length and equivalent geometry.

5.4.2.5 The airflow rate of the upstream and downstream sampling system shall be <20 % of the system airflow rate. This requirement excludes low flow conditions (i.e. idle or low RPM). The operator should try and minimize airflow rate of the upstream system as much as possible as pulling too much air from the system air flow rate could affect separator performance.

5.4.2.6 The auxiliary pump and associated flow control and flow measurement devices of the sampling lines shall be downstream of secondary probes.

5.4.2.7 Because a correlation test will be used, the operator does not need to provide equal dilution to both the upstream and downstream samples.

5.4.2.8 All metal tubing should be grounded. The upstream and downstream sample lines are to be nominally identical in geometry. The use of a short length (50 mm [2 in.] maximum) of straight, flexible, metal tubing to make the final connection to the aerosol particle counter is acceptable.

5.4.2.9 The inlet nozzles of upstream and downstream sample probes shall be sharp edged and of appropriate entrance diameter to maintain isokinetic sampling within +0 to -10 % at the test airflow rate.

5.5 Particle Counter(s) sizing and counting monitor(s)

Permissible instruments used to measure the size and concentration of the aerosol shall meet the following criteria.

- a) If you are only measuring upstream particle distribution, the operator shall measure particle diameters between 0,3 µm and 10 µm particles and group them into at least 4 channels per decade.
- b) If the operator is using this technical specification to measure efficiency, an 8-channel particle counter (or greater) shall be used. The operator shall measure particle diameters between 0,3 µm and 10 µm as long as [8.7.4.3](#) is met.
- c) At least 90 % of all observed counts shall register between 0,7 µm to 1,3 µm when the particle counter is challenged with monodisperse 1,0 µm diameter PSL particles.
- d) Shall have at least 50 % counting efficiency at 0,3 µm³.
- e) Shall have less than 10 % coincidence loss during the measurement.
- f) Shall measure no more than 10 counts per minute over the 0,30 µm to 10 µm range with a HEPA filter mounted at the inlet of the counter.
- g) The particle counter shall be periodically calibrated according to manufacturer specifications.
- h) Shall be able to handle the high air temperatures seen by the raw or conditioned blowby gas coming off an engine.

6 Test procedure

6.1 General

A fractional efficiency test shall be performed on a complete aerosol separator assembly.

3) Taken from ISO 21501-1.

6.2 Test equipment

NOTE The definitions of the following terms related to the test equipment are defined in ISO 17536-1; upstream particle counter, particle counter calibration, maximum particle concentration and particle counter flow.

6.2.1 If the user is measuring efficiency, the setup arrangement to determine the efficiency is shown in [Annex B, Figure B.1](#). Use an engine to supply blowby to the crankcase ventilation system. If the user is only measuring the distribution from an engine, the arrangement is shown in [Annex B, Figure B.2](#).

6.2.2 Use a wall flow trap between the engine and the inlet tube described in ISO 17536-1 to eliminate any oil flow to the inlet tube.

NOTE The piezometer can be contaminated without the use of the wall flow trap.

6.2.3 Use an inlet piezometer tube conforming to [Figure B.3](#). The cross-section shall be the same as the aerosol separator inlet.

6.2.4 Use a manometer or other differential pressure measuring device with the specified accuracy.

6.2.5 Orientation of the unit under test shall be as in application.

6.2.6 Use a wall flow trap similar to the one shown in ISO 17536-1 between the unit under test and the outlet piezometer tube described in [6.2.3](#) to eliminate any oil flow to the piezometer, if applicable.

6.2.7 Use an outlet piezometer tube conforming to [Figure B.3](#). The cross-section shall be the same as the aerosol separator outlet. In the case of non-uniform flow conditions caused by special inlet tubes, special precautions may be required.

6.2.8 Use an air flow rate measuring system having the accuracy described in ISO 17536-1. Use a system that is capable of holding the RPM and torque described in ISO 17536-1. Make sure that the isokinetic sampling tubes meet the specs given in [5.4](#).

6.2.9 If an engine is not capable of generating the blowby flow rate requested, use compressed air/blower/exhauster for inducing air flow through the system, which has adequate flow rate and pressure characteristics for the separators to be tested. Pulsation of flow rate shall be so low that it is not measurable by the flow rate measuring system.

6.2.10 If the components downstream of the unit under test and the environment have a pressure drop greater than 500 Pa, and it is proven that this pressure drop affects the particle size upstream and/or downstream of the UUT, a blower/exhauster on the downstream of the system shall be used to regulate the outlet pressure of the unit under test.

6.2.11 Grounding is required for all test apparatus to reduce the effects of static charge and to improve the consistency of the test results. Grounding of metallic and non-metallic surfaces, housings, transport tubes, injectors and associated hardware is recommended.

6.2.12 All tubing up to the point of the downstream sampling device (if present) should be insulated, or heated, or any other method that will keep the blowby gas above the dew point to eliminate condensation without changing the particle size distribution. If no separator is being tested, the tubing should be insulated up to the point of the sampling device (in cases where the operator is only measuring the engine distribution).

NOTE If the temperature of the blowby gas not maintained, the aerosol distribution could shift due to the presence of water droplets in the airstream.

6.2.13 Tubing should be the shortest length and have as few bends as possible.

6.2.14 The blank duct should be smooth, conductive metal tubing that includes the minimum bends and area changes required to replace the separator housing and connect the inlet and outlet piezometers in the same positions as when the device to be tested is installed.

6.3 Concentration Limit of the Particle Counter

6.3.1 To confirm you do not have coincidence error, either use a particle counter that automatically determines when you have coincidence error, or watch your total counts to make sure they are below the manufacturer's limit specification.

6.4 100 % Efficiency Test and Development of Purge Time

6.4.1 An initial efficiency test should be performed using a HEPA filter as the test device to ensure that the test duct and sampling system are capable of providing a > 99 % efficiency measurement. The test procedures for determination of efficiency given in [Clause 8](#) shall be followed, and the test should be performed at two engine conditions, idle and a loaded condition.

6.4.2 The computed efficiency values shall meet the requirements specified in [6.8, Table 1](#).

6.4.3 One parameter affecting the efficiency during the 100 % efficiency test is the purge time. The purge time is too short if, after switching from the upstream to the downstream line, residual particles from the upstream sample are counted during the downstream sampling and yield an efficiency of < 99 %. In this case, the purge time shall be increased and the 100 % efficiency test repeated.

6.5 Correlation Test

6.5.1 A test shall be performed without a test device in place to check the adequacy of the overall duct, sampling, measurement, and engine.

6.5.2 The test procedures for determination of the correlation ratio given in [8.4](#) shall be followed.

6.5.3 The correlation ratio for each particle size shall meet the requirements specified in [6.8, Table 1](#).

6.6 Particle Counter(s) Zero

The zero count of the particle counter(s) shall meet the requirements specified in [6.8, Table 1](#)

6.7 Particle Counter(s) Sizing Accuracy

The sizing accuracy of the particle counter(s) shall be checked by sampling an aerosol containing monodisperse polystyrene spheres of known size. A relative maximum particle count shall appear in the particle counter sizing channel that encompasses the PSL diameter.

6.8 Summary of Qualification Test Requirements

Qualification test criteria shall conform to [Table 1](#).

Table 1 — System Qualification Measurement Requirements

<i>Parameter</i>	<i>Requirement</i>
100 % Efficiency Test: Based on HEPA filter test	> 99 %
Correlation Ratio Test	0,30 to 1,0 µm: 0,90 to 1,10 1,0 to 3,0 µm: 0,80 to 1,20 3,0 to 10 µm: 0,70 to 1,30
Particle Counter Zero Count Check: Based on HEPA filter attached to the instrument's inlet	< 10 counts per minute over the 0,30 µm to 10 µm range
Particle Counter Sizing Accuracy Check: Based on sampling of aerosolized monodisperse PSL spheres of known size	Relative maximum shall appear in the appropriate sizing channel

6.9 Apparatus validation and maintenance

Maintenance items and schedules should conform to [Table 2](#).

Table 2 — Apparatus Maintenance Schedule

<i>Maintenance Item (Section Reference)</i>	<i>Daily</i>	<i>Monthly</i>	<i>Biannually</i>	<i>After a Change in separator type or engine</i>	<i>Comment</i>
Correlation ratio measurement (6.5)		X		X	
Particle counter zero check (6.6)		X			
Particle counter(s) primary calibration using PSL					NOTE 1
Overloading test of particle counter(s) (6.3.1)			X		
Flow rates, pressure drops, temperature, relative humidity, etc.		NOTE 3			NOTE 2
Cleaning of test duct and components					NOTE 4

NOTE

- 1) Calibration performed annually.
- 2) In accordance with manufacturer's recommendations but at least annually.
- 3) Monthly visual inspection for proper installation and operation.
- 4) Cleaning intervals of the test duct, engine, aerosol sampling lines, and other test components is discretionary.

7 Test Procedures

7.1 General

The purpose of these tests is either to determine the fractional efficiency of an aerosol separator while attached to an engine or to just to measure the size distribution of the aerosol coming from the engine.

Due to the fact that the engine aerosol generated varies in distribution and concentration, if the user is running the separator efficiency test procedure, it shall be done with a pair of particle counters that are used to sample the upstream and downstream flow nearly simultaneously. There is a finite measurable delay for particle transport from the upstream sample probe to the downstream sample probe. It is possible to improve data quality by starting the downstream sample count after a delay equal to the

transport time between the sample probes. The transport time can be measured (using 6.4, 100 % Efficiency Test and Development of Purge Time) or calculated. Estimating the upstream counts from measurements that are not taken during the test is not allowed. Estimating the upstream counts from measurements with a different sizing method is not allowed. If only the upstream size distribution measurement is being done, then only one particle counter is necessary.

All appropriate validation procedures, system checks, correlation tests, and reference filter tests as described in [Clause 6](#) should be done prior to starting a test.

For tests as shown in [Figure B.1](#), correlations are done with a blank duct replacing the aerosol separator to be tested.

7.2 Fractional Efficiency Test Procedure

7.2.1 The purpose is to determine the fractional separation efficiency of an aerosol separator while mounted to an engine. The particle counts upstream and downstream of the separator are used to calculate the fractional efficiency.

NOTE 1 The mass feed rate is dependent on the engine operating conditions of that specific engine.

NOTE 2 When measuring particle sizes by closed loop system, care is taken that the measurement results do not become unstable due to the effect of negative intake pressure.

7.2.2 Set up the test stand as shown in [Figure B.1](#) for all aerosol separators. Seal all joints to prevent air leakage.

7.2.3 Install the blank duct or element housing in the test system in place of the test device. Turn on the engine and set at the specified rpm and torque, measure and record the tare pressure loss correlation ratios. See [Clause 8](#) for sampling sequence, number of samples required, calculations, and for criteria for accepting data.

7.2.4 Mount the separator assembly or separator element in their respective test housing according to [Figure B.1](#). Test separator assemblies should be mounted in the same orientation as when installed in the vehicle.

7.2.5 Verify and document the required oil level, record the oil run time, engine run time, and ambient temperature, pressure, and humidity.

7.2.6 Start and bring the engine to the RPM and load condition or start the measurement at a particular RPM and load, using a device as specified in [6.2.8](#). Record the oil temperature, blowby temperature, differential pressure and crankcase pressure.

NOTE Warm up of engine to a customer prescribed condition is intended to be completed prior to this step.

7.2.7 The operator should compensate for the increased differential pressure over 500 Pa that the tubing and downstream wall flow trap between the unit under test and the piezometer tubes introduce. The operator can also modify the setup to reduce this differential pressure.

NOTE The downstream wall flow trap is present to protect the downstream piezometer tube from contamination of liquid oil wall flow.

7.2.8 Condition the aerosol separator for at least 15 minutes.

7.2.9 Measure and record the pressure loss (ΔP_i).

7.2.10 Allow the upstream and downstream aerosol concentration to stabilize as much as possible and measure fractional efficiency. See [Clause 8](#) for sampling sequence, number of samples required, calculations, and for criteria for accepting data.

7.2.11 Stop the engine or measurement system.

7.2.12 Measure and record temperature, relative humidity and barometric pressure.

7.2.13 Calculate the efficiency, E, by the formula in [8.7.5](#).

7.3 Engine aerosol sampling procedure

7.3.1 General

The purpose is to give the user a method to sample the aerosol coming directly from the crankcase of an engine.

7.3.2 Set up the test stand as shown in [Figure B.2](#). Seal all joints to prevent air leakage.

7.3.3 Verify and document the required oil level, record the oil run time, engine run time, and ambient temperature, pressure, and humidity.

7.3.4 Install the correct isokinetic sampling port that corresponds to the blowby flow rate per [5.4.2.2](#).

7.3.5 Start and bring the engine to the RPM and load condition or start the measurement at a particular RPM and load, using devices as specified in [6.2.8](#). Record the oil temperature, blowby temperature, blowby flow rate, differential pressure and crankcase pressure.

NOTE 1 Warm up of engine to a customer prescribed condition is intended to be completed prior to this step.

NOTE 2 Some operators will map the engine's flow rate vs. the RPM and load condition independently of sampling the blowby particle distribution. Then later sample the distribution without taking flowmeter readings and use the engine conditions to correlate between the two.

7.3.6 Once the engine has stabilized, the user shall sample for as long as necessary to get at least 500 particle counts⁴⁾ total for all important channel sizes. Record the distribution.

NOTE Any channel with less than 500 counts should be ignored.

7.3.7 Stop the engine and measurement system.

7.3.8 Measure and record temperature, relative humidity and barometric pressure.

8 Calculations and data acceptance criteria for the engine fractional efficiency test

8.1 General

These equations are set up to calculate values by channel. At no time should the user be combining data for multiple channels.

4) Taken from ASHRAE 52.2

8.2 Symbols and Subscripts used in the following equations

8.2.1 Symbols

U	upstream counts of each size range (or channel)
D	downstream counts of each size range (or channel)
R	correlation ratio
P	penetration
P'	penetration calculated using Poisson statistics
E	efficiency
T	sampling time
δ	standard deviation of a sample
n	number of sample sets
t	t distribution variable

8.2.2 Subscripts

i	sample number
o	observed
c	correlation
t	testing an aerosol separator
u	upstream
d	downstream
e	estimated
lcl	lower confidence limit
ucl	upper confidence limit
n	number of sample sets

Over bar is used to denote averages e.g. $\bar{P}$.

8.3 Test Sampling

8.3.1 [Table 3](#) is an illustration of the test sequence, [Table 4](#) is the sampling sequence for single counter single sampling system. [Table 5](#) is the sampling sequence for a dual counter dual sampling system. Sample counts in each size range shall be handled the same way, and this pattern shall be followed for all fractional efficiency tests. An initial upstream sample shall be followed by an upstream to downstream purge. The first downstream sampling shall be followed by a downstream to upstream purge and then shall be followed by another upstream sample. The last four time periods shall be repeated for as many sample sets as are required.

NOTE Dual counter dual sampling systems are often referred to as dual counter systems without referring to the number of sampling inputs.

Table 3 — Test sequence

#	Procedure Section #		Device in test position	Engine	Counters sampling, or protected
1	8.4	Correlation	Blank duct or empty housing.	On	On
2	8.5	Efficiency	Housing with separator	On	On

Within each counting sequence:

Table 4 — Sampling sequence for single counter, single sampling systems

Sampling step	Particle counting	Purging
0	No	For first upstream sample
1	Upstream	No
2	No	Upstream to downstream purge
3	Downstream	No
4	no	Downstream to upstream purge
5	Upstream	No

Repeat steps 2 through 5 until a minimum of 4 upstream samples and 3 downstream samples have been taken. More repetitions may be required to meet the data quality requirements.

Table 5 — Sampling sequence for dual counter, simultaneous sampling systems.

Sampling step	Particle counting	Purging
0	No	For first sample
1	Upstream and downstream	No
2	Upstream and downstream	No
3	Upstream and downstream	No

Take additional samples as needed to meet data quality requirements.

8.3.2 The calculations and data quality requirements of [8.4](#) through [8.7](#) are performed separately for each of the particle sizing ranges.

8.4 Correlation Ratio

8.4.1 The correlation ratio R shall be used to correct for any bias between the upstream and downstream sampling systems and counters. The correlation ratio shall be established from the ratio of downstream to upstream particle counts with a blank duct for inertial separator tests or with an empty housing (for separators using removable elements) installed in the test system and before testing an aerosol separator. The correlation ratio measurement shall be performed at the same engine running conditions that the test device fractional efficiency test will be run at. The general equation for the correlation ratio as used in this standard is with the engine on but without a test device in place.

$$R = \frac{\text{downstream particle concentration}}{\text{upstream particle concentration}} \quad (1)$$

8.4.2 Begin sampling after stabilization of the test aerosol, starting with an upstream sample $U_{1,o,c}$, followed by a downstream sample $D_{1,o,c}$. An additional upstream sample $U_{(n+1),o,c}$ shall be made following

the last downstream sample $D_{n,o,c}$. The total number of samples and sampling times shall be determined by the data quality requirements in 8.7.2. Sampling times upstream and downstream shall be the same for this test.

8.4.3 The correlation ratio shall then be calculated in accordance with 8.7.1.

8.5 Penetration/Fractional efficiency

8.5.1 For the purposes of this document, penetration P shall be the fraction of particles that pass through the separator, and the general equation for penetration shall be:

$$P = \frac{\text{downstream particle concentration}}{\text{upstream particle concentration}} \quad (2)$$

with the engine on and the test device in place.

8.5.2 Start sampling with an upstream sample $U_{1,o,t}$ followed by a downstream sample $D_{1,o,t}$ after stabilization of the test aerosol. Take an additional upstream sample $U_{(n+1),o,t}$ following the last downstream sample $D_{n,o,t}$. Test device penetration shall then be calculated in accordance with 8.7.3.

8.6 Efficiency

8.6.1 In this document, the general equation for fractional efficiency shall be:

$$E = \left(1 - \frac{\text{downstream particle concentration}}{\text{upstream particle concentration}} \right) = (1 - P) \quad (3)$$

8.6.2 Separator efficiency shall be calculated in accordance with 8.7.5.

8.7 Data Reduction

8.7.1 Correlation Ratio Data Reduction

8.7.1.1 The upstream counts from two samples shall be averaged to obtain an estimate of the upstream counts that would have occurred at the same time as the downstream counts were taken:

$$U_{i,e,c} = \frac{U_{i,o,c} + U_{(i+1),o,c}}{2} \quad (4)$$

8.7.1.2 The correlation ratio shall be calculated for each upstream and downstream sample set using the observed downstream count and the estimated upstream count:

$$R_i = \frac{D_{i,o,c}}{U_{i,e,c}} \quad (5)$$

8.7.1.3 These correlation ratios shall be averaged to determine a final correlation ratio value:

$$\bar{R} = \frac{\sum_{i=1 \rightarrow n} R_i}{n} \quad (6)$$

8.7.1.4 The standard deviation of the correlation ratio shall be determined by:

$$\delta_c = \sqrt{\frac{\sum_{i=1 \rightarrow n} (R_i - \bar{R})^2}{n-1}} \quad (7)$$

8.7.1.5 The 95 % confidence limits of the correlation value shall be determined by:

$$\bar{R}_{lcl} = \bar{R} - \delta_c \cdot \frac{t}{\sqrt{n}} \quad (8)$$

$$\bar{R}_{ucl} = \bar{R} + \delta_c \cdot \frac{t}{\sqrt{n}} \quad (9)$$

using the t distribution variable from [Table 6](#) for a given n .

Table 6 — t Distribution Variable

Number of Samples n	Degrees of Freedom $\nu = n - 1$	t
3	2	4,303
4	3	3,182
5	4	2,776
6	5	2,571
7	6	2,447
8	7	2,365
9	8	2,306
10	9	2,262
11	10	2,228
12	11	2,201
13	12	2,179
14	13	2,160
15	14	2,145
16	15	2,131
17	16	2,120
18	17	2,110
19	18	2,101
20	19	2,093
21	20	2,086
22	21	2,080
23	22	2,074
24	23	2,069
25	24	2,064
26	25	2,060
27	26	2,056
28	27	2,052
29	28	2,048
30	29	2,045
inf.	inf.	1,960

8.7.2 Correlation Ratio Data Acceptance Criteria

8.7.2.1 Correlation Ratio Error Limit. The number of correlation sample runs n shall be at least three and sufficient to satisfy the following conditions:

- for particle size ranges $\leq 3 \mu\text{m}$:

$$\delta_c \cdot \frac{t}{\sqrt{n}} \leq 0,05 \quad (10)$$

- for particle size ranges $\geq 3 \mu\text{m}$:

$$\delta_c \cdot \frac{t}{\sqrt{n}} \leq 0,10 \quad (11)$$

This requirement shall be satisfied by calculating this expression after each sample set and halting the testing sequence when the requirement is reached for each size range, or by an acceptance criterion for a predetermined number of sample sets.

8.7.2.2 Limits on Magnitude of Correlation Ratio.

The correlation ratio shall meet the requirements specified in [Table 7](#).

Table 7 — Limits on magnitude of correlation ratio

Size range	Limits on correlation ratio
0,30 μm to 1,0 μm	0,90 to 1,10
1,0 μm to 3,0 μm	0,80 to 1,20
3,0 μm to 5 μm	0,70 to 1,30

8.7.2.3 Correlation Ratio Minimum Average Upstream Counts. The sum of the observed upstream counts shall be greater than or equal to 500. If a sufficient number of counts is not obtained, the sample time or aerosol concentration shall be increased. The aerosol concentration shall not exceed the concentration limit of the particle counter(s), as determined by [6.3](#).

$$\sum_{i=1 \rightarrow n} U_{i,e,c} \geq 500 \quad (12)$$

8.7.3 Penetration Data Reduction

8.7.3.1 The upstream counts from the first two samples shall be averaged to obtain an estimate of the upstream counts that would have occurred at the same time as the downstream counts where taken:

$$U_{i,e,t} = \frac{U_{i,o,t} + U_{(i+1),o,t}}{2} \quad (13)$$

8.7.3.2 The observed penetration shall be calculated for each upstream and downstream set using the observed downstream count, the upstream count, the upstream sampling time, and the downstream sampling time:

$$P_{i,o} = \frac{D_{i,o,t}}{U_{i,e,t}} \cdot \frac{T_u}{T_d} \quad (14)$$

8.7.3.3 These observed penetrations shall be averaged to determine an average observed penetration value:

$$\bar{P}_o = \frac{\sum_{i=1 \rightarrow n} P_{i,o}}{n} \quad (15)$$

8.7.3.4 The standard deviation of the observed penetration shall be determined by:

$$\delta_t = \sqrt{\frac{\sum_{i=1 \rightarrow n} (P_{i,o} - \bar{P})^2}{n-1}} \quad (16)$$

8.7.3.5 The observed penetration shall be corrected by the correlation ratio to yield the final penetration:

$$\bar{P} = \frac{\bar{P}_o}{R} \quad (17)$$

8.7.3.6 The standard deviation of the correlation ratio shall be combined with the standard deviation of the observed penetration to determine the total error by:

$$\delta = \bar{P} \cdot \sqrt{\left(\frac{\delta_c}{R}\right)^2 + \left(\frac{\delta_t}{\bar{P}_o}\right)^2} \quad (18)$$

8.7.3.7 The 95 % confidence limits of the penetration shall be determined by:

$$\bar{P}_{lcl} = \bar{P} - \delta \cdot \frac{t}{\sqrt{n}} \quad (19)$$

$$\bar{P}_{ucl} = \bar{P} + \delta \cdot \frac{t}{\sqrt{n}} \quad (20)$$

using the t distribution variable from [Table 6](#) for a given n .

8.7.4 Penetration Data Acceptance Criteria

8.7.4.1 Penetration Error Limit. The number of sample runs n shall be at least three and sufficient to satisfy the following condition:

— for particle size ranges 0,3 μm to 3 μm :

$$\delta \cdot \frac{t}{\sqrt{n}} \leq 0,07 \cdot \bar{P} \text{ or } \leq 0,05, \text{ whichever is greater} \quad (21)$$

— for particle size ranges 3 μm to 5 μm :

$$\delta \cdot \frac{t}{\sqrt{n}} \leq 0,15 \cdot \bar{P} \text{ or } \leq 0,05, \text{ whichever is greater} \quad (22)$$

The requirement shall be satisfied by calculating this expression after each sample set and halting the testing sequence when the requirement is reached for each size range, or by acceptance criteria for a predetermined number of sample sets. If these conditions are met, $\bar{P}$ is used to calculate the efficiency⁵⁾.

8.7.4.2 Penetration calculation if penetration error limit not met. If the above condition cannot be met, the sum of the upstream counts and the sum of the downstream counts shall be calculated.

$$U'_t = \sum_{n=1 \rightarrow n} U_{i,e,t} \text{ (sequential) or } U'_t = \sum_{n=1 \rightarrow n} U_{i,o,t} \text{ (simultaneous)} \quad (23)$$

$$D'_t = \sum_{n=1 \rightarrow n} D_{i,o,t} \quad (24)$$

The sums of the upstream and downstream counts are used to calculate an alternate upper confidence limit for observed penetration P'_{ucl} using Poisson statistics.

$$P'_{ucl,o} = \frac{D'_{ucl,t}}{U'_{lcl,t}} \quad (25)$$

For values ≤ 50 , $D'_{ucl,t}$ and $U'_{lcl,t}$ are found in [Table C.1](#). For values > 50 , $D'_{ucl,t}$ and $U'_{lcl,t}$ are found by

$$D'_{ucl,t} = D'_t + 2 \cdot \sqrt{D'_t} \quad (26)$$

$$U'_{lcl,t} = U'_t + 2 \cdot \sqrt{U'_t} \quad (27)$$

The observed upper confidence level penetration using Poisson statistics shall be corrected by the correlation ratio specified in [Annex C](#), in order to yield the final upper confidence level penetration:

$$P'_{ucl} = \frac{P'_{ucl,o}}{\bar{R}} \quad (28)$$

The greater of the two upper confidence limits for penetration, $\bar{P}_{ucl}$ or P'_{ucl} shall be used to calculate efficiency for that size range.

8.7.4.3 Penetration Minimum Upstream Counts

The sum of the observed upstream counts shall be greater than or equal to 500:

$$\sum_{i=1 \rightarrow n} U_{i,e,t} \geq 500 \quad (29)$$

8.7.5 Efficiency

Fractional efficiency is determined by

$$E = (1 - P) \quad (30)$$

where P is replaced by $\bar{P}$ or $\bar{P}_{ucl}$ or P'_{ucl} as determined in [8.7.3.5](#), or [8.7.3.7](#), or [8.7.4.2](#) respectively

5) There are several reasons that the Penetration Error Limit may not be met. Possible causes include but are not limited to: unsteady upstream concentration and separator efficiency changing during the sampling periods.

Annex A (informative)

Aerosol separator engine fractional efficiency test report

Aerosol separator engine fractional efficiency test report according to ISO/TS 17536-5							
1. Test Unit							
Manufacturer:							
Model/Type No.:							
Aerosol separator description:							
Round inlet diameter:			mm	Non-round inlet: dimensions:			mm
For non-round inlets; piezometer diameter:			mm	Transition length:			mm
Round outlet diameter:			mm	Non-round outlet: dimensions:			mm
For non-round outlets; piezometer diameter:			mm	Transition length:			mm
2. Test materials and test equipment							
Engine oil:							
Oil Type				Batch No.:			
Oil Viscosity at temperature:		cSt	°C	Surface tension at temperature		mN/m	°C
Engine Make							
Engine Size and displacement							
Particle Counter							
Make:				Model:			
Flow Rate:							
3. Test conditions							
Oil Temperature:							
Blowby Temperature:							
Test Flow Rate:							
Test Termination Criteria:							
Engine Speed:							
Engine Torque:							
Initial Differential Pressure:							
Test Termination Differential Pressure:							
Test Duration:							
4. Test results							
Fractional Efficiency - See attached graph							
5. General Comments							
Date:				Test conducted by:			

Figure A.1 — Test Report

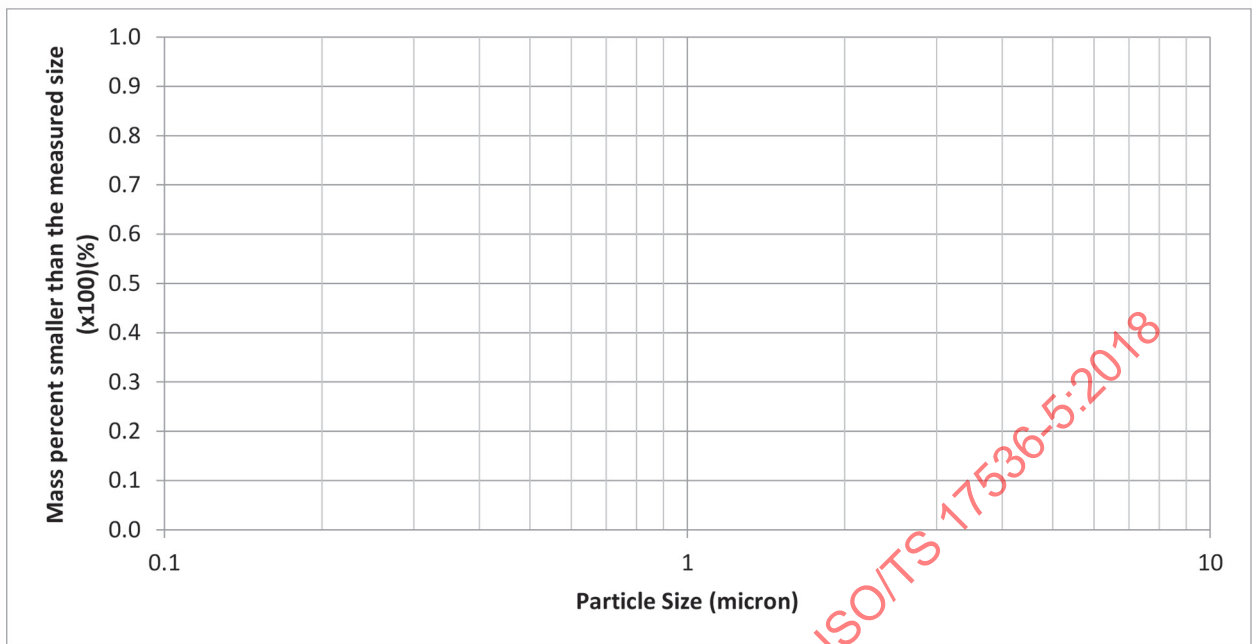


Figure A.2 — Engine aerosol size distribution

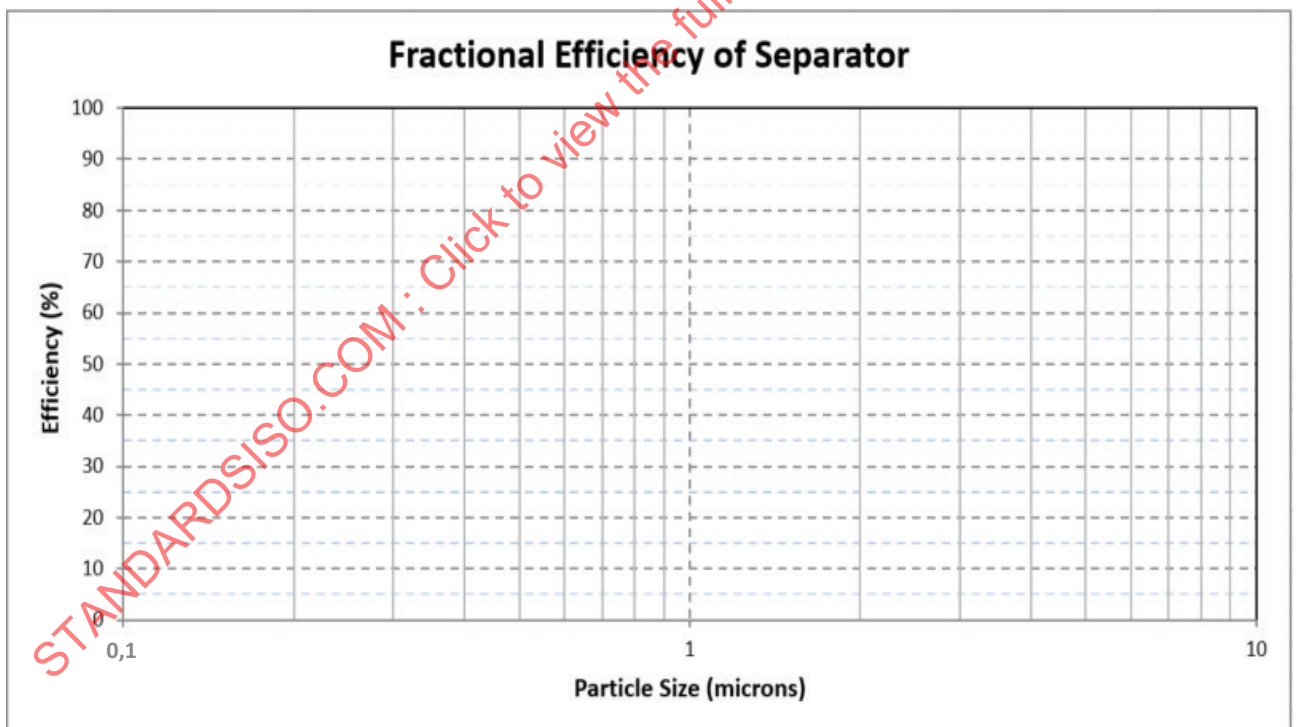
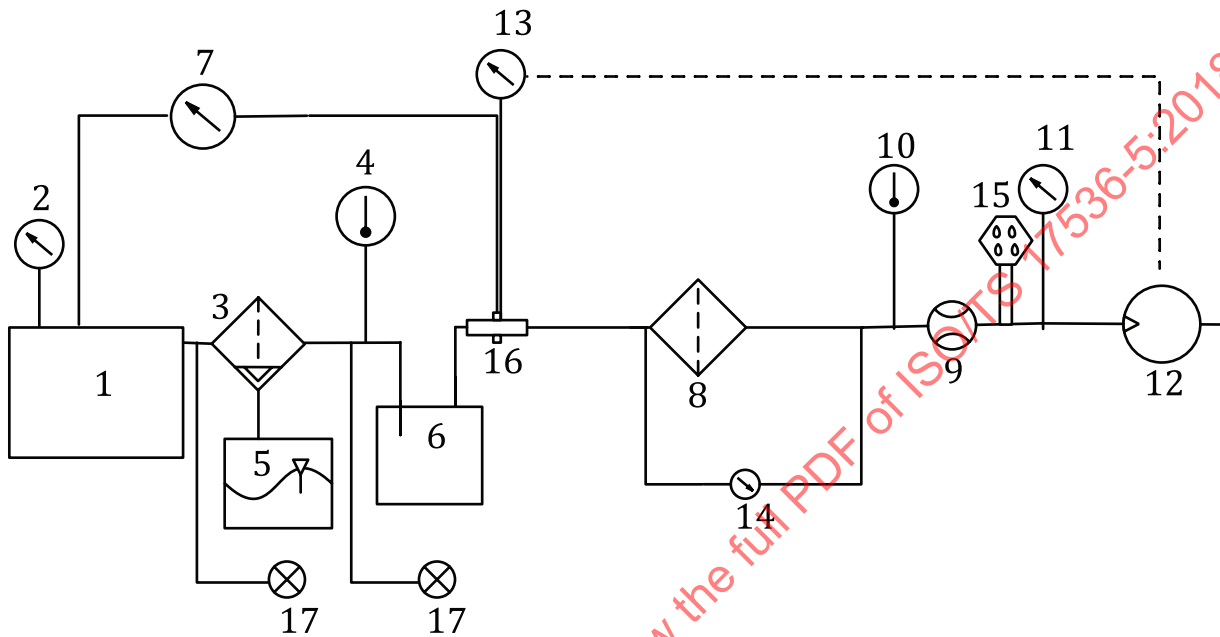


Figure A.3 — Element Efficiency vs. Particle Size

Annex B (normative)

Test equipment



Key

- | | | | |
|---|--------------------------------|----|---|
| 1 | engine | 10 | flow meter temperature |
| 2 | crankcase pressure | 11 | flow meter absolute pressure |
| 3 | aerosol separation device | 12 | downstream pump |
| 4 | outlet temperature | 13 | outlet pressure, pump control feedback |
| 5 | separator drain | 14 | differential pressure — absolute pressure |
| 6 | wall flow trap (if applicable) | 15 | flow meter humidity |
| 7 | differential pressure device | 16 | piezometer tube |
| 8 | absolute filter | 17 | particle counter |
| 9 | flow meter | | |

Figure B.1 — Engine — Aerosol separator efficiency test set-up