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

Part 1: **General**

Véhicules routiers — Essai de performance du séparateur d'aérosols pour les moteurs à combustion interne —

Partie 1: Généralités

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Foreword

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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).

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The committee responsible for this document is Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 34, *Propulsion, powertrain and powertrain fluids*.

ISO 17536 consists of the following parts, under the general title *Road vehicles — Aerosol separator performance test for internal combustion engines*:

— *Part 1: General*

— *Part 3: Method to perform engine gravimetric test* [Technical Specification]

The following parts are under preparation:

— *Part 2: Laboratory gravimetric test method* [Technical Specification]

— *Part 4: Laboratory fractional test method*

— *Part 5: Method to perform engine fractional test* [Technical Specification]

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 need to be 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 alternatively returns the cleaned product to the combustion process by feeding into the engine air intake prior to the turbo compressor (if present). The latter has led to the requirement for a pressure control device to isolate the engine crankcase from air intake pressure.

The engine test methods presented in ISO 17536 are general guidelines for performing an engine test.

Annexes A to I specify general and common provisions for aerosol separator performance test.

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

Part 1: General

1 Scope

This part of ISO 17536 specifies general conditions, defines terms and establishes the basic principles for blowby oil aerosol separator performance tests by laboratory or engine and gravimetric or fractional test method.

2 Terms, definitions, symbols and units

2.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1.1
blowby
aerosol produced from engines and released through a crankcase vent

2.1.2
oil carryover
total amount of liquid oil captured in the downstream wall flow trap

2.1.3
filter element
replaceable part of the crankcase system, consisting of the filter material and carrying frame

2.1.4
crankcase ventilation system
device which separates oil and particles from the engine blowby before venting to either the engine (closed crankcase ventilation, CCV) or the environment (open crankcase ventilation, OCV)

2.1.5
differential pressure
difference in static pressure measured immediately upstream and downstream of the unit under test

2.1.6
pressure loss
measure of the loss of aerodynamic energy caused by an aerosol separator at the observed air flow rate due to different flow velocities at the measuring point.

Note 1 to entry: It is expressed as the differential pressure corrected for any difference in the dynamic head at the measuring points

Note 2 to entry: For further information, see Annex A.

2.1.7
wall flow trap
device to capture oil that is flowing along the walls

Note 1 to entry: The wall flow trap design is drawn in Figure I.2.

2.1.8
absolute filter
filter downstream of the unit under test to retain the contaminant passed by the unit under test

2.1.9
piezometer tube
duct that has a hole or holes drilled in the wall to obtain a pressure reading

Note 1 to entry: For further information, see Figure B.2.

2.1.10
separator efficiency
ability of the aerosol separator or the unit under test to remove contaminant under specified test conditions

2.1.11
optical diameter
optical equivalent diameter
$D_{o,i}$
diameter of a particle of the type used to calibrate an optical sizing instrument that scatters the same amount of light as the particle being measured

Note 1 to entry: Optical diameter depends on the instrument, the type of particle used to calibrate the instrument (usually polystyrene latex spheres), and the optical properties of the particle being measured.

2.1.12
aerodynamic diameter
aerodynamic equivalent diameter
D_{ae}
diameter of a sphere of density 1 g/cm^3 with the same terminal velocity due to gravitational force in calm air, as the particle being measured

Note 1 to entry: Annex C provides additional information about aerodynamic diameter.

Note 2 to entry: Aerodynamic diameter depends on the instrument, the type of particle used to calibrate the instrument (usually polystyrene latex spheres), and the properties of the particle being measured.

2.1.13
pressure regulator
device between the outlet of the aerosol separator and air intake to regulate the crankcase pressure in high vacuum conditions

2.1.14
mass oil flow
mass amount of oil per unit time

2.1.15
relief valve
device to direct a portion of the flow around a separation device due to a pressure difference, usually venting to the atmosphere

2.1.16
bypass valve
device to direct a portion of the flow around a separation device due to pressure difference, usually venting downstream of the bypassed separation device

2.1.17
challenge aerosol
output from the aerosol generator or engine which corresponds to the distribution in testing and with the amount of the mass feed rate

Note 1 to entry: The aerosol distribution by mass is prescribed in ISO/TS 17536-2.

2.1.18
particle size
polystyrene latex equivalent size expressed as a diameter in micrometers

2.1.19
isokinetic sampling
sampling in which the flow in the sampler inlet is moving at the same velocity and direction as the flow being sampled

Note 1 to entry: Annex D provides additional information about isokinetic sampling.

2.1.20
particle counter
instrument for sizing and/or counting aerosol particles

Note 1 to entry: Recommended particle counters are optical particle counters (in accordance with ISO 21501-1) or other counters demonstrating good correlation in measuring particle sizes such as aerodynamic particle counters.

2.1.21
coefficient of variation
COV
standard deviation of a group of measurements divided by the mean

2.1.22
unit under test
UUT
either a single aerosol separator element or a complete crankcase ventilation system

2.1.23
open crankcase ventilation
OCV
aerosol separator system that is attached to the crankcase and is vented to the environment

2.1.24
closed crankcase ventilation
CCV
aerosol separator system that is attached between the crankcase and the engine

2.1.25
aerosol separator
device that separates oil from the blowby stream or test stand airstream

2.1.26
high efficiency particulate air filter
HEPA filter
filter having 99,95 % efficiency at most penetrating particle size (class H13 in accordance with EN 1822), or 99,97 % (or higher) fractional efficiency at 0,3 µm using dispersed oil particulate (DOP) aerosol as defined by IEST RP-CC001 recommended practice

2.1.27
inertial separator
device that separates oil from the blowby stream using inertia

2.1.28
combination separator
device that separates oil from the blowby stream using inertia as well as a filter element

2.1.29
rated air flow
flow rate specified by the user or manufacturer

Note 1 to entry: The rated air flow is usually used as the test air flow.

2.1.30
test air flow
measure of the quantity of air pushed or drawn through the aerosol separator per unit time

2.1.31
aerosol generator
laboratory equipment that can produce a simulated blowby particle distribution from oil and compressed air

Note 1 to entry: The aerosol distribution by mass is prescribed in ISO/TS 17536-2.

2.1.32
drainage vessel
device that captures the separated oil from the crankcase separation system, not to include oil carryover

Note 1 to entry: Filter life is not used in all parts of ISO 17536. Life reference is given in Annex E.

2.1.33
mass feed rate
mass amount of challenge aerosol or liquid subjected to the unit under test per unit time

Note 1 to entry: Filter life is not used in all parts of ISO 17536. Life reference is given in Annex E.

2.2 Symbols and units

Quantity	Symbol	Unit
Volume flow rate	q_V	l/min
Velocity	v	m/s
Density	ρ	kg/m^3
Mass flow rate	q_m	g/h
Pressure	p	Pa
Differential pressure	Δp_d	Pa
Pressure loss	Δp_l	Pa
Mass	m	g
Time	t	s
Speed	N	rev/min
Torque	T	N-m

3 Measurement equipment accuracy

Air flow rate to within ± 5 % of reading.

Differential pressure to within ± 25 Pa of reading.

Temperature to within ± 1,5 °C of reading.

Mass to within 0,1 g except for absolute filter mass and downstream wall flow trap.

Mass to within 0,01 g for absolute filter mass and downstream wall flow trap.

Relative humidity (RH) with an accuracy of ± 2 % RH.

Barometric pressure to within ± 3 hPa.

Crankcase pressure to within ± 25 Pa of reading

RPM to within ± 0,5 % of maximum engine speed

Torque within ± 2 % of operating torque

Leak rate shall be < 1 % of the air flow rate.

The measurement equipment shall be calibrated at regular intervals to ensure the required accuracy.

4 Absolute filter, wall flow trap and leakage

4.1 Absolute filter

4.1.1 Absolute filter material

Separation efficiency of the absolute filter shall be equal to or greater than 97 % for the challenge aerosol based on the calculation in Annex F. The absolute filter shall be stable up to temperatures equal or greater than 105 °C, and resistant to oil, all kind of fuels, water, and other components of blowby.

The validation of absolute filter media efficiency is given in Annex F.

NOTE The use of an absolute filter with a backing will minimize fibre loss.

4.1.2 Absolute filter mass measurement method

The absolute filter shall be weighed, at least to the nearest 0,01 g, after the mass has stabilized. Weigh stabilization may be achieved for water removal and minimal volatile content loss by storage in a ventilated oven at a constant temperature of 65,5 °C. Other temperatures may be used to meet customer requirements. Alternatively, place absolute filter in an ambient temperature and humidity controlled enclosure.

The absolute filter shall be weighed in the same environment as at the beginning of the test. Heated weighing should be in an enclosed heated chamber.

NOTE See Annex F for the validation process and 4.1.3 for process control.

4.1.3 Absolute media measurement process validation

Using the method of choice, the absolute pad weight method shall be performed once each day for three days and have no more than ± 0,03 g variation between measurements.

4.2 Wall flow trap

NOTE An example of the wall flow trap design is given in Figure I.2.

4.2.1 Weight measurement

The wall flow trap shall be weighed, to the nearest 0,01 g, after the mass has stabilized.

The wall flow trap should be weighed in the same environment as at the beginning of the test. Heated weighing should be in an enclosed heated chamber.

4.2.2 Validation of wall flow trap liquid oil efficiency

Arrange two wall flow traps in series. Challenge the wall flow trap with a high mass flow rate to determine gravimetric efficiency according to the test procedure given in the corresponding clauses in the relevant part of ISO 17536. Wall flow trap efficiency from the validation setup shall be equal to or greater than 97 % for the challenge aerosol with a minimum of 1 g gained in the upstream wall flow trap.

Challenge the wall flow trap with a high mass flow rate to determine gravimetric efficiency test.

The wall flow trap efficiency, E_t, shall be calculated as shown in Formula (1):

$$E_t = \frac{\Delta m_C}{\Delta m_C + \Delta m_D} \times 100 \quad (1)$$

where

Δm_C is the mass increase of upstream wall flow trap;

Δm_D is the mass increase of downstream wall flow trap.

4.2.3 Validation of wall flow trap aerosol efficiency

Conduct a test similar to the method explained in Annex F, to obtain an aerosol efficiency value using the specified challenge aerosol. The test setup shall consist of an oil mist generator, wall flow trap, and an absolute filter to measure the aerosol. The absolute filter shall meet the requirements in 4.1.1. A minimum of 3 g shall be subjected to the wall flow trap during this efficiency test. The wall flow trap shall meet an efficiency of less than 1 %.

4.3 Leakage

It is important to minimize leakage into the test system to obtain good data. Depending on where the leakage occurs, it can cause major errors in particle counting.

As a minimum all connections and joints should be checked for visual leakage using soap bubbles or smoke. Any known soap solution can be used for the test. Preferably, the soap solution (foam) will be applied using a brush at all connections and joints. Leaks are especially important on the clean side of the oil separator.

Leakage shall be evaluated according to Annex G.

5 Principles for aerosol separator performance tests

5.1 General

Performance tests shall be performed on a complete aerosol separator assembly. The tests may consist of one or more of the following: laboratory gravimetric test (see ISO/TS 17536-2), an engine gravimetric test (see ISO/TS 17536-3), a laboratory fractional test method (see ISO/TS 17536-4) and an engine fractional method (see ISO/TS 17536-5).

For performance tests which require pressure reading to be measured, either static or differential, this shall be done in accordance with Annex A.

The test equipment used to measure pressure readings shall be as specified in Annex B.

5.2 Test equipment

5.2.1 Grounding

Grounding is required for all test apparatus to reduce the effects of static charges 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.

5.2.2 Upstream sample probe

Sampling probe shall be isokinetic (average local velocity of duct and probe to be equal) to within +0 % and −10 %. The same probe design should be used before the oil separator. Sampling probe shall be located on the centreline of the test duct. Sample probes shall be located at least seven diameters downstream of any bends, reducers, expanders, etc. The sampling probe shall be at least four diameters upstream of any bends, reducers, expanders, etc. The sampler will also be located in the centre of duct. The probes shall be made of electrically conductive metallic tubing with a smooth inside surface. The design of the probe and sampling line will reduce particle losses. The inlet of the sampling probe shall be sharp edged and shall be located near the centre of the duct. The tube shall be straight, (or no more than one bend) and as short as possible. See Annex D for details on isokinetic sampling. A short flexible connection to the particle counter may be used to allow some flexibility and reduce stress on the counter inlet. Polytetrafluoroethylene (PTFE) may not be used as flexible tubing. Use conductive tubing [e.g. plasticized polyvinyl chloride (PVC)] instead.

Sampling probe ducting to the particle counter shall be set up in a way that no sedimentation of large particles takes place while paying attention to the following.

— vertical orientation of the tubing;

— sufficient flow velocity;

— short connection length between particle counter and sampling probe;

— avoidance of bends in the tubing;

— no sharp angles if bends are necessary.

5.2.3 Upstream particle counter

The airborne particle counter shall be capable of counting particles in the 0,35 µm to 55 µm optical size range and 0,5 µm to 10,0 µm aerodynamic size range. It is also desirable for the Particle Counter to have a design incorporating clean sheath air to protect the optics and keep the optics clean. The particle counters may also need to be adapted with an exhaust port that can be routed back to the test system vacuum. Without this exhaust set up the particle counter may not be able to perform at the rated flow. Counters shall be calibrated using accredited lot traceable polystyrene latex (PSL) spheres (see ISO 21501-1 calibration procedure.). Data should also be reported in equivalent aerodynamic size ranges. Most laboratories currently use optical particle counters, however the technical advantages of using aerodynamic particle counters is also well recognized.

The particle counter shall be able at a minimum, to discriminate eight logarithmically spaced particle size classes.

5.2.4 Particle counter calibration

The particle counters shall be calibrated with polystyrene latex particles of appropriate size prior to system start-up and a minimum of once a year to verify that the size calibration has not changed. It is recommended that the particle counter calibration be verified periodically during the year between calibrations.

5.2.5 Maximum particle concentration

The maximum total particle concentration shall be established to prevent coincidence counting, (i.e. counting more than one particle at a time). A recommended method for establishing this limit is to conduct oil separator gravimetric efficiency tests at a series of different concentrations and compare the results. The maximum concentration is determined at the point where increasing the concentration by a factor of two causes the fractional efficiency in the smallest size range at the higher concentration to be more than 5 % less than the fractional efficiency at the lower concentration. Another method is to increase the concentration in steps (e.g. by using a diluted and an undiluted aerosol) and determine the concentration where the particle counter starts showing significant deviation from the expected concentration in the smallest size range. An example is given in Annex H.

5.2.6 Particle counter flow

The particle counter flow rate shall remain constant within ± 5 % for the duration of a test including the correlation done before the test.

5.3 Determination of gravimetric separation efficiency

5.3.1 General

The purpose is to determine the gravimetric separation efficiency. The device should be operated at the prescribed air flow rate and oil flow rate. The weight changes of the component parts and the absolute filter during the test period shall be used to calculate the gravimetric efficiency.

The weight increase of the absolute filter after conditioning for a gravimetric efficiency test shall be greater than 0,05 g.

5.3.2 Calculations

Calculate the aerosol efficiency, E_a, by the method shown in Formula (2):

$$E_a = \frac{\Delta m_u + \Delta m_D + \Delta m_d}{\Delta m_u + \Delta m_F + \Delta m_D + \Delta m_d} \times 100 \quad (2)$$

Calculate the total efficiency, E_{Tx}, by the method shown in Formula (3) and Formula (4):

$$E_{T1} = \frac{\Delta m_u + \Delta m_d}{\Delta m_u + \Delta m_F + \Delta m_D + \Delta m_d} \times 100 \quad (3)$$

$$E_{T2} = \frac{\Delta m_T - \Delta m_F}{\Delta m_T} \times 100 \quad (4)$$

Formula (4) shall be used only for calculating total efficiency in ISO/TS 17536-3 gravimetric tests.

NOTE If a wall flow trap is not used, aerosol efficiency cannot be measured, only total efficiency is recorded.

Calculate the liquid penetration per unit time, P_L, by the following method:

$$P_L = \frac{\Delta m_D}{t} \quad (5)$$

Calculate the mass feed rate, O_m, by the following method:

$$O_m = \frac{\Delta m_u + \Delta m_F + \Delta m_D + \Delta m_d}{t} \quad (6)$$

where

E_a is the efficiency of the unit under test;

t is the test time in hours;

E_{T1} is the total efficiency (liquid and aerosol) of the unit under test;

E_{T2} is the total efficiency (liquid and aerosol) of the unit under test for engine gravimetric;

P_L is the liquid penetration of the unit under test;

Δm_u is the mass increase of the unit under test;

Δm_F is the mass increase of the absolute filter;

Δm_D is the mass increase of the downstream wall flow trap;

Δm_d is the mass increase of the drain;

Δm_T is the mass increase of the alternative method of capturing the total challenge (absolute filter method).

Annex A
(normative)

Explanation of differential pressure and pressure loss of an aerosol separator

When differential pressure across a separator has been measured ($p_2 - p_1$ in Table A.1), any difference in the cross-sectional area of the ducts at the upstream and downstream pressure tapping points shall be taken into account in determining the pressure loss across the separator. The pressure loss across the separator, Δp_l, is given by Formula (A.1):

$$\Delta p_l = \Delta p_d - \Delta p_c \quad \text{(A.1)}$$

where Δp_d is the measured differential pressure, and Δp_c is calculated according to Formula (A.2):

$$\Delta p_c = \frac{\rho_2 \times v_2^{\,2}}{2} - \frac{\rho_1 \times v_1^{\,2}}{2} \quad \text{(A.2)}$$

where

ρ_1 is the density of the air at the upstream pressure tapping point;

ρ_2 is the density of the air at the downstream pressure tapping point;

v_1 is the velocity of the air in the duct at the upstream pressure tapping point;

v_2 is the velocity of the air in the duct at the downstream pressure tapping point.

Table A.1 — Illustration of differential pressure, pressure loss of an aerosol separator

Term	Air being pushed through the separator	Explanation
Differential pressure	$\Delta p_d = p_2 - p_1$	Used with normally equal diameter piezometers. See Figure B.1.
Pressure loss	$\Delta p_l = \Delta p_d - \Delta p_c$ $\Delta p_l = (p_2 - p_1) - \frac{(\rho_2 \times v_2^{\,2}) - (\rho_1 \times v_1^{\,2})}{2}$	Used when the inlet and outlet piezometers have different diameters

Key

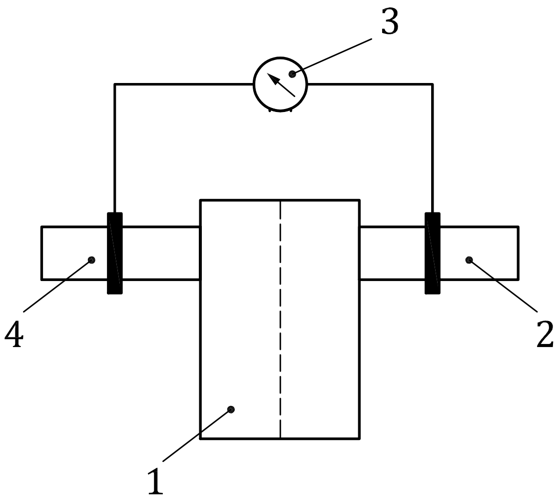
p_1 pressure measured at the upstream pressure tapping point

p_2 pressure measured at the downstream pressure tapping point

Annex B
(normative)

Test equipment

The test equipment shall consist of a wall flow trap (see Annex I) and an inlet/outlet piezometer tube. Typical set-up for pressure loss test, wall flow trap design (see Annex I) and the inlet/outlet piezometer tube dimensions are shown in Figures B.1 and I.1 and Figures B.2 and I.2 respectively.



Key

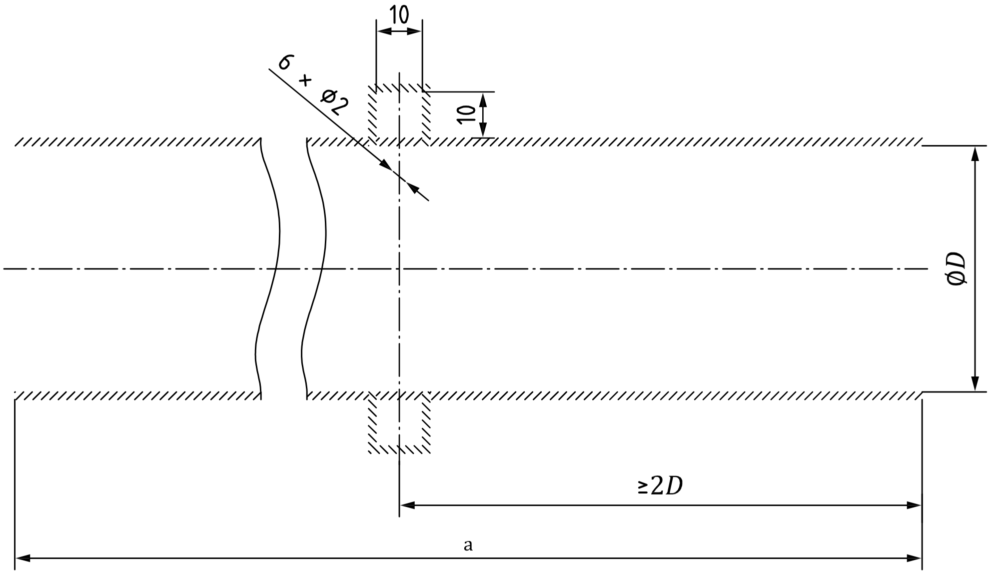
1 unit under test

2 outlet tube (see Figure B.2)

3 differential pressure measuring device

4 inlet tube (see Figure B.2)

Figure B.1 — Set-up for pressure loss test



Key

a outlet tube: 4D min; inlet tube: 6D min

Figure B.2 — Inlet/outlet piezometer tube

The piezometer hole diameters shown in Figure B.2 of six holes at a size of 2 mm is the standard size recommended in ISO 17536. Alternative number and size holes may be used if a comparison of < 1 % to the static pressure of a six-hole, 2 mm system is achieved.

The piezometer measurement connection shall be plumbed to always face upward, as much as possible, to deter oil from settling at the connection opening.

Annex C
(informative)

Aerodynamic diameter

To be able to describe the properties of non-spherical particles, the definition of equivalent diameters is necessary. For example, the deposition of airborne particles in an oil separator, transportation losses in ducts, and the behaviour of particles in the human respiratory tract are based on the particle's aerodynamic properties. Therefore, the aerodynamic diameter is used to characterize particles in these cases.

The equivalent aerodynamic diameter is the diameter of a sphere of density 1 g/cm^3 with the same terminal velocity due to gravitational force in calm air, as the particle, under the prevailing conditions of temperature, pressure and relative humidity.

NOTE The particle diffusion diameter is the diameter of a sphere with the same diffusion coefficient as the particle under the prevailing conditions of temperature, pressure and relative humidity.

The equivalent aerodynamic diameter, D_{ae}, is defined as shown in Formula (C.1):

$$D_{ac} = \left[\frac{C_c\left(D_g\right) \times \rho}{C_c\left(D_{ae}\right) \times \rho_o \times \chi} \right]^{1/2} \times D_g \quad \text{(C.1)}$$

where

D_g is the geometric (volume equivalent) diameter of the particle, g/cm^3;

ρ is the density of the aerosol particle, g/cm^3;

ρ_o is the unit density, 1g/cm^3;

C_c is the slip correction factor;

χ is the dynamic shape factor of the aerosol particle.

For particle bulk material densities between 0,5 g/cm^3 and 3 g/cm^3 and particles aerodynamically larger than 0,5 µm, Formula (C.1) simplifies to Formula (C.2):

$$D_{ac} = \left(\frac{\rho}{\rho_o \times \chi} \right)^{1/2} \times D_g \quad \text{(C.2)}$$

with a relative size error less than 5 %.

The densities and shape factors specified in Table C.1 shall be used.

Table C.1 — Density and shape factors

Efficiency aerosol	Density ρ g/cm^3	Dynamic shape factor χ
Challenge oil	Measured at temperature of use	1,0

An optical particle counter measures the optical equivalent diameter, where the light scattered by the particle equals the light scattered by a calibration particle (e.g. PSL) of known size. For precision work, an optical particle counter may be calibrated with the material to be measured. In that case, the optical equivalent diameter equals the geometric diameter, and Formula (C.2) can be used directly. Otherwise, the conversion of the optical equivalent diameter of the particles into the geometric (volume equivalent) diameter before applying Formula (C.2) is required to minimize the conversion error. For the purpose of this document, use the optical equivalent diameter as the geometric (volume equivalent) diameter for calculating the aerodynamic equivalent diameter, which is current practice.

Annex D
(informative)

Isokinetic sampling probes and information

One of the challenges of particle counting is the ability to collect representative samples for analysis. Isokinetic sampling, including proper probe alignment, provides a method for obtaining representative samples at the inlet of the upstream sampling probe. Isokinetic sampling, using thin walled, sharp edged tubes or nozzles, ensures that there is no distortion of the streamlines at the nozzle inlet and, therefore, no loss or gain of particles regardless of their size or inertia. Sampling is considered isokinetic when the probe is aligned parallel to the air streamlines and the air velocity entering the probe is the same as the free stream velocity approaching the inlet, as shown in Figure D.1 a), and as represented in Formula (D.1):

$$V_s = V_\infty \qquad \text{(D.1)}$$

where

V_s is the velocity of the sampling probe;

V_∞ is the velocity in the flow stream.

In most cases, for circular ducts, the probe inlet is located along the duct centerline, parallel to the flow, facing upstream, at least four to six diameters from bends or obstructions. Cases requiring probe locations of less than four to six diameters downstream from bends or obstructions, or when sampling in non-circular ducts, are likely to require samples from multiple cross-sectional regions, greatly complicating the sampling task. Local velocities can be measured across the duct to establish the velocity profile in support of isokinetic sampling. It is important to recognize that the particle size distribution of the upstream particles can be skewed from the velocity profile, depending on duct geometry and upstream and downstream obstructions. In addition, isokinetic sampling does not guarantee that there are no particle losses between the nozzle entrance and the particle counter.

Failure to sample isokinetically, termed anisokinetic sampling, is likely to cause distortions in both particle size distribution and particle concentration. This is caused by particle inertia along the curved streamlines, as the flow converges or diverges at the nozzle inlet, as illustrated in Figures D.1b and D.1c for super- and sub-isokinetic sampling, respectively. The extent of the errors in concentration for given particle sizes, depends on the square root of the Stokes number, which is directly proportional to particle size and depends on the actual sampling conditions.

As shown in Figure D.1 b), the suction area in the case of super-isokinetic sampling (when the velocity entering the probe exceeds the stream velocity) is greater than for isokinetic sampling. In this case, larger particles with high inertia from this area cannot follow the converging streamlines and will be lost from the sample, while an excessive number of finer particles will follow the streamlines and enter the nozzle. This will lead to an overrepresentation of fine particles in the aerosol sample.

For sub-isokinetic sampling [Figure D.1 c), with probe velocity less than stream velocity], the suction area is smaller than for isokinetic sampling. In this case, larger particles from outside of the original sampling area will enter the nozzle, while some of the finer particles originally in the sampling area will follow the streamlines and diverge past the nozzle. This will lead to an overrepresentation of larger particles in the aerosol sample.

Isoaxial and isokinetic sampling is the ideal sampling configuration and will aspirate all representative particlesizes with nearly 100 % efficiency, especially for particles in the submicron to 10 µm range. A departure from this ideal configuration into regions of anisokinetic and anisoaxial sampling results in non-representative sampling. This should be avoided when making fractional efficiency measurements.

Because particle counters have fixed flow rates, isokinetic sampling is achieved by changing the size of the sampling probe inlet to provide velocity matching. This is accomplished using the following formula, assuming the probe inlet and approach velocities are equal and that probe and duct air flow rates are known. For this case, the probe inside diameter d would normally be equal to the main duct diameter D times the square root of the ratio of the sampler flow rate, q_V, to the main duct flow rate, Q_V, as shown in Formula (D.2).

$$d = D\sqrt{\frac{q_V}{Q_V}} \tag{D.2}$$

It has been shown, however, that more accurate results are obtained when using Formula (D.3) to determine inside probe diameter:

$$d = \sqrt{\frac{q_V\left(D^2 - d_o{}^2\right)}{Q_V}} \tag{D.3}$$

where:

Q_V is the volume flow rate in test duct;

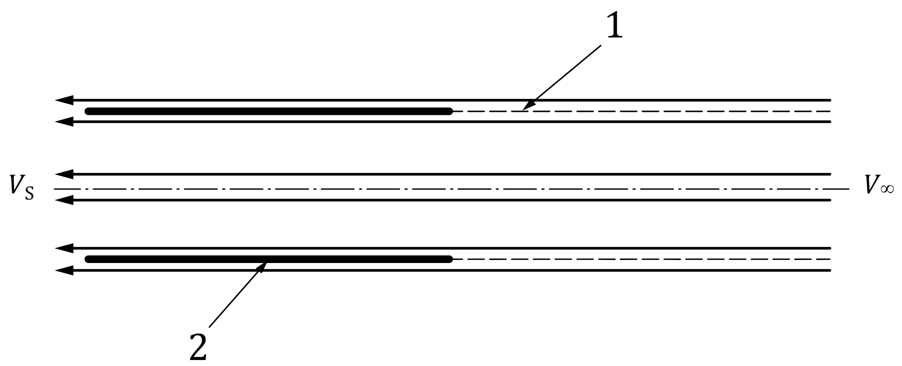
D is the inside diameter of test duct;

d_o is the outside diameter of inlet side of the sampling probe;

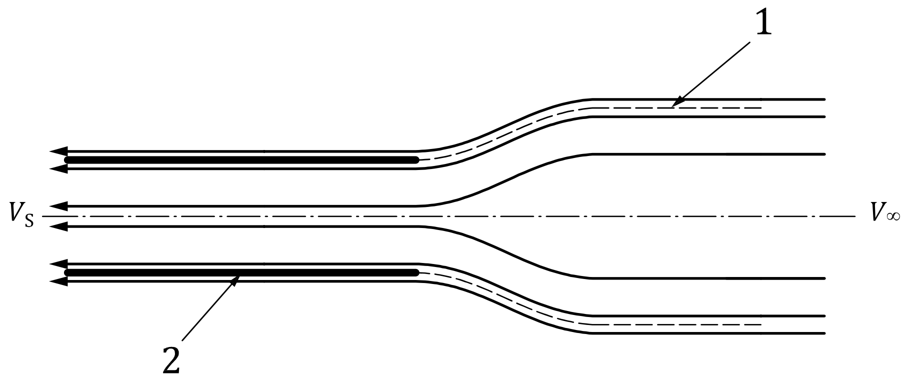
q_V is the volume flow rate in sample line.

Acceptable sampling tip designs are shown in Figure D.2.

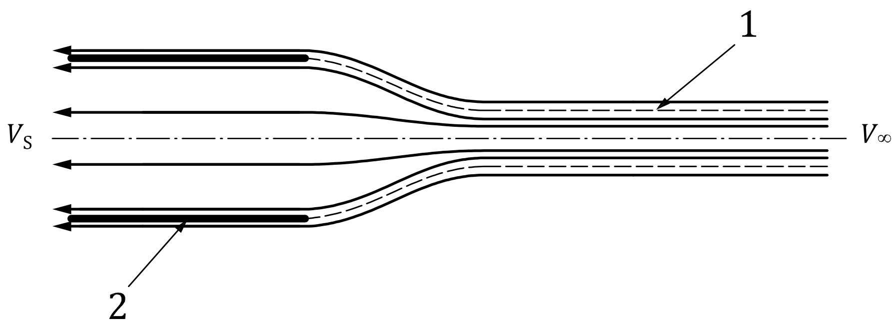
As noted, anisoaxial sampling causes particles with sufficient inertia to diverge from the aerosol streamlines resulting in lower sampling efficiencies that can significantly deviate from 100 %. Thus, anisoaxial sampling will almost always underestimate particle concentration. However, for misalignments up to 15 °, the error in concentration is small for all particle sizes. Because misalignment is visually obvious, eye positioning of the sample probe is adequate when the direction of the streamlines is well known.



a) Isokinetic sampling, $V_S = V_\infty$



b) Super-isokinetic sampling, $V_S > V_\infty$



c) Sub-isokinetic sampling, $V_S < V_\infty$

Key

1 limiting streamline

2 sampling nozzle

V_∞ air velocity entering the probe

V_S free stream velocity approaching the inlet

Figure D.1 — Types of aerosol sampling

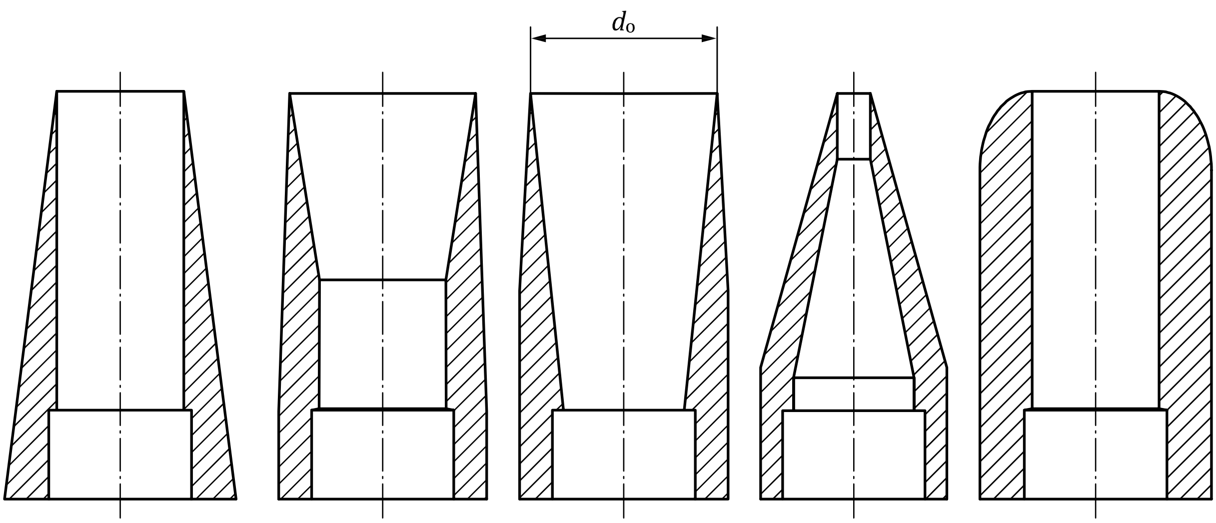


Figure D.2 — Types of sampling nozzles

Annex E
(informative)

Life reference

The useful life of blowby removal devices is an important parameter to be considered when choosing or designing crankcase ventilation systems. The prediction of useful life is difficult to make in the case of blowby devices as the conditions that affect their life are very closely related to specific engine running conditions that cause, for instance, variation in air flow, discharge of soot, oil additive depletion, lacquer formation, etc. There has not been sufficient research to see what correlation exists between, for instance, the use of fine carbon as a blocking contaminant in laboratory tests and the actual life experienced in the field on engine typical for a given application. Because of this it is recommended that life determination should be carried out on a representative sample of actual engines.

Annex F
(normative)

Validation of the absolute filter media

F.1 Absolute filter validation challenge aerosol

The challenge shall correspond to the smallest downstream distribution which shall be tested using this standard. The challenge aerosol shall be tested using the equipment specified in 5.2.3.

F.2 Validation of absolute filter media efficiency

Arrange two absolute filter housings in series. Perform a gravimetric efficiency test with a challenge aerosol with a D50 of 0,60 micron or an output challenge distribution from the highest performing product tested and determine the mass increase of each absolute filter according to the test procedure given in the corresponding corresponding clauses in the relevant part of ISO 17536.

Calculate the absolute filter media efficiency, E_a,as shown in Formula (F.1):

$$E_a = \frac{\Delta m_A}{\Delta m_A + \Delta m_B} \times 100\ \% \quad \text{(F.1)}$$

where

Δm_A is the mass increase of upstream absolute filter;

Δm_B is the mass increase of downstream absolute filter.

The mass increase on the upstream absolute filter shall be greater than 1,0 g before performing the validation on the absolute filter material.

Annex G
(normative)

Leakage

G.1 General

The maximum leak rate is 1 % of the test and total air flow rate. To evaluate the leakage, block off the ductwork and measure the flow required to maintain a pressure condition referenced to specified test flow rates. This method would require putting in an elbow, the unit under test, or other tube section in the test specimen location.

G.2 Types of leaks

G.2.1 Upstream leaks

Leaks in the inlet HEPA filtration will be seen at the upstream sample location. If the concentration and size distribution of the aerosol in the leakage flow is consistent and a low enough level to be overwhelmed by the challenge aerosol it may be acceptable. If it is inconsistent, it may affect the correlation values established for the particle counter.

G.2.2 Leaks between the upstream probe location and the system under test

These leaks will basically add to the feed aerosol. Plugging and testing that section of ductwork should easily eliminate these leaks. Note that this section includes the aerosol generator. The compressed air will need to be shut off to keep ambient air from leaking in.

G.2.3 Leaks in the test housing

This can be tested off of a test stand with a pressure/vacuum source. To evaluate the leakage, block off the ductwork and measure the flow required to maintain a pressure condition referenced to specified test flow rates.

G.2.4 Other leaks

Leaks in the sample lines themselves need to be detected and eliminated. Leaks inside a particle counter can be a problem and need to be checked for.

Annex H
(informative)

Determination of maximum efficiency aerosol concentration

It is recommended to perform fractional efficiency tests vs. particle concentration for particle size ranges using particle counters. An example is illustrated in Figure H.1. When the concentration is low, the fractional efficiencies are not stable due to lack of enough counts as seen on left hand side of the curves. The fractional efficiencies will then be stable over a range of particle concentrations. As the particle concentration is further increased, the efficiency of the lowest size channel will start to drop due to coincidence problem. The appropriate particle concentration range should be the range in which the fractional efficiencies are stable (e.g. approximately five to fifteen particles per cubic centimeter for the 0,3 µm to 0,5 µm channel shown in Figure H.1). Note that the appropriate particle concentration range for different size distributions of challenge aerosol and for different particle counters may be different. The tests described here should be performed when different counters or different challenges aerosol are used

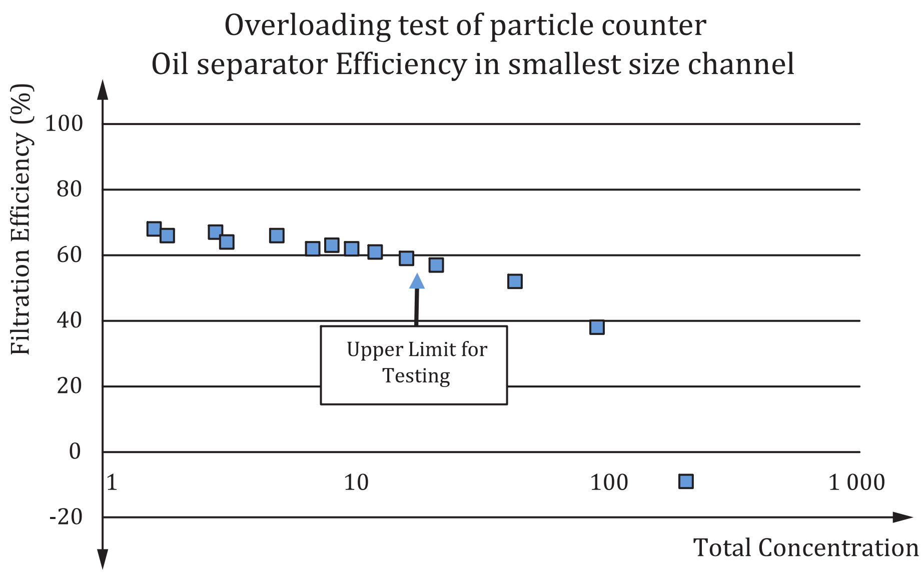
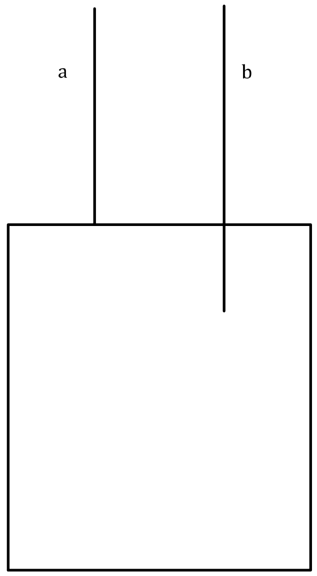


Figure H.1 — Example efficiency at various sizes vs. particle counts

Annex I
(informative)

Test equipment — Wall flow trap design

Figures I.1 and I.2 are examples of functional wall flow traps. The use of other wall flow trap designs is permitted as long as the wall flow trap meets the validation requirements of 4.2.2 and 4.2.3.

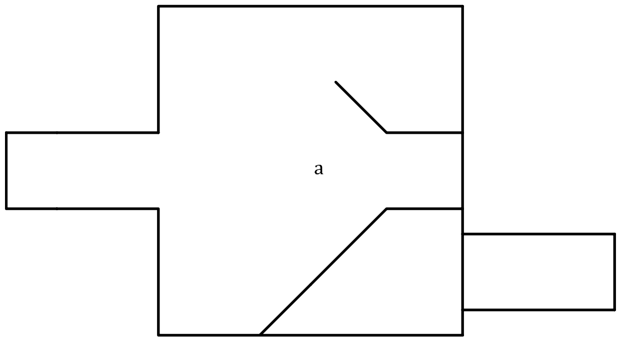


Key

a inlet

b outlet

Figure I.1 — Wall flow trap design A



Key

a inlet

Figure I.2 — Wall flow trap design B

Figure I.1 and I.2 are examples of functional wall flow traps. The use of other wall flow trap designs is permitted as long as the wall flow trap meets the validation requirements of 4.2.2 and 4.2.3.

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[5] ISO/TS 17536-2, *Road Vehicles — Aerosol separator performance test for internal combustion engines — Part 2: Laboratory gravimetric test method*1)

[6] ISO/TS 17536-3, *Road vehicles — Aerosol separator performance test for internal combustion engines — Part 3: Method to perform engine gravimetric test*

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[8] ISO/TS 17536-5, *Road Vehicles — Aerosol separator performance test for internal combustion engines — Part 5: Method to perform engine fractional test*3)

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[13] IEST RP-CC001, *HEPA and ULPA filters*

1) Under preparation.

2) Under preparation.

3) Under preparation.

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