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

Moteurs alternatifs à combustion interne à allumage par compression — Appareillage de mesure de l'opacité et du coefficient d'absorption de la lumière des gaz d'échappement

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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.

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.

International Standard ISO 11614 was prepared by Technical Committee ISO/TC 22, *Road vehicles,* Subcommittee SC 5, *Engine tests*, in collaboration with ISO/TC 70, *Internal Combustion engines*, Subcommittee SC 8, *Exhaust gas emisssion measurement*.

This first edition of ISO 11614 cancels and replaces ISO 3173:1974 and ISO/TR 4011:1976, which have been technically revised.

Annex A forms a normative part of this International Standard.

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

1 Scope

This International Standard specifies the general requirements and the installation of apparatus for measurement of the opacity and for the determination of the light absorption coefficient of exhaust gas from internal combustion engines (not confined to road vehicles). These instruments are known as opacimeters.

2 Normative references

The following normative documents contain provisions that, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard 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 IEC and ISO maintain registers of currently valid International Standards.

ISO 2602:1980, *Statistical interpretation of test results — Estimation of the mean — Confidence interval.*

IEC 60068-2-1:1990, *Environmental testing — Part 2: Tests — Test A: Cold*.

IEC 60068-2-2:1974, *Environmental testing — Part 2: Tests — Test B: Dry heat*.

IEC 60068-2-3:1969, *Environmental testing — Part 2: Tests — Test Ca: Damp heat, steady state*.

IEC 60068-2-31:1969, *Environmental testing — Part 2: Tests — Test Ec: Drop and topple, primarily for equipment-type specimens*.

IEC 61000-4-2:1995, *Electromagnetic compatibility (EMC) — Part 4: Testing and measurement techniques — Section 2: Electrostatic discharge immunity test — Basic EMC publication.*

IEC 61000-4-3:1998, *Electromagnetic compatibility (EMC) — Part 4: Testing and measurement techniques — Section 3: Radiated, radio-frequency, electromagnetic field immunity test.*

IEC 61000-4-4:1995, *Electromagnetic compatibility (EMC) — Part 4: Testing and measurement techniques — Section 4: Electrical fast transient/burst immunity test — Basic EMC publication.*

CIE S 001:1986, *Colorimetric illuminants.*

3 Terms and definitions

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

3.1
transmittance, τ
fraction of light transmitted from a source through a smoke-obscured path, which reaches the observer or the apparatus receiver

$$\tau = \frac{I}{I_0} \times 100$$

3.2
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

$$N = 100 - \tau$$

3.3
effective optical path length, L_A
length of a light beam between the emitter and the receiver that is intersected by the exhaust gas stream, corrected as necessary for non-uniformity due to density gradients and fringe effect

3.4
light absorption coefficient, k
coefficient defined by the Beer-Lambert law:

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

or

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

NOTE 1 To obtain proper comparisons when making opacity measurements, the temperature and pressure prevailing in the measuring zone must be known since they influence the light absorption coefficient k. Reference conditions for these are given in 7.1.

NOTE 2 The term "light absorption coefficient" is in common use and is, therefore, used in this International Standard. However, "light extinction coefficient" would be more accurate terminology. As used, the two terms describe exactly the same parameter.

4 Symbols and units

For the purposes of this International Standard, the symbols and units given in Table 1 apply.

Table 1

Symbol	Unit	Description	Subclause concerned
d_a	dm^3/s	Minimum gas flow.	11.7.1
d_b	dm^3/s	Maximum gas flow.	11.7.1
d_c	dm^3/s	Average gas flow.	11.7.1
I	cd	Light intensity at the receiver when the measuring zone is filled with exhaust gas.	3.1
I_0	cd	Light intensity at the receiver when the measuring zone is filled with clean air.	3.1

Table 1 *(concluded)*

Symbol	Unit	Description	Subclause concerned
k	m^{-1}	Light absorption coefficient. [a]	3.4; 7
k_t	m^{-1}	Light absorption coefficient at temperature T.	7.3.7
k_{cor}	m^{-1}	Observed light absorption coefficient corrected for pressure and temperature.	7.3.7
k_{obs}	m^{-1}	Observed light absorption coefficient.	7.3.7
L_A	mm	Effective optical path length.	3.3; 7.3.4
L_{A1}	mm	Effective optical path length of an opacimeter under test.	11.6.5
L_{A2}	mm	Effective optical path length of a known opacimeter.	11.6.5
l_m	mm	Distance specifying the position in an opacimeter where the temperature equals the mean temperature in the measuring zone.	11.6.1.1
l_{m1}, l_{m2}	mm	Distances relating to separate halves of certain designs of opacimeters.	11.6.1.1
l_1, l_2	mm	Length of tube.	annex A
N	%	Opacity.	3.2; clause 6
N_1	%	Reading of an opacimeter under test.	11.6.5
N_2	%	Reading of a known or modified opacimeter.	11.6.5
P_1, P_2	dm^3/s	Extreme positions of division of flow allowed by the manufacturer.	11.6.12
p_{atm}	kPa	Atmospheric pressure.	7.3.6
p_{obs}	kPa	Observed static pressure in the measuring zone.	7.3.6
Q	dm^3/s	Rate of flow of gas through the measuring zone.	8.2.1
T	K	Temperature.	—
T_a	K	Mean temperature with minimum sample temperature and minimum sample flow.	11.6.1.1
T_b	K	Mean temperature with maximum sample temperature and maximum sample flow.	11.6.1.1
T_g	K	Temperature of the mixture.	annex A
T_m	K	Mean temperature of the gas being measured.	7.3.7
T_s	K	Scavenge air temperature.	annex A
T_1	K	Mean temperature in an opacimeter under test.	11.6.5
T_2	K	Mean temperature of known or modified opacimeter.	11.6.5
t	s	Time.	—
t_p	s	Physical response time.	8.2.1
t_e	s	Electrical response time.	8.2.2
t_o	s	Overall response time.	8.2.3
td	s	Physical delay time	8.3
t_T	s	Temperature response time.	8.4
V	dm^3	Volume of the measuring zone.	8.2.1
v	m/s	Gas velocity.	—
v_a	m/s	Velocity at minimum gas flow.	11.7.1
v_b	m/s	Velocity at maximum gas flow.	11.7.1
v_c	m/s	Velocity of the average gas flow.	11.7.1
τ	%	Transmittance.	3.1

a In principle, k with 5/5, means k_{cor}, unless otherwise specified.

5 Principles of opacimeters

5.1 General

The principle of measurement is that light is transmitted through a specific length of the smoke to be measured and that proportion of incident light which reaches a receiver (for example: a photoelectric device) is used to assess the light obscuration properties of the medium.

The "length of smoke" over which the opacity is measured depends on the design for the apparatus. It may be the whole exhaust in an exhaust pipe (in-line full flow opacimeter, see Figure 1) or in free air (end of line or plume type full flow opacimeter, see Figure 2) or it may be a sample of the exhaust extracted from the exhaust pipe (sampling or partial flow opacimeter).

It is important to note that opacity readings shall always be specified for a given optical path length. The value has no meaning without the optical path length for the measurement.

Also the temperature of the gas can significantly affect the reading, and this should be noted when it is not controlled or measured by the apparatus.

5.2 Measurement of light absorption coefficient

Not all apparatus which measure opacity are suitable for the measurement of the light absorption coefficient, since the effective optical path length is not always readily determined, and, with end of line (or plume-type) apparatus, the exhaust gas being measured is not in a non-reflective enclosure. The general specification to be met by all opacimeters is given in clause 6. The additional specifications for opacimeters to measure light absorption coefficient are given in clause 7.

5.3 Conditions of use

Opacimeters may be used in the following test conditions:

— steady-state conditions (SS): the engine is run at constant speed and load, under stabilized conditions;

— transient conditions (TC): the engine is run under transient conditions of speed and/or load.

Additional specifications for opacimeters for measurements under transient conditions are given in clause 8.

6 Specifications of opacimeters for measurement of opacity[1)]

6.1 Basic specifications

6.1.1 The gas to be measured may be contained within the exhaust pipe (in-line apparatus) or as a free plume at the exit from the exhaust pipe (end of line apparatus) or within a specially designed chamber (taking full or partial flow of the exhaust gas).

6.1.2 The indicator shall be in opacity units and shall have a resolution of at least 0,1 % of the full scale.

6.1.3 The zero and the full-scale setting of the apparatus shall not drift more than 0,5 % opacity or 2 % of the full scale, whichever is the smaller, over 1 h or the length of the test, whichever is the shorter.

6.1.4 Any method used for keeping the light source and receiver protected (e.g. scavenge air) shall not cause the effective optical path length of the gas being measured to change by more than 2 %.

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1) Comparison of the results is only possible if the opacity is indicated for a specified effective optical path length L_A (e.g. 430 mm) and a specified smoke temperature T (e.g. 373 K).

6.1.5 Any device which may be situated upstream and downstream of the measuring zone shall not affect the opacity of the gas entering the measuring zone by more than 0,5 % opacity or 2 % of the full scale, whichever is the smaller, for a gas of approximately 50 % of the full scale.

6.1.6 The opacimeter shall be capable of being used for a period sufficient to take measurements without soiling of the light source or receiver. This is considered satisfactory if the overall drift of the apparatus is less than 0,5 % opacity or 2 % of the full scale, whichever is the smaller, over 1 h or the length of the test, whichever is the less.

6.1.7 All maintenance of the apparatus, specified by the manufacturer (see 10.2.13) shall be performed by the user in an easy way and without risk of impairing the correct functioning of the apparatus.

6.1.8 The preconditioning of the apparatus (warming-up and stabilizing) shall not be longer than 15 min. During this time, measurements with the smoke meter shall be inhibited.

6.1.9 The apparatus shall have an adequate insensitivity to the following influences:

— climatic influences (IEC 60068-2-1, IEC 60068-2-2, IEC 60068-2-3);

— mechanical shock (IEC 60068-2-31);

— electromagnetical compatibility (IEC 61000-4-2, IEC 61000-4-3, IEC 61000-4-4);

— external sources of light.

6.1.10 Apparatus specified for use with commercial vehicles shall provide practical and safe means of connecting to standard vehicle exhaust pipe positions, including vertical exhausts and central exhausts under the chassis.

6.1.11 Those parts of the apparatus which may be used outside or are moved by the operator around the vehicle (for example, a measuring head) shall operate from a 50 V or less isolated supply unless it can be shown that the supply provided is equally safe.

6.2 Design specifications

6.2.1 Measuring zone

The measuring zone is that part of the apparatus in which the measurement is made.

6.2.1.1 Opacimeters with a measuring chamber

The measuring zone is bounded:

— at its two extremities by the devices provided for the protection of the light source and the receiver;

— parallel to the gas flow, by the limits of the smoke chamber;

— if applicable, perpendicular to the gas flow, by two imaginary planes (one of them representing the front of the incoming gas, the other the rear of the incoming gas) which form tangents to the light beam.

6.2.1.2 End of line opacimeter

The measuring zone shall be taken as a section of the plume of depth equal to the distance between two imaginary planes, one representing the front of the gas flow, the other the rear of the gas flow and parallel to the light beam. The path length of the plume is more difficult to define accurately and is dependent on how close to the end of the exhaust pipe the light source passes through the smoke plume. Because of the difficulty of accurately defining the effective optical path length, the conversion of the measurement to k should only be made with reservations.

6.2.2 Light source

The light source shall be an incandescent lamp with a colour temperature in the range of 2 800 K to 3 250 K (conforming to CIE S 001) or a green light emitting diode (LED) with a spectral peak between 550 nm and 570 nm.

6.2.3 Receiver

The receiver shall be a photocell or a photo diode (with filter if necessary) which in the case when the light source is an incandescent lamp shall have a spectral response similar to the photopic curve of the human eye (maximum response) in the range 550 nm to 570 nm, to less than 4 % of that maximum response below 430 nm and above 680 nm.

6.2.4 Combined light source and receiver characteristics

6.2.4.1 The apparatus shall be so designed that:

— the rays of the light beam shall be parallel within a tolerance of 3° of the optical axis;

— the receiver is not affected by direct or reflected light rays with an angle of incidence greater than 3° to the optical axis.

Any system giving equivalent results will be acceptable.

6.2.4.2 The design of the electrical circuit, including the indicator, shall be such that the relationship between indicator reading and the intensity of the light received remains linear within ± 0,5 % over the range of adjustment of the circuit and over the operating temperature range of the light source and receiver.

6.2.5 Adjustment and calibration of the measuring apparatus

6.2.5.1 The electric circuit of the light source and receiver shall be adjustable so that the readout can be reset to zero when the light flux passes through the measuring zone filled with clean air or an equivalent zone. The indication of negative values and values above full scale shall be provided.

The apparatus shall provide means of setting and checking full scale (e.g. by the use of a screen or neutral optical density filter perpendicular to the light beam or, in the case of apparatus which read to 100 % opacity, by turning off or blocking the light source completely). The apparatus shall have an automatic or semi-automatic sequence to ensure that the apparatus is correctly adjusted for zero and span before the measurement begins.

6.2.5.2 An intermediate check shall be carried out with a screen or neutral optical density filter perpendicular to the light beam representing a gas opacity between 15 % and 80 % of full scale and known to an accuracy of ± 1 % opacity. This neutral optical density filter shall not be an integral part of the apparatus.

Provision shall be made for placing the filter in the path of the light beam passing through the measuring zone filled with clean air. This test shall be applicable without any tools and without the need to open the case of the apparatus.

The indicator reading, with the filter inserted between the light source and the receiver, shall be within 2 % opacity of the known value of the filter.

6.2.6 Recorder output terminal

The apparatus shall provide, along with a visual readout, a recorder output terminal.

7 Additional specifications for opacimeters to measure light absorption coefficient

7.1 Reference conditions

For practical engine testing, it is convenient to use a reference pressure of ambient and a reference temperature of 373 K. This is because visible emissions of smoke are at ambient pressure and because, in current practice, opacimeters measure at approximately ambient pressure. Also, the smoke correction factors, which include the effect of atmospheric changes on smoke-producing performance of the engine as well as the effect of atmospheric pressure on smoke, have been derived from smoke measurements made at atmospheric pressure and a reference temperature of 373 K.

However, if absolute comparison of two exhaust gases is required (ignoring any effects of conditions on engine performance) then a reference pressure of 100 kPa and a reference temperature of 373 K shall be used. It should be noted that, at the reference conditions for engine performances given in ISO 1585 and ISO 3046-1 (engine air inlet pressure of 100 kPa), the absolute and the practical units coincide.

7.2 Basic specifications

7.2.1 The gas to be measured shall be confined in or passed through an enclosure having a non-reflective internal surface, or equivalent optical environment.

7.2.2 In determining the effective optical path length, L_A, through the gas, account shall be taken of the possible influence of devices used for protecting the light source and the receiver.

7.2.3 The effective optical path length should be indicated on the apparatus and specified in the manufacturer's data.

7.2.4 Unless the manufacturer specifically states that the opacimeter is only suitable for measuring very low light absorption coefficients, the indicator of the opacimeter shall have a scale in absolute units of the light absorption coefficient k from 0 m^{-1} to at least 10 m^{-1} (in addition to the opacity scale according to 6.1.2).

7.2.5 The indicator scale for the light absorption coefficient, k, shall have a resolution of at least 0,01 m^{-1}.

7.2.6 The zero and the full-scale setting of the apparatus shall not drift more than 0,025 m^{-1} or 2 % of the full scale, whichever is the smaller, over 1 h or the length of the test, whichever is the shorter.

7.3 Design specifications

7.3.1 General

7.3.1.1 The design shall be such that under steady-state (SS) operating conditions the measuring chamber is filled with smoke of uniform opacity, except for fringe effects. This condition shall be considered to be met if in addition to the flow requirements of 6.2.1.1, the requirements of 7.3.1.2 and 7.3.1.3 are met. Unless it is shown by the manufacturer that the measuring chamber is always flushed by the sample, a check of flow shall be performed in order to prevent sample oscillations in the apparatus.

7.3.1.2 The variation of the opacimeter indicator output over a period of 10 s, with smoke at constant temperature, having a constant light absorption coefficient k of approximately 1,7 m^{-1} (or about 90 % of full scale, if the opacimeter full scale is less than 2 m^{-1}), and measured with a recorder having a response time of 1 s, is not more than ± 0,075 m^{-1} (or ± 4% of the full scale if the opacimeter full scale is less than 2 m^{-1}).

7.3.1.3 Where the smoke chamber is divided, any inequality of flow between the two halves shall not affect the reading by more than 0,05 m^{-1} when measuring smoke with an absorption of about 1,7 m^{-1}.

7.3.2 Light source and receiver

These shall be in accordance with 6.2.2, 6.2.3 and 6.2.4. However, 7.3.3 may be used as an alternative to 6.2.4.1.

7.3.3 Smoke chamber and opacimeter casing

The impingement of stray light on the receiver due to internal reflections or diffusion effects shall be reduced to a minimum (for example by finishing internal surfaces in matte black or a suitable general layout).

Where all surfaces are not matte black, or the light beam is not collimated according to 6.2.4, the optical general layout shall be such that the combined effect on diffusion and reflection shall not exceed 0,075 m^{-1} on the k scale when the smoke chamber is filled with smoke having a light absorption coefficient of approximately 1,7 m^{-1} (or shall not exceed 4 % of the full scale with smoke of about 90 % of full scale if the opacimeter full scale is less than 2m^{-1}).

7.3.4 Determination of the effective optical path length, L_A

When the effective optical path length, L_A, of a type of opacimeter cannot be assessed directly from its geometry, it may be determined either:

— by the method described in 11.6.5.3;

— by correlation with another type of opacimeter for which L_A is known (see 11.6.5.2);

— by other equivalent methods.

7.3.5 Adjustment and calibration of the measuring apparatus

In addition to the requirements of 6.2.5.2, an additional intermediate check shall be provided if the intermediate check screen required in 6.2.5.2 does not have an opacity equivalent to an absorption coefficient (as defined in 3.4) of between 1,5 m^{-1} and 2 m^{-1} calculated with the effective optical path length of the specified apparatus. This additional intermediate check shall be in the form of a screen or neutral optical density filter having an opacity equivalent to an absorption coefficient of between 1,5 m^{-1} and 2 m^{-1}, known to an accuracy of ± 0,05 m^{-1}. The indicator reading with the filter inserted between the light source and the receiver shall be within ± 0,15 m^{-1} of the equivalent absorption coefficient of the filter.

Apparatus with automatic gas temperature compensation shall be set to simulate 373 K during this check.

7.3.6 Pressure of the gas to be measured and of scavenging air

7.3.6.1 The pressure of the exhaust gas in the smoke chamber shall not differ from the atmospheric pressure by more than 0,75 kPa (7,5 mbar). The pressure variation of the gas and the scavenging air in the smoke chamber shall not cause the light absorption coefficient, k, to vary by more than 0,05 m^{-1} in the case of a gas having an absorption coefficient of approximately 1,7 m^{-1} (or in the case of opacimeters having a full-scale reading of less than 2 m^{-1}, by more than 2 % of the full-scale reading).

7.3.6.2 Unless it can be shown that, by design, the pressure in the smoke chamber cannot differ from atmospheric pressure by more than 0,75 kPa (with the opacimeter operating within its specified limits), the opacimeter shall be equipped with appropriate devices for measuring the pressure in the smoke chamber. Such devices shall have an accuracy of at least 0,2 kPa and a resolution of 0,1 kPa). The apparatus shall provide means of calibrating the device for measuring the pressure with an external instrument.

Where it is not possible to make measurements at atmospheric pressure (e.g. in-line measurements distant from the exhaust pipe outlet), the opacimeter reading shall be corrected to atmospheric pressure by the formula:

$$k_{cor} = k_{obs} \times \frac{p_{atm}}{p_{obs}} \qquad (2)$$

7.3.6.3 The limits of pressure variations of the gas and of the scavenging air shall be automatically checked by the apparatus.

7.3.6.4 Unless it can be shown that, by design, the effective optical length, L_A, cannot change more than 2 % by the method for keeping the light source and receiver protected (see 6.1.4), the opacimeter shall be equipped with appropriate devices for checking whether the method is working within the specified limits. The apparatus shall provide means of calibrating the devices with an external instrument.

Where an engine is tested in a controlled atmosphere (e.g. decompression chamber), it is essential to ensure that the opacimeter is located in an area where the ambient pressure is the same as the ambient pressure to which the engine is subject. When this is not done, the opacimeter reading shall be corrected for the difference in pressure between the engine and the opacimeter.

7.3.7 Temperature of the gas to be measured

7.3.7.1 To prevent condensation, the temperature of the exhaust gas shall be sufficiently above the dew point temperature at any point in the exhaust and measuring system (e.g. upstream of the fitted probe, while passing the probe and the measuring apparatus). This condition shall be regarded as fulfilled if gas at 373 K leaving the exhaust pipe arrives in the measuring cell with a temperature above 343 K.

Where the wall temperature of the gas containing system up to the exit of the measurement system would be lower, the system shall be heated to an appropriate temperature (e.g. 373 K).

7.3.7.2 The apparatus shall prohibit the measurements if the temperature of the gas or the chamber temperature (if applicable) drops below its limit.

The opacimeter shall be equipped with appropriate devices for assessing the mean temperature of the gas in the smoke chamber, T_m, and the manufacturer shall specify operating limits. The mean temperature must be indicated to an accuracy of 5 K. The apparatus shall provide means of calibrating the device for measuring the temperature of the gas with an external instrument.

Where the mean temperature corrected T_m is other than 373 K, the opacimeter reading shall (within the limits defined below) be converted to 373 K by the formula:

$$k_{cor} = k_{obs} \times \frac{T_m}{373} \quad (3)$$

When correction is not possible, k at a given temperature shall be written k_{xxx} (example: k_{500}).

7.3.7.3 The temperature of the exhaust gas at all points of the measuring chamber shall be between 343 K and 553 K for use of the above formula. If the temperatures are outside this range, the readings shall be recorded without correction but with the temperatures noted.

The above temperature range is one in which it is considered that all the water present is in the dry vapour form and all other uncondensed non-solid particles (i.e. the amount of uncondensed, unburnt fuel or lubricating oil) are insignificant in normal full-load exhaust smoke. Under these conditions the conversion formula for the effect of temperature is valid. If the exhaust gas contains an abnormal proportion of non-solid constituents, the conversion formula may not be valid. For example, the formula will not apply to exhaust gases from engines operating on heavy fuel oil having a high sulfur content when the exhaust gas at 373 K may include condensed acidic sulfur droplets. In these cases, it is necessary for comparative purposes to measure with a more restrictive temperature range of about 373 K or, if it is required to avoid measuring these droplets, then the exhaust gas of these engines shall be kept above 413 K and, if required, corrected to 373 K to give a nominal reference value for comparison.

8 Measurement of transients

8.1 General

It is necessary to be clear what is being measured. The measurement can either be the *time* smoke resides at the end of the exhaust pipe, or with gas velocity taken into account, it can be an indication of the *amount* of smoke emitted.

Normally the *amount* of smoke emitted will be regarded as the more significant measurement. The difference can be considerable for turbo vehicles which may give out a short puff of smoke at low speed before the engine accelerates the turbo to correct the air/fuel mixture. An example of a time measurement system is a full-flow opacimeter mounted directly at the end of an exhaust pipe. A small near stationary puff of smoke would be read as a wide pulse, giving the same reading as a large fast moving smoke output, although with much less volume of smoke. The shape of the smoke against time curve is distorted by the changing speed of the gas in, for example, a free acceleration test.

If this opacimeter is mounted at the end of a long extension pipe such that the gas is moving at maximum speed before the smoke passes through the opacimeter (see "delay time t_d" in 8.3), then this will remove the effect of changing gas velocity, and the wave form can be used to measure the *amount* of smoke.

Opacimeters are particularly suitable for the measurement of opacity and light absorption coefficient under transient conditions but they will only give accurate readings if the response of the opacimeter is adequate in duration compared with the transient to be measured.

For measurement of transient, two possibilities exist, as follows.

a) To define the curve of smoke versus time. For this, the overall response time must be at least five times shorter than the time of the transient. Gas velocity must be considered to avoid "turbo puff" transients being given a high weighting because of initial low gas velocity in, for example, a free acceleration test.

b) To define an average value of the transient (see, for example, EEC Directive 72/306 or UN/ECE Regulation No. 24)[2)] so that a peak reading may be taken. Gas velocity must be considered to avoid "turbo puff" transients being given a high weighting because of low gas velocity. Note that it is of little value to measure the peak value of a transient pulse without knowing something about its width. Damping is added so that the peak reading gives a measure of the amount of smoke in the transient.

For this, the overall response time, t_0 (see 8.2.4) or the physical and electrical response time, t_p and t_e (see 8.2.2 and 8.2.3), shall be fixed at given values and characteristics with tolerance. Also the physical delay time t_d (see 8.3) shall be fixed at a given value . All transient readings of different opacimeters can only be compared if they have similar values and characteristics of t_0 and t_d. In defining t_0, it should be noted that many opacimeters of established designs cannot achieve a t_p of less than about 0,4 s.

8.2 Response of the opacimeter

8.2.1 General

The overall response time, t_0, has two parts: the physical response time, t_p, and the electrical response time, t_e.

a) The physical response time, t_p, consists of the actual filling time of the measuring zone with smoke and inherent analogue response times (such as the response of the light detector, and signal conditioning). These are an integral part of the so-called raw opacity signal.

   For evaluation of t_p, this signal needs to be converted to the scale of the light absorption coefficient. This converted signal without further corrections is called the raw k-signal.

b) The electrical response time, t_e, consists of the filtering which may be analog filtering (for example a simple resistor/capacitor circuit for an exponential response) or digital filtering (for example a moving average applied to digitized samples). The filtering may be applied to the raw opacity, the opacity after conversion to that equivalent for a different effective optical path length, or after conversion from opacity to light absorption coefficient (raw k-signal). Note that where the filter is applied (referring to the three positions detailed above) can make a significant change to the reading, especially for fast transient signals.

Added filtering is normally included to meet a specific legislative response time.

2) For in-service measurement of smoke during free acceleration, a physical response time of less than 0,4 s and an electrical response time between 0,9 s and 1,1 s have been defined in UN-ECE Regulation No. 24 and Directive 72/306/EEC for control of smoke from diesel engines. In ISO 8178-9, a response time of less than 0,2 s is specified for non-road engine applications.

8.2.2 Physical response time, t_p

This is the 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.

The physical response time of the sampling opacimeter is defined with the probe and sample line. For instruments with different systems of probe and sample lines (several probes), the physical response time shall be given for all combinations.

For opacimeters such as certain full flow types, where the measuring zone is in a straight section of a pipe of uniform diameter, the physical response can be estimated by the formula:

$$t_p = 0{,}8\ V/Q \qquad (4)$$

and indicated by the manufacturer as "calculated physical response time" [3)].

For such apparatus, the speed of the gas through the measuring zone shall not differ by more than 50 % from the average speed over 90 % of the length of the measuring zone.

For all other opacimeters, the physical response time and characteristics[4)] shall be determined by experiment (see 11.7.2).

8.2.3 Electrical response time, t_e

8.2.3.1 General

A given opacimeter will have more than one electrical output (e.g. recorder output, analog display, digital display).

When used in a given application, the electrical response will be that corresponding to whichever mode of output is used (e.g. when measuring transients, the peak hold of digital display may be used and the response as defined in 8.2.2.4 will be relevant).

Indicating electrical response time, it is important to specify the output, the scale (opacity or light absorption coefficient), the effective optical path length L_A, and the characteristics of the response.

8.2.3.2 Recorder output response time

The recorder output will normally be the raw opacity signal (without additional filtering and transformation). If the output is in the k-scale, it is the physical response time.

The recorder output response time is the difference between the times when the apparatus recorder output signal goes from 10 % to 90 % of full deviation, when the opacity or the light absorption coefficient is changed in less than 0,01 s.

8.2.3.3 Analog display response time

Where the output is also indicated on an analog display, the "analog display response" is defined as the time taken for the display indication to go from 10 % to 90 % of full deviation when the opacity or the light absorption coefficient is changed less than 0,01 s.

3) The factor 0,8 is used to give a response time value more comparable to that which might be determined experimentally where the rise time from 10 % to 90 % is used.

4) Long response times and different characteristics may influence the result.