CHAPTER 7 : SMOKE METERS AND THEIR INSTALLATIONS

1 Scope : This Chapter covers the requirements of smoke meters and their installation on engines for full load and free acceleration tests, mentioned in para 3.4 of Chapter 3 and para 2.4 of Chapter 4 of this Part.

2 Technical Specifications of Opacimeters

2.1 General

2.1.1 The gas to be measured shall be confined in an enclosure having a non-
2.1.2 reflecting internal surface in the instrument.

2.1.2 In determining the effective length of the light path through the gas, account shall be taken of the possible influence of devices protecting the light source and the photoelectric cell. This effective length shall be indicated on the instrument.

2.1.3 The indicating dial of the opacimeter shall have two measuring scales one in absolute units of light absorption from 0 to (∞ (m^{-1})) and the other, linear from 0 to 100; both scales shall range from 0 at total light flux to full scale at complete obscuration.

2.1.4 The design shall be such that under steady-speed operating conditions the smoke chamber is filled with smoke of uniform opacity.

2.2 Construction specifications

2.2.1 Smoke chamber and opacimeter casing

2.2.1.1 The impingement on the photoelectric cell of stray light due to internal reflections or diffusion effects shall be reduced to a minimum (e.g. by finishing internal surfaces in mat black and by a suitable general layout).

2.2.1.2 The optical characteristics shall be such that the combined effect of diffusion and reflection does not exceed one unit on the linear scale when the smoke chamber is filled with smoke having an absorption coefficient near 1.7 per meter..

2.2.2 Light source

The light source shall be an incandescent lamp with a colour temperature in the range 2,800K to 3,250K.

2.2.3 Receiver.

2.2.3.1 The receiver shall consist of a photoelectric cell with a spectral response curve similar to the photopic curve of the human eye (maximum response in the range 550/570 nm ; less than 4% of that maximum response below 430 nm and above 680 nm).

2.2.3.2 The construction of the electrical circuit, including the indicating dial, shall be such that the current output from the photoelectric cell is a linear function of the intensity of the light received over the operating temperature range of the photoelectric cell.

2.2.4 Measuring Scales

2.2.4.1 The light-absorption coefficient k shall be calculated by the formula $F = Fo.e^{(-k*L)}$ where L is the effective length of the light path through the gas to be measured, Fo the incident flux and F the emergent flux. When the effective length L of a type of opacimeter cannot be assessed directly from its geometry, the effective length L shall be determined -

- Either by the method described in paragraph 2.7 of this Part

or

- through correlation with another type of opacimeter for which the effective length is known.

2.2.4.2 The relationship between 0 - 100 linear scale and the light absorption coefficient k is given by the formula

$$k = (-1/L)*(\text{Log}_e\ (1-N/100))$$

where N is the reading on the linear scale and k the corresponding value of the absorption coefficient.

2.2.4.3 The indicating dial of the opacimeter shall enable an absorption coefficient of 1.7/m to be read with an accuracy of 0.025/m.

2.3 Adjustment and calibration of the measuring apparatus

2.3.1 The electrical circuit of the photoelectric cell and of the indicating dial shall be adjustable so that the pointer can be reset at 0 when the light flux passes through the smoke chamber filled with clean air or through a chamber having identical characteristics.

2.3.2 With the lamp switched off and the electrical measuring circuit open or short circuited, the reading on the absorption coefficient scale shall be ∞ and it shall remain at ∞ with the measuring circuit reconnected.

2.3.2 An intermediate check shall be carried out by placing in the smoke chamber a
2.3.3 screen representing a gas whose known light absorption coefficient k, measured
2.3.4 as described in paragraph 2.2.4.1 is between 1.6/m and 1.8/m. The value of k

2.3.5 must be known to within 0.025/m. The check consists in verifying that this does
2.3.6 not differ by more than 0.05/m from that read on the opacimeter indicating dial
2.3.7 when the screen is introduced between the source of light and the photoelectric
2.3.8 cell.

2.4 Opacimeter Response

2.4.1 The response time of electrical measuring circuit, being the time necessary for the indicating dial to reach 90% of full scale deflection on insertion of a screen fully obscuring the photoelectric cell, shall be 0.9 to 1.1 second.

2.4.2 The damping of the electrical measuring circuit shall be such that the initial overswing beyond the final steady reading after any momentary variation in input (eg. calibration screen) does not exceed 4% of that reading in linear scale units.

2.4.3 The response time of opacimeter which is due to physical phenomena in the smoke chamber is the time taken from the start of the gas entering the chamber to complete filling of the smoke chamber; it shall not exceed 0.4 second.

2.4.4 These provisions shall apply solely to opacimeters used to measure opacity under free acceleration.

2.5 Pressure of the Gas to be measured and of scavenging air

2.5.1 The pressure of the exhaust gas in the smoke chamber shall not differ by more than 75 mm (water gauge) from the atmospheric pressure.

2.5.2 The variations in the pressure of the gas to be measured and of the scavenging air shall not cause the absorption coefficient to vary by more than 0.05/m in the case of a gas having an absorption coefficient of 1.7/m.

2.5.3 The opacimeter shall be equipped with appropriate devices for measuring the pressure in the smoke chamber.

2.5.4 The limits of pressure variation of gas and scavenging air in the smoke chamber shall be stated by the manufacturer of the apparatus.

2.6 Temperature of the Gas to be measured

2.6.1 At every point in the smoke chamber the gas temperature at the instant of measurement shall be between 70 deg. C and a maximum temperature specified by the opacimeter manufacturer such that the readings over the temperature range do not vary by more than 0.1/m when the chamber is filled with a gas having an absorption coefficient of 1.7/m.

2.6.2 The opacimeter shall be equipped with appropriate devices for measuring the temperature in the smoke chamber.

2.7 Effective Length "L" of the Opacimeter

2.7.1 In some types of opacimeters, the gas between the light source and the photoelectric cell, or between transparent parts protecting the source and the photoelectric cell, is not of constant opacity. In such cases the effective length L shall be that of a column of gas of uniform opacity which gives the same absorption of light as that obtained when the gas is normally admitted into the opacimeter.

2.7.2 The effective length of the light path is obtained by comparing the reading N of the opacimeter operating normally with the reading N obtained with the opacimeter modified so that the test gas fills a well defined length Lo

2.7.3 It will be necessary to take comparative readings in quick succession to determine the correction to be made for shifts of zero.

2.7.4 Method of assessment of L

2.7.4.1 The test gas shall be an exhaust gas of constant opacity or a light absorptive gas of a gravimetric density similar to that of exhaust gas.

2.7.4.2 A column of length Lo of the opacimeter, which can be filled uniformly with the test gas, and the ends of which are substantially at right angles to the light path shall be accurately determined. This length Lo shall be close to the effective length of the opacity meter.

2.7.4.3 The mean temperature of the test gas in the smoke chamber shall be measured.

2.7.4.4 If necessary an expansion tank of sufficient capacity to damp the pulsations and of compact design may be incorporated in the sampling line as near to the probe as possible. A cooler may also be fitted. The addition of the expansion tank and of the cooler should not unduly disturb the composition of the exhaust gas.

2.7.4.5 The test for determining the effective length shall consist in passing a sample of test gas alternately through opacity meter operating normally and through the same apparatus modified as indicated in paragraph 2.7.2.

2.7.4.6 The opacimeter readings shall be recorded continuously during the test with a recorder whose response time is equal to or shorter than that of the opacimeter.

2.7.4.7 With opacimeter operating normally, the reading on the linear scale of opacity is N and that of the mean gas temperature expressed in Kelvin degrees is T.

2.7.4.8 With the known length Lo filled with the same test gas, the reading on the linear scale of opacity is No and that of the mean gas temperature expressed in Kelvin degrees is To.

2.7.4.9 The effective length will be

L = Lo *(T*(Log(1-N/100))/(To*(Log(1-No/100))))

2.7.4.10 The test shall be repeated with at least 4 test gases giving readings evenly spaced between the readings 20 and 80 on the linear scale.

2.7.4.11 The effective length L of the opacimeter will be the arithmetic average of the effective lengths obtained as stated in paragraph 2.7.4.9 for each of the gases.

3 Installation of the Opacimeter :

3.1 The instrument should be prepared, used and maintained following the directions given in the instrument manufacturer's operation manual,and it should be serviced and calibrated at such intervals as to ensure accuracy.

3.2 Sampling Opacimeter :

3.2.1 Installation for full load tests

3.2.1.1 The ratio of the cross-sectional area of the probe to that of the exhaust pipe shall not be less than 0,05. The back pressure measured in the exhaust pipe at the opening of the probe shall not exceed 75 mm (water gauge).

3.2.1.2 The probe shall be a tube with an open end facing forward in the axis of the exhaust pipe, or of the extension pipe if one is required. It shall be situated in a section where the distribution of smoke is approximately uniform. To achieve this, the probe shall be placed as far downstream in the exhaust pipe as possible, or, if necessary, in an extension pipe so that, if D is the diameter of the exhaust pipe at the opening, the end of the probe is situated in a straight portion at least 6D in length upstream of the sampling point and 3 D in length downstream. If an extension pipe is used, no air shall be allowed to enter the joint.

3.2.1.3 The pressure in the exhaust pipe and the characteristics of the pressure drop in the sampling line shall be such that the probe collects a sample sensibly equivalent to that which would be obtained by isokinetic sampling.

3.2.1.4 If necessary, an expansion tank of compact design and of sufficient capacity to damp the pulsations may be incorporated in the sampling line as near to the probe as possible. A cooler may also be fitted. The design of the expansion tank and cooler shall not unduly disturb the composition of the exhaust gas.

3.2.1.5 A butterfly valve or other means of increasing the sampling pressure may be placed in the exhaust pipe at least 3 D downstream from the sampling probe.

3.2.1.6 The connecting pipes between the probe, the cooling device, the expansion tank (if required) and the opacimeter shall be as short as possible while satisfying the pressure and temperature requirements prescribed. The pipe shall be inclined upwards from the sampling point to the opacimeter, and sharp bends

where soot might accumulate shall be avoided. If not embodied in the opacimeter, a by-pass valve shall be provided upstream.

3.2.1.7 A check shall be carried out during the test to ensure that the requirements of para 2.5, concerning pressure and those of para 2.6 concerning temperature in the measuring chamber are observed.

3.2.2 Installation for tests under free acceleration :

3.2.2.1 The ratio of cross sectional area of the probe to that of the exhaust pipe shall not be less than 0.05. The back pressure measured in the exhaust pipe at the opening of the probe shall not exceed 75 mm (water gauge).

3.2.2.2 The probe shall be a tube with an open end facing forward in the axis of exhaust pipe, or of the extension pipe if one is required. It shall be situated in a section where the distribution of smoke is approximately uniform. To achieve this, the probe shall be placed as far downstream in the exhaust pipe as possible or if necessary in an extension pipe so that, if D is the diameter of exhaust pipe at the opening, the end of the probe is situated in a straight portion at least 6 D in length upstream of the sampling point and 3 D in length downstream. If an extension pipe is used, no air shall be allowed to enter the joint.

3.2.2.3 The sampling system shall be such that at all engine speeds, the pressure of the sample at the opacimeter is within the limits specified. This may be checked by noting the sample pressure at engine idling and maximum no load speeds. Depending on the characteristics of the opacimeter, control of sample pressure can be achieved by a fixed restriction or butterfly valve in the exhaust pipe or extension pipe. Whichever method is used, the back pressure measured in the exhaust pipe at the opening of the probe shall not exceed 75 mm (water gauge).

3.2.2.4 The pipes connecting with the opacimeter shall also be as short as possible. The pipe shall be inclined upwards from the sampling point to the opacimeter and sharp bends where soot might accumulate shall be avoided. A bypass valve may be provided upstream of opacimeter to isolate it from the exhaust gas flow when no measurement is being made.

Full Flow Opacimeter

The only general precautions to be observed in steady-speed and free acceleration tests are the following :

3.2.3 Joints in the connecting pipes, if any, between the exhaust pipe and the opacimeter shall not allow air to enter from outside.

The pipes connecting with opacimeter shall be as short as possible, as prescribed in the case of sampling opacimeters. The pipe system shall be inclined upwards from the exhaust pipe to the opacimeter, and sharp bends where soot might accumulate shall be avoided. A by-pass valve may be provided upstream

of the opacimeter to isolate it from the exhaust gas flow when no measurement is being made.

3.2.4 A cooling system may also be required upstream of the opacimeter.

4 Any other method/equipment may be approved, if it is found that they yield equivalent results.