

CHAPTER 3 : TEST PROCEDURE FOR MEASUREMENT OF GASEOUS POLLUTANTS FROM DIESEL ENGINES

- 1 Scope : This chapter describes the method of determining emissions of gaseous pollutants from the engine to be tested, as defined in para 5.2 of Chapter 1 of this Part.
- 2 Measurement Principle : The test shall be carried out with the engine mounted on a test bench and connected to a dynamometer. The gaseous emissions from the exhaust of the engine include hydrocarbons, carbon monoxide and oxides of nitrogen. During a prescribed sequence of warmed up engine operating conditions the amounts of the above gases in the exhaust shall be examined continuously. The prescribed sequence of operations consist of a number of speed and power modes which span the typical operating range of diesel engines. During each mode the concentration of each pollutant, exhaust flow and power output shall be determined and the measured values weighted and used to calculate the grams of each pollutant emitted per kilowatt hour, as described in this part.
- 3 Equipment :
 - 3.1 Dynamometer and Engine Equipment

The following equipment shall be used for emission tests of engines on engine dynamometers:

 - 3.1.1 An engine dynamometer with adequate characteristics to perform the test cycle described in Paragraph 4.1 below.
 - 3.1.2 Measuring instruments for speed, torque, fuel consumption, air consumption, temperature of coolant and lubricant, exhaust gas pressure and section flow resistance, air inlet temperature, atmospheric pressure, fuel temperature and humidity. The accuracy of these instruments shall satisfy the method of measuring the power of the internal combustion engines of road vehicles, given in Chapter 6 of Part IV of this Rule.
 - 3.1.3 An engine cooling system with sufficient capacity to maintain the engine at normal operating temperatures for the duration of the prescribed engine tests;
 - 3.1.4 A non-insulated and uncooled exhaust system extending at least 0.5m past the point where the exhaust probe is located, and presenting an exhaust back pressure within ± 650 Pa of the upper limit at the maximum rated power, as established by the engine manufacturer's sale and service literature for vehicle application;
 - 3.1.5 An engine air inlet system presenting an air inlet restriction within ± 300 Pa of the upper limit for the engine operating condition which results in maximum air flow, as established by the engine manufacturer for an air cleaner, for the engine being tested. When an engine is tested for exhaust emissions, the complete engine shall be tested with all standard accessories which might reasonably be expected

to influence emissions to the atmosphere installed and functioning as listed in Chapter 6 of Part IV of this regulation.

3.2 Exhaust Gas Sampling System :

3.2.1 The exhaust gas sampling system shall be designed to enable the measurement of the true mass emissions of the exhaust.

3.2.2 The probe shall extract a true sample of the exhaust gases.

3.2.3 The system should be free of gas leaks. The design and materials shall be such that the system does not influence the pollutant concentration in the diluted exhaust gas. Should any component (heat exchanger, blower, etc.) change the concentration of any pollutant gas in the diluted gas, then the sampling for that pollutant shall be carried out before that component, if the problem cannot be corrected.

3.2.4 The various valves used to direct the exhaust gases shall be of a quick-adjustment, quick-acting type.

3.3 Analytical Equipment :

3.3.1 Pollutant gases shall be analysed with the following instruments

3.3.1.1 Carbon monoxide (CO) and carbon dioxide (CO₂) analysis.

The carbon monoxide and carbon dioxide analysers shall be of the NON-DISPERSIVE INFRA RED (NDIR) absorption type.

3.3.1.2 Hydrocarbon (HC) analysis

The Hydrocarbon analyser shall be of the Flame Ionisation type with the whole FID system maintained at a temperature between 453K to 473K. It shall be calibrated with propane gas of equivalent to carbon atoms (C1).

3.3.1.3 Nitrogen oxide (NO_x) analysis.

The nitrogen oxide analyser shall be of the heated Chemiluminescent (HCLA) type with an NO_x-NO converter or equivalent .

3.3.1.4 Accuracy

The analysers shall have a measuring range compatible with the accuracy required to measure the concentrations of the exhaust gas sample pollutants. Measurement errors shall not exceed ± 3 % disregarding the true value of the calibration gases. For concentrations of less than 100 ppm the measurement error shall not exceed ± 3 ppm. The ambient air sample shall be measured on the same analyser and range as the corresponding diluted exhaust sample.

3.3.1.5 Chapter 4 of this Part describes the analytical systems recommended. Other systems of analysers which have proved to give equivalent results may be used.

3.4 Gases

3.4.1 The following pure gases shall be available when necessary, for calibration and operation :

Purified nitrogen (purity < 1ppm C, < 1ppm CO, < 400ppm CO₂, < 0.5ppm NO);

Purified synthetic air (purity < 3ppm C, < 1ppm CO, < 400ppm CO₂, < 0.5ppm NO);

Oxygen content between 18 and 21 percent vol.;

Purified oxygen (purity > 99.5 percent Vol. O₂) ;

Purified hydrogen (and mixture containing hydrogen) (Purity < 1ppm C, < 400ppm CO₂).

3.4.2 Calibration and span gases :

Gases having the following chemical compositions shall be available C₃ H₈ and purified synthetic air (see paragraph 3.4.1 above); CO and purified nitrogen; CO₂ and purified nitrogen; NO and purified nitrogen (the amount of NO₂ contained in this calibration gas must not exceed 5 percent of the NO content)

3.4.3 The true concentration of a calibration gas shall be within $\pm 2\%$ of the stated figure.

3.4.4 The concentrations specified in Para 4.3 below may also be obtained by means of a gas divider, diluting with purified nitrogen or with purified synthetic air. The accuracy of the mixing device shall be such that the concentrations of the diluted calibration gases may be determined within $\pm 2\%$.

4 Test Procedure :

4.1 Test Cycle :

The following 13-mode cycle shall be followed in dynamometer operation on the test engine:-

Mode No.	Engine Speed	% Load
1	Idle	----
2	intermediate	10

3	'''	25
4	'''	50
5	'''	75
6	'''	100
7	Idle	----
8	rated	100
9	'''	75
10	'''	50
11	'''	25
12	'''	10
13	Idle	-----

4.2 Measurement of Exhaust Gas Flow :

For calculation of the emission it is necessary to know the exhaust flow, as given in Para 4.8.1 below. For determination of exhaust flow either of the following methods may be used:-

4.2.1 Direct measurement of the exhaust flow by flow nozzle or equivalent metering system.

4.2.2 Measurement of the air flow and the fuel flow by suitable metering systems and calculation of the exhaust flow by the following equations :

$$G_{EXH} = G_{AIR} + G_{FUEL}$$

or

$$V'_{EXH} = V_{AIR} - 0.75 G_{FUEL}$$

or

$$V''_{EXH} = V_{AIR} + 0.77 G_{FUEL}$$

4.2.3 The accuracy of exhaust flow determination shall be $\pm 2.5\%$ or better.

4.2.4 The concentration of carbon monoxide and nitric oxide are measured in the dry exhaust. For this reason the CO and Nox emissions shall be calculated using the dry exhaust gas volume V'_{EXH} . If the exhaust mass flow rate (G_{EXH}) is used in the calculation the CO and NOx concentrations shall be related to the wet exhaust.

Calculation of the HC emission shall include G_{EXH} and V''_{EXH} according to the measuring method used.

4.3 Operating and Calibrating Procedure for Analysers and Sampling System :

The operating procedure for analysers shall follow the startup and operating instructions of the instrument manufacturer. The following minimum requirements shall be included.

4.3.1 Establishment of Calibration Curve

4.3.1.1 The analyser calibration curve shall be established by at least five calibration points, spaced as uniformly as possible. The nominal concentration of the calibration gas of the highest concentration shall be at least equal to 90% of the full scale.

4.3.1.2 The calibration curve is calculated by the least square method.
If the degree of the polynomial resulting from the curve is greater than 3, the number of calibration points shall be at least equal to this polynomial degree plus 2.

4.3.1.3 The calibration curve shall not differ by more than $\pm 2\%$ from the nominal value of calibration gas of each calibration point.

4.3.1.4 The different characteristic parameters of the analyser, particularly the scale, the sensitivity, the zero point and the date of carrying out the calibration should be indicated on the calibration curve.

4.3.1.5 It can be shown to the satisfaction of the testing authority, that alternative technology e.g. computer, electronically controlled range switch etc., can give equivalent accuracy, then these alternatives may be used.

4.3.2 Verification of Calibration

4.3.2.1 The calibration procedure shall be carried out as often as necessary and in any case within one month preceding the type approval emission test and once in six months for verifying conformity of production.

4.3.2.2 The verification should be carried out using standard gases. The same gas flow rates shall be used as when sampling exhaust.

4.3.2.3 A minimum of two hours shall be allowed for warming up the analysers.

4.3.2.4 The NDIR analyser shall be tuned, where appropriate, and the flame combustion of the FID analyser optimised.

4.3.2.5 Using purified dry air (or nitrogen), the CO and NO_x analysers shall be set at zero; dry air shall be purified for the HC analyser. Using appropriate calibrating gases mentioned in 3.4 above. the analysers shall be reset.

- 4.3.2.6 The zero setting shall be rechecked and the procedure described in Para 4.3.2.4 and 4.3.2.5 above repeated, if necessary.
- 4.3.2.7 The calibration curves of the analysers should be verified by checking at least five calibration points, spaced as uniformly as possible. The nominal concentration of the calibration gas of the highest concentration shall be at least equal to 90% of the full scale. It should meet the requirement of para 4.3.1.3 above.
- 4.3.2.8 If it does not meet, the system should be checked, fault, if any, corrected and a new calibration curve should be obtained.
- 4.3.2.9 Efficiency test of the NO_x Converter Refer 4.5 of Chapter 7, Part 3
- 4.3.3 Pre-test Checks
- 4.3.3.1 A minimum of two hours shall be allowed for warming up the infra-red NDIR analyser, but it is preferable that power be left on continuously in the analysers. The chopper motors may be turned off when not in use.
- 4.3.3.2 Each normally used operating range shall be checked prior to each analysis.
- 4.3.3.3 Using purified dry air (or nitrogen), the CO and NO_x analysers shall be set at zero; dry air shall be purified for the HC analyser.
- 4.3.3.4 Span gas having a concentration of the constituent that will give a 75-95% full-scale deflection shall be introduced and the gain set to match the calibration curve. The same flow rate shall be used for calibration, span and exhaust sampling to avoid correction for sample cell pressure.
- 4.3.3.5 The nominal value of the span calibration gas used shall remain with $\pm 2\%$ of the calibration curve.
- 4.3.3.6 If it does not, but it remains within $\pm 5\%$ of the calibration curve, the system parameters such as gain of the amplifier, turning of NDIR analysers, optimisation of FID analysers etc. may be adjusted to bring within $\pm 2\%$.
- 4.3.3.7 If the system does not meet the requirement of 4.3.3.5 and 4.3.3.6 above, the system should be checked, fault, if any corrected and a new calibration curve should be obtained.
- 4.3.3.8 Zero shall be checked and the procedures described in para 4.3.3.3 and 4.3.3.4 above repeated, if required.

4.4 System Leak Test :

A system leakage test shall be performed. The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be

switched on. After an initial stabilisation period all flow meters and pressure gauges should read zero. If not, the sampling line(s) shall be checked and the fault corrected.

4.5 Fuel

The fuel shall be the reference fuel specified in Chapter 5 of Part IV to this rule.

4.6 Test Laboratory

4.6.1 The absolute temperature T of the laboratory expressed in degrees Kelvin and the dry atmospheric pressure ps expressed in Kilopascals shall be measured and the parameter F shall be determined by the formula

Naturally aspirated and Mechanically supercharged engines :

$$F = (99/P_s) * (T/29)^{0.7}$$

Turbo supercharged engines with or without cooling of inlet air:

$$F = (99/P_s)^{0.7} * (T/298)^{1.5}$$

4.6.2 For a test to be recognised as valid, the parameter F shall be between 0.98 and 1.02 as per the notification issued by MOST from 1/4/96.

4.7 Test Run

During each mode of the test cycle, the specified speed shall be held to within ± 50 rpm and the specified torque shall be held to within $\pm 2\%$ of the maximum torque at the test speed. The fuel temperature at the injection pump inlet shall be $311 \pm 5K$. The governor and fuel system shall be adjusted as established by the manufacturer's sales and service literature. The following steps shall be taken for each test :-

4.7.1 Instrumentation and sample probes shall be installed as required;

4.7.2 The cooling system shall be started;

4.7.3 The engine shall be started and warmed up until all temperatures and pressures have reached equilibrium;

4.7.4 The torque curve at full load shall be determined by experimentation to calculate the torque values for the specified test modes;

4.7.5 The emission analysers shall be set at zero and spanned;

4.7.6 The test sequence as given in para 4.1 above shall be started The engine shall be operated for six minutes in each mode, completing engine speed and load

changes in the first minute. The responses of the analysers shall be recorded on a strip chart recorder for the full six minutes with exhaust gas flowing through the analysers at least during the last three minutes. the engine speed and load, intake air temperature and vacuum exhaust back pressure, fuel flow and air or exhaust flow shall be recorded during the last five minutes of each mode, with the speed and load requirements being met during the last minute of each mode;

4.7.7 Any additional data required for calculation shall be read and recorded as given in para 4.7.

4.7.8 The zero and span settings of the emission analysers shall be checked and reset, as required, at least at the end of the test. The test shall be considered satisfactory if the adjustment necessary after the test does not exceed the accuracy of the analysers prescribed in Paragraph 3.3 above.

4.8 Chart Reading

During the last 60 seconds of each mode the average chart reading for HC, CO and NOx shall be determined. The concentration of HC, CO and NOx during each mode shall be determined from the average chart readings and the corresponding calibration data or any other equivalent method.

4.9 Calculations

4.9.1 The final reported test results shall be derived through the following steps :-

The exhaust gas mass flow rate G_{EXH} or V'_{EXH} and V''_{EXH} shall be determined as given in Para 4.2 above for each mode. When applying G_{EXH} , the measured carbon monoxide and nitric oxide concentration shall be converted to a wet basis according to 4.10 below. The NOx concentration shall be corrected according para 4.11 below. The pollutant mass flow for each mode shall be calculated as follows :

$$\begin{aligned} NO_{x_{mass}} &= 0.001587 * (NO_{x_{conc}}) * (G_{EXH}) \\ CO_{mass} &= 0.000966 * (CO_{conc}) * (G_{EXH}) \\ HC_{mass} &= 0.000478 * (HC_{conc}) * (G_{EXH}) \\ \text{or} \\ NO_{x_{mass}} &= 0.00205 * (NO_{x_{conc}}) * (V'_{EXH}) \\ CO_{mass} &= 0.00125 * (CO_{conc}) * (V'_{EXH}) \\ HC_{mass} &= 0.000618 * (HC_{conc}) * (V''_{exh}) \end{aligned}$$

4.9.2 The emissions shall be calculated in the following way :

$$\text{----} \quad NO_x = \Sigma(NO_{x_{mass}} * WF_i) / \Sigma(P_i * WF_i)$$

$$\text{----} \quad CO = \Sigma(CO_{mass} * WF_i) / \Sigma P_i * WF_i$$

$$\frac{\text{HC}}{\text{HC}} = \frac{\sum (\text{HC}_{\text{mass}} * \text{WF}_i)}{\sum \text{P}_i * \text{WF}_i}$$

The weighting factors used in the above calculation are according to the following table :

Mode No	WF
1	0.25/3
2	0.08
3	0.08
4	0.08
5	0.08
6	0.25
7	0.25/3
8	0.10
9	0.02
10	0.02
11	0.02
12	0.02
13	0.25/3

- 4.10 Conversion of CO and NO_x Concentration to a Wet Basis. The CO and NO_x exhaust gas concentration as measured in this procedure are on a dry basis. To convert the measured values to the concentrations present in the exhaust (wet basis), the following relationship may be employed :-

$$\text{ppm (wet basis)} = \text{ppm (dry basis)} * (1 - (1.85 * G_{\text{FUEL}} / G_{\text{AIR}}))$$

Where :-

G_{FUEL} = is the fuel flow (kg/s)

G_{AIR} = is the air flow (kg/s)

- 4.11 Correction Factor for Nitric Oxide for Humidity. The values of the nitric oxides shall be multiplied by the following humidity correction factor :-

$$1 / (1 + A * (7m - 75) + 1.8 * B * (T - 302))$$

Where $A = 0.044 * (G_{\text{fuel}} / G_{\text{air}}) - 0.0038$.

$$B = 0.0053 + 0.116 * (G_{\text{fuel}} / G_{\text{air}})$$

m = humidity of the inlet air in grams of water per kilogram of dry air

T = temperature of the air in degree K.

$G_{\text{Fuel}} / G_{\text{Air}}$ = Fuel air ratio (dry air basis)