Chapter 7

CALIBRATION OF CVS SYSTEM AND GAS ANALYSIS SYSTEM AND TOTAL SYSTEM VERIFICATION

1.   Scope:

1.1   This Chapter describes the methods used for calibrating and verifying CVS System and Analysis System.

2.   Calibration of the CVS System:

2.1   The CVS system shall be calibrated by using an accurate flow meter and a restricting device. The flow through the system shall be measured at various pressure readings and the control parameters of the system measured and related to the flows. Various types of flow meter may be used, e.g. calibrated venturi, laminar flow meter, calibrated turbine meter provided that they are dynamic measurement systems and can meet the requirements of paragraphs 4.2.2 and 4.2.3 of Chapter 3 of this Part.

2.1.1   The following sections give details of methods of calibrating PDP and CFV units, using a laminar flow meter, which gives the required accuracy, together with a statistical check on the calibration validity.

2.2   Calibration of the Positive Displacement Pump (PDP):

2.2.1   The following calibration procedure outlines the equipment the test configuration, and the various parameters which shall be measured to establish the flow rate of the CVS-pump. All the parameters related to the pump are simultaneously measured with the parameters related to the flow meter, which is connected in series with pump. The calculated flow rate (given in m $_3$ /min at pump inlet, absolute pressure and temperature) can then be plotted versus a correlation function, which is the value of a specific combination of pump parameters. The linear equation, which relates the pump and the correlation function, is then determined. In the event that a CVS has a multiple speed drive, a calibration for each range used shall be performed.

2.2.2   This calibration procedure is based on the measurement of the absolute values of the pump and flow meter parameters that relate the flow rate at each point. Three conditions must be maintained to ensure the accuracy and integrity of the calibration curve as given below:

2.2.2.1 The pump pressures shall be measured at tappings on the pump rather than at the external piping on the pump inlet and outlet. Pressure taps that are mounted at the top centre and bottom centre of the pump drive head plate are exposed to the

actual pump cavity pressures, and therefore reflect the absolute pressure differentials.

2.2.2.2 Temperature stability shall be maintained during the calibration. The laminar flow meter is sensitive to inlet temperature oscillations, which cause the data points to be scattered. Gradual changes of ± 1K in temperature are acceptable as long as they occur over a period of several minutes.

2.2.2.3 All connections between the flow meter and the CVS pump shall be free of any leakage.

2.2.3 During an exhaust emission test, the measurement of these same pump parameters enables the user to calculate the flow rate from the calibration equation.

2.2.3.1 Fig.13 in this chapter shows one possible test set-up. Variations are permissible, provided that they are approved by the Authority granting the approval as being of comparable accuracy. If the set-up shown in Fig.7 is used, the following data shall be found within the limits of precision given:

Barometric pressure (corrected (PB) ± 0.03 kPa

Ambient temperature (T) ± 0.2 K

Air temperature at LFE (ETI) ± 0.15 K

Pressure depression upstream of LFE (EPI) ± 0.01 kPa

Pressure drop across the LFE matrix (EDP) ± 0.0015 kPa

Air temperature at CVS pump inlet (PTI) ± 0.2 K

Air temperature at CVS pump outlet (PTO) ± 0.2 K

Pressure depression at CVS pump inlet (PPI) ± 0.22 kPa

Pressure head at CVS-pump outlet (PPO) ± 0.22 kPa

Pump revolutions during test period (n) ± 1 rev.

Elapsed time for period (min 250 sec) (t) ± 0.1 sec

2.2.3.2 After the system has been connected, as shown in Fig.13, the variable restrictor is set in the wide-open position and the CVS pump run for 20 minutes before starting the calibration.

2.2.3.3 The restrictor valve is adjusted in steps to get an increment of pump inlet depression (about 1 kPa) that will yield a minimum of six data points for the total

calibration. The system is allowed to stabilize for three minutes and the data acquisition repeated.

2.2.4   Data analysis:

2.2.4.1 The air flow rate, Qs, at each test point is calculated in standard m^3 /min from the flow meter data using the manufacturer's prescribed method.

2.2.4.2 The air flow rate is then converted to pump flow, V_o, in m^3 per revolution at absolute pump inlet temperature and pressure.

$$V_o = \frac{Q_s}{n} \cdot \frac{T_p}{273.2} \cdot \frac{101.33}{P_p}$$

Where,

V_o = pump flow rate at T_p and P_p given in m^3 /rev

Q_s = air flow at 101.33 kPa and 273.2 K given in m^3 /min

T_p = pump inlet temperature (K)

P_p = absolute pump inlet pressure, in kPa

n = pump speed in revolutions per minute

To compensate the interaction of pump speed, pressure variations at the pump and the slip rate, the correlation function (X_o) between the pump speed (n), the pressure differential from the pump inlet to pump outlet and the absolute pump outlet Pressure is then calculated as follows:-

$$X_o = \frac{1}{n} * \sqrt{\frac{\Delta P_p}{P_e}}$$

Where,

X_o = correlation function

ΔP_p = pressure differential from pump inlet to pump outlet (kPa)

P_e = absolute pump outlet pressure (PPO + PB) (kPa)

A linear least square fit is performed to generate the calibration equations, which have the formula

$V_o = D_o - (M * X_o)$
$n = A - B(\Delta P_p)$

where –

D$_o$, M, A and B are the slope-intercept constants describing the lines.

2.2.4.3 A CVS system that has multiple speeds shall be calibrated on each speed used. The calibration curves generated for the ranges should be approximately parallel and the intercept values (D$_o$) should increase as the pump flow decreases.

2.2.4.4 If the calibration has been performed carefully, the calculated values from the equation should be within ± 0.5 % of the measured value of V$_o$. Values of M should vary from one pump to another. Calibration shall be performed at pump start-up and after major maintenance.

2.3   Calibration of the Critical-Flow Venturi (CFV) (Fig.14)

2.3.1   Calibration of the CFV is based upon the flow equation for a critical venturi.

$$Q_s = K_v * \frac{P}{\sqrt{T}}$$

Where,

Q$_s$ = Flow rate in m^3 / min at 101.33 kPa and 273.2 K

K$_v$ = Calibration coefficient

P = Absolute pressure (kPa)

T = Absolute temperature (K)

Gas flow is a function of inlet pressure and temperature. The calibration procedure described below establishes the value of the calibration coefficient at measured value of pressure, temperature and airflow.

2.3.2   The manufacturer's recommended procedure shall be followed for calibrating electronic portions of the CFV.

2.3.3   Measurements for flow calibration of the critical flow venturi are required and the following data shall be found within the limits of precision given:
Barometric pressure (corrected) (P$_B$) ± 0.03 kPa

LFE air temperature flow meter (ETI) ± 0.15 K

Pressure depression up-stream of LFE (EPI) ± 0.01 kPa

Pressure drop across (EDP) LFE matrix ± 0.0015 kPa

Air Flow (Q$_s$) ± 0.5 %

CFV inlet depression (PPI) ± 0.02 kPa

Temperature at venturi inlet (T_v) ± 0.2 K

2.3.4   The equipment shall be set up as shown in fig.14 and checked for leaks. Any leaks between the flow measuring device and the critical flow venturi will seriously affect the accuracy of the calibration.

2.3.5   The variable flow restrictor shall be set to the "open" position, the blower shall be started and the system shall be stabilised. Data from all instruments shall be recorded.

2.3.6   The flow restrictor shall be varied and at least eight readings across the critical flow range of the venturi shall be made.

2.3.7   The data recorded during the calibration shall be used in the following calculations. The air flow rate, Qs, at each test point is calculated from the flow meter data using the manufacturer's prescribed method.

Values of the calibration coefficient Kv for each test point is calculated as below –

$$K_v = \frac{Q_s * \sqrt{T_v}}{P_v}$$

Where,

Q_s = flow rate in m^3/min at 273.2 K and 101.33 kPa

T_v = temperature at the venturi inlet (K)

P_v = absolute pressure at the venturi inlet (kPa)

Plot K_v as a function of venturi inlet pressure. For sonic flow K_v will have a relatively constant value. As pressure decreases (vacuum increases) the venturi becomes unchoked and K_v decreases.

The resultant K_v changes are not permissible.

For a minimum of eight points in the critical region calculate the average K_v and the standard deviation.

If the standard deviation exceeds 0.3 % of the average K_v, corrective action shall be taken.

3   Calibration of Gas Analysis System:

3.1   Establishment of Calibration Curve

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 80% of the full scale.

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.

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

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.

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.

3.2   Verification of Calibration

3.2.1   Each normally used operating range must be checked prior to each analysis in accordance with the following:

3.2.2   The calibration is checked by using a zero gas and a span gas whose nominal value is within 80 to 95% of the supposed value to be analyzed.

3.2.3   If, for the two points considered, the value found does not differ by more than ± 5% of full scale from the theoretical value, the adjustment parameters may be modified. Should this not be the case, a new calibration curve must be established in accordance with clause 4.1.

3.2.4   After testing, zero gas and the same span gas used for re-checking. The analysis is considered acceptable if the difference between the two measuring results is less than 2 %.

3.2.5   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.

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

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

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

3.2.9   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 4.5 of Chapter 3 of this part, the analysers shall be reset.

3.2.10 The zero setting shall be rechecked and the procedure described in Para 4.2.4 and 4.2.5 above repeated, if necessary.

3.2.11 The calibration curves of the analysers should be verified by checking at least at 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 80% of the full scale. It should meet the requirement of Para 3.1.3 above.

3.2.12 If it does not meet, the system should be checked, fault, if any, corrected and a new calibration curve should be obtained.

3.3   Pre-test Checks

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.

3.3.2   Each normally used operating range shall be checked prior to each analysis.

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.

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.

3.3.5   The nominal value of the span calibration gas used shall remain within ± 2% of the calibration curve.

3.3.6   If it does not, but it remains within ± 5% of the calibration curve, the system parameters such as gain of the amplifier, tuning of NDIR analysers, optimisation of FID analysers etc. may be adjusted to bring within ± 2%.

3.3.7   If the system does not meet the requirement of 4.3.5 and 4.3.6 above, the system should be checked, fault, if any corrected and a new calibration curve should be obtained.

3.3.8 Zero shall be checked and the procedures described in Para 4.3.4 above repeated, if required.

3.4 Post test checks:

After testing zero gas and the span gas shall be used for re-checking. The analysis is considered acceptable if the difference between two measuring results is less than 2%.

3.5 Check for FID Hydrocarbon Response

3.5.1 Detector response optimization:

The FID shall be adjusted as specified by the instrument manufacturer. Propane in air shall be used to optimize the response, on the most common operating range.

3.5.2 Response factor of different hydrocarbons and recommended limits

3.5.2.1 The response factor (R_f) for a particular hydrocarbon species is the ratio of the FID C_1 reading to the gas cylinder concentration, expressed as ppm C_1.

3.5.2.2 The concentration of the test gas shall be at a level to give a response of approximately 80% of full scale deflection for the operating range. The concentration shall be known to an accuracy of ± 2% in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder shall be preconditioned for 24 hours at a temperature between 293 & 303 K (20 °C and 30 °C).

3.5.2.3 Response factors are to be determined when introducing an anlyser into service and thereafter at major service intervals. The test gases to be used and the recommended response factors are:

For methane and purified air $1.00 < R_f < 1.15$, or $1.00\ R_f < 1.05$ for NG fuelled vehicles
For propylene and purified air $0.90 < R_f < 1.00$,
For toluene and purified air $0.90 < R_f < 1.00$,

Relative to a response factor (R_f) of 1.00 for propane and purified air.

3.5.3 Oxygen interference check and recommended limits. The response factor shall be determined as described in 4.5.2. The test gas to be used and recommended response factor range is:
Propane and nitrogen $0.95 \leq R_f \leq 1.05$,

3.6 Efficiency Test of the NO_x Converter:

3.6.1 The efficiency of the converter used for the conversion of N$_{O2}$ into NO is tested as follows:

3.6.1.1 Using the test set up shown in Fig.15 and the procedure described below, the efficiency of converters can be tested by means of an ozonator.

3.6.2 Calibrate the CLA analyser in the most common operating range following the manufacturer's specifications using zero and span gas (the NO content of which should amount to about 80 % of the operating range and the NO_2 concentration of the gas mixture shall be less than 5 % of the NO concentration). The NO_x analyser shall be in the NO mode so that span gas does not pass through the converter. Record the indicated concentration.

3.6.3 Via a T-fitting, oxygen or synthetic air is added continuously to the gas flow until the concentration indicated is about 10 % less than the indicated calibration concentration given in paragraph 4.5.2 above. Record the indicated concentration (c). The ozonator is kept deactivated throughout this process.

3.6.4 The ozonator is now activated to generate enough ozone to bring the NO concentration down to 20 % (minimum 10 %) of the calibration concentration given in 4.6.2. Record the indicated concentration (d).

3.6.5 The NO_x analyser is then switched to the NO_x mode which means that the gas mixture (consisting of NO, NO_2, O_2 and N_2) now passes through the converter. Record the indicated concentration (a).

3.6.6 The ozonator is now deactivated. The mixture of gases described in paragraph 4.6.3 above passes through the converter into the detector. Record the indicated concentration (b).

3.6.7 With the ozonator deactivated, the flow of oxygen or synthetic air is also shut off. The NO_x reading of the analyser shall then be no more than 5 % above the figure in paragraph 4.6.2

3.6.8 The efficiency of the NO_x converter is calculated as follows:

$$\text{Efficiency (\%)} = \left(1 + \frac{(a - b)}{(c - d)} \right) * 100$$

3.6.9 The efficiency of the converter shall not be less than 95%.

3.6.10 The efficiency of the converter shall be tested at least once a week.

3.7 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.   Total System Verification:

4.1   To comply with the requirements of paragraph 4.7 of Chapter 3 of this Part, total accuracy of the CVS, sampling and analytical systems shall be determined by introducing a known mass of a pollutant gas into the system while it is being operated as if during a normal test and then analysing and calculating the pollutant mass according to the formulae in chapter 8 except that the density of propane shall be taken as 1.833 kg/m^3 at standard conditions. The following two techniques are known to give sufficient accuracy: -

4.1.1   Metering a constant flow of pure gas (CO or C_3H_8 using a critical flow orifice device) is fed into the CVS system through the calibrated critical orifice. If the inlet pressure is high enough, the flow rate (q), which is adjusted by means of the critical flow orifice, is independent of orifice outlet pressure (critical flow). If deviations exceed by 5 %, the cause of the malfunction shall be located and determined. Then CVS system operated as in an exhaust emission test for about 5 to 10 minutes. The gas collected in the sampling bag is analysed by the usual equipment and the results compared to known quantity of pure gas.

4.2   Metering a limited quantity of pure gas (CO or C_3H_8) by means of a gravimetric technique.

4.2.1   The following gravimetric procedure may be used to verify the CVS system. The mass of a small cylinder filled with either carbon monoxide or propane is determined with a precision of ± 0.01 gram. For about 5 to 10 minutes the CVS system is operated as in a normal exhaust emission test, while CO or propane is injected into the system. The quantity of pure gas involved is determined by means of differential weighing. The gas accumulated in the bag is then analysed by means of the equipment normally used for the exhaust gas analysis. The results are then compared to the concentration figures computed previously.
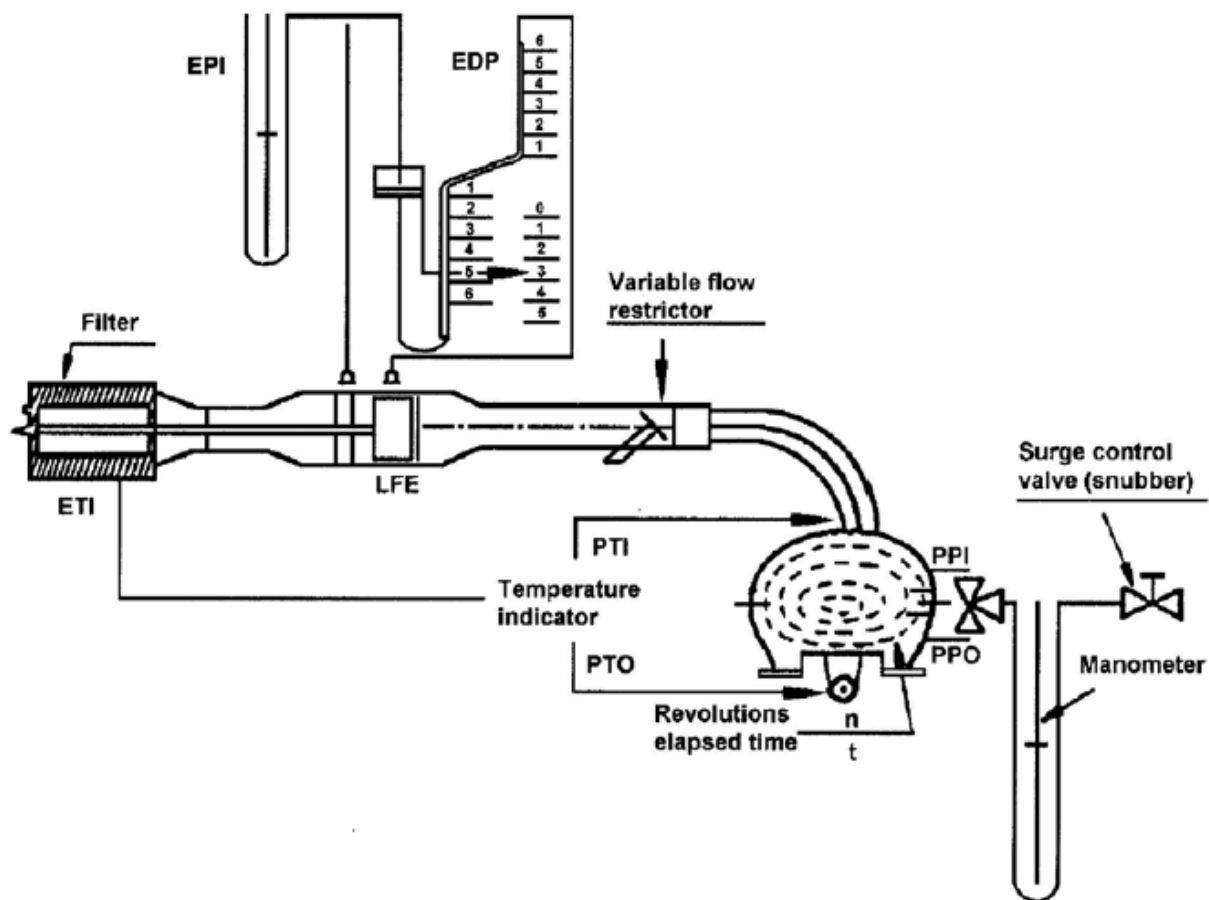
Figure 13: Schematic of PDP-CVS Calibration Set-up
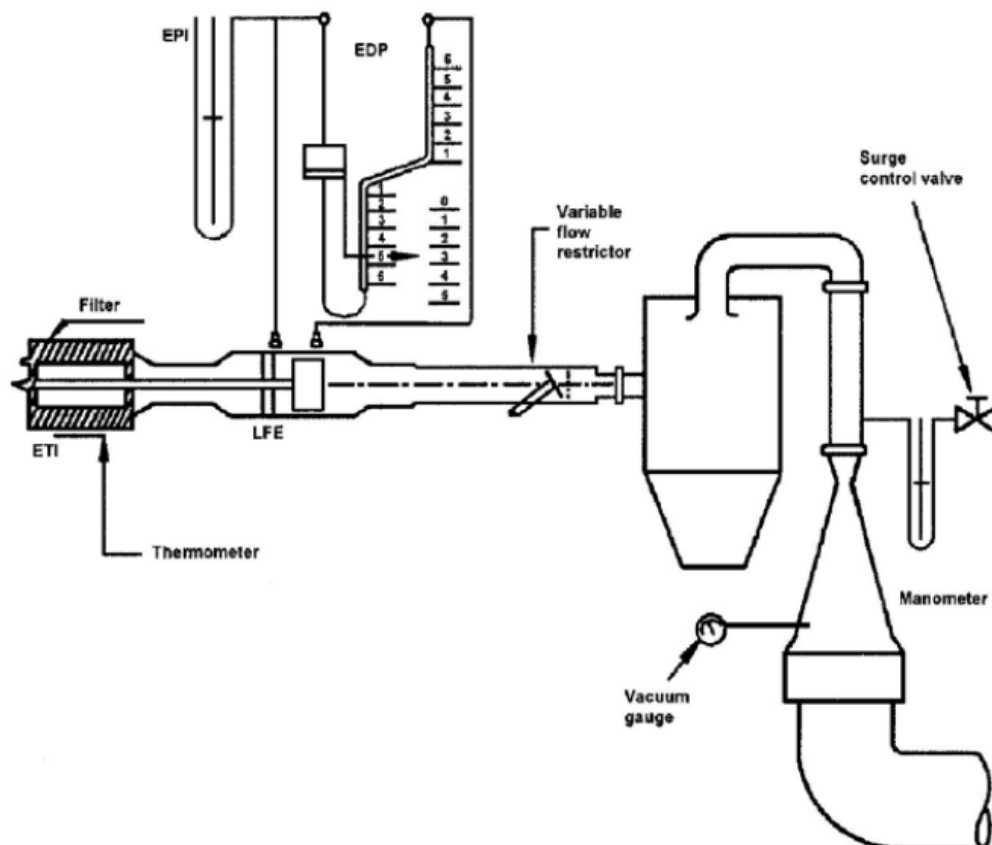(Pls. Ref. Para 2.2.3.1 of this Chapter)

Figure 14: Schematic of CFV-CVS Calibration Set-up
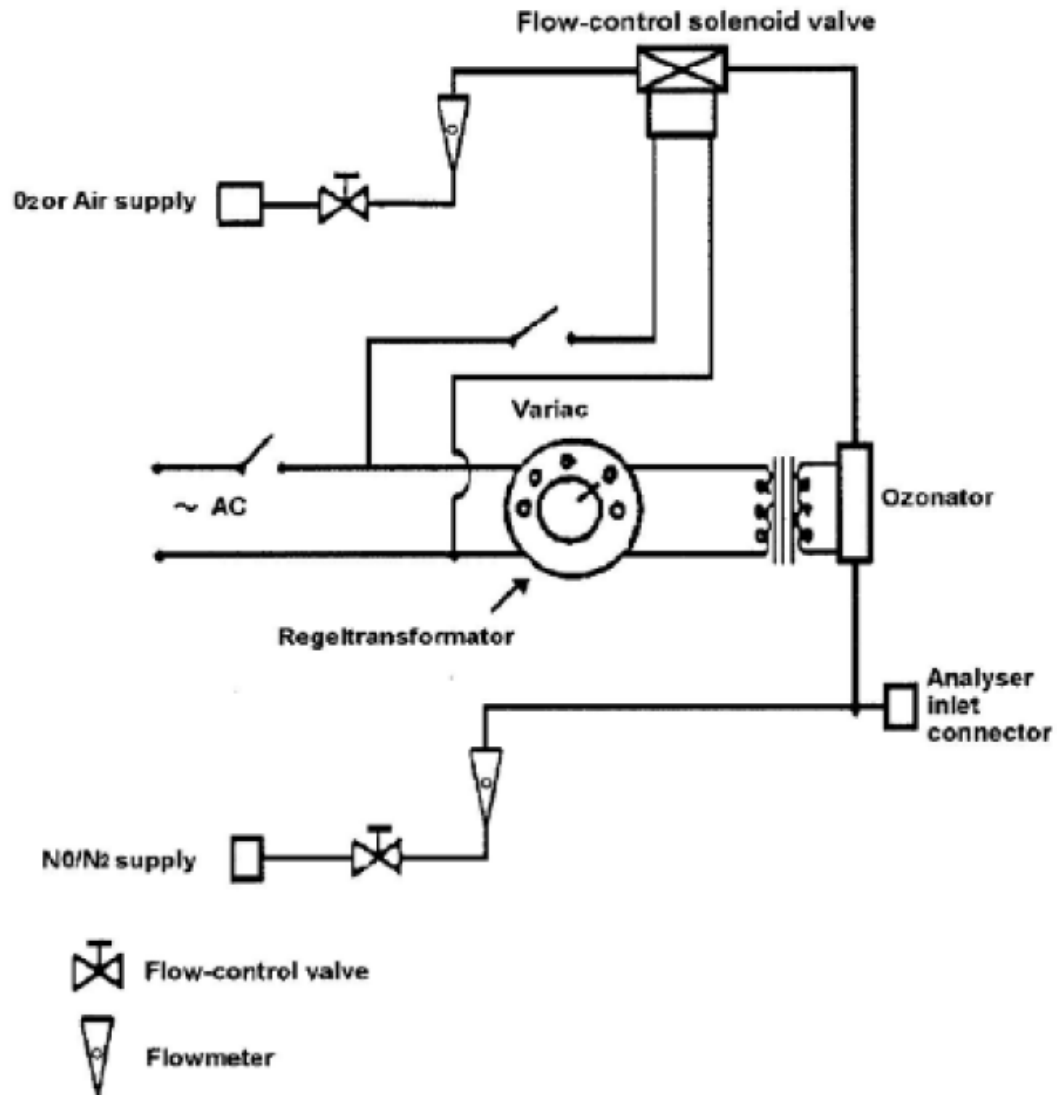(Pls. Ref. Para 2.3.4 of this Chapter)

Figure 15: Schematic of Set-up for checking the efficiency of NO$_x$ converter
(Pls. Ref. Para 3.6.1.1 of this Chapter)