APPENDIX 1

1. Error Analysis

The errors associated with various measurements and in calculation of performance parameters are computed in this section. The maximum possible errors in brake thermal efficiency and other performance parameters were estimated by using the method proposed by [Moffat]. Errors were estimated from the minimum values of output and the accuracy of the instrument. This method is based on careful specification of the uncertainties in the various experimental measures.

If an estimated quantity, S depends on independent variables like \((x_1, x_2, x_3, \ldots x_n)\) then the error in the value of ‘S’ is given by

\[
\frac{\Delta S}{S} = \sqrt{\left(\frac{\Delta x_1}{x_1}\right)^2 + \left(\frac{\Delta x_2}{x_2}\right)^2 + \ldots \ldots + \left(\frac{\Delta x_n}{x_n}\right)^2}
\]  

(1.1)

Where \(\frac{\Delta x_1}{x_1}\), \(\frac{\Delta x_2}{x_2}\), etc. are the errors in the independent variables

\(\Delta x_i = \) accuracy of the measuring instrument

\(\Delta x_j = \) minimum value of the output measured

2. Uncertainty Analysis

Uncertainty analysis involves systematic procedures for calculating error estimates for experimental data. When estimating errors in heat engine experiments, it is usually assumed that data is gathered under fixed (known) conditions and detailed knowledge of all system components is available. Measurement errors arise from various sources, but they can be broadly classified as bias errors and precision (or random) errors. Bias errors remain constant during a set of measurements. They are often estimated from
calibration procedures or past experience. Alternatively, different methods of estimating the same variable can be used, so that comparisons between those results would indicate the bias error. Elemental bias errors arise from calibration procedures or curve-fitting of calibrated data.

To quantify errors in experimental work, some calculations and estimation have to be applied to sensors, devices and machines that have been used to measure the experimental parameters. As the experiments performed as it need to express measurement uncertainty as

\[ x' = x \pm u_x \quad (\text{P\%}) \]  

(1.2)

where, \( x' \), \( x \), \( u_x \) and \( \text{P\%} \) are true value, tested value, uncertainty of the measurement and confidence respectively. To do this with assurance, total uncertainty of each component or portion of the experiment or procedure is determined. Total uncertainty is determined by finding error due to equipment (bias) and due to environment (precision). Wherever possible, uncertainty of each component or portion of experiment is found to determine where uncertainty may be minimized. Uncertainties are propagated in post-processing phase, two quantities that are nonlinear functions of a measurement or functions of multiple measurements with uncertainties based upon the functional relationship.

Both bias and precision errors are present in an experiment. The precision is measured whereas the bias error is usually determined from equipment vendor specs. The total error is the vector sum of these errors and it is to be noted that errors in estimating each error affect the value of the total error.

\[ U_x = \sqrt{(B_x^2 + P_x^2)} \]  

(1.3)

where, \( B_x \) and \( P_x \) are bias and precision error respectively.
In case of several measurements of the same quantity like engine load, the uncertainty is estimated using statistical measures of spread. Several measurements of the same quantity are: $X_1, X_2, X_3, X_4, X_5, \ldots, X_n$. Average load of the dynamometer is calculated as

$$Average = \frac{(X_1, X_2, X_3, X_4, X_5, \ldots, X_n)}{n} \quad (1.4)$$

Now, there are two ways to describe the scatter in these measurements. The mean deviation from the mean is the sum of the absolute values of the differences between each measurement and the average, divided by the number of measurements:

$$Mean \ deviation \ from \ mean \ = \ \frac{\sum_{i=1}^{n} (X_i - average)}{1-n} \quad (1.5)$$

The standard deviation from the mean is the square root of the sum of the squares of the differences between each measurement and the average, divided by one less than the number of measurements:

$$Standard \ deviation \ from \ mean = \sqrt{\frac{\sum_{i=1}^{n} (X_i - average)^2}{1-n}} \quad (1.6)$$

Either the mean deviation from the mean, or the standard deviation from the mean, gives a reasonable description of the scatter of data around its mean value.

Tested load - mean deviation < true load < tested load + mean deviation \hspace{1cm} (1.7)

Tested load - mean deviation < true load < tested load + standard deviation \hspace{1cm} (1.8)

For parameter that have been evaluated depending on two or more independent parameters, propagation of uncertainty is carried out using
\[
U_y = \sqrt{\left(\frac{u_{x_1}}{x_1}\right)^2 + \left(\frac{u_{x_2}}{x_2}\right)^2 + \ldots + \left(\frac{u_{x_n}}{x_n}\right)^2}
\]  \quad (1.9)

Where, \(U_y\) and \(y\) are uncertainty and the testing value of the evaluated parameter \(x_1, x_2, \ldots, x_n\) respectively.

The uncertainty analysis carried out in this Appendix is based on the lines suggested by [Kline and McClintock]. It should be noted that the uncertainty analysis presented here considers only the errors that relate to the measurements made during testing is used here to symbolize the error in the quantity.

2.1 Uncertainty Calculations

2.1.1 Uncertainties in Performance Parameters

The uncertainty calculation shown here are carried out correspond to CR 19, IP 200bar and fuel as POME shown in Table 1.2 in Appendix 1. The full load is taken as 10kg and low load is taken as 2kg.

2.1.1.1 Uncertainty in Brake Power

BP = \(2 \text{ NT/60} \times 1000\), \(T = W \times R\)

At Full Loading Condition (Load is 10kg)

\[
\Delta BP/\text{BP} = \sqrt{[(\Delta N/N)^2 + (\Delta w/w)^2]}
\]

\[
= \sqrt{[(30/1500)^2 + (0.1/10)^2]}
\]

\[
= \sqrt{[0.0004 + 0.0001]}
\]

\[
= 0.022 = 2.2\%
\]

At Low Loading Condition (Load is 2kg)

\[
\Delta BP/\text{BP} = \sqrt{[(\Delta N/N)^2 + (\Delta w/w)^2]}
\]
\[ = \sqrt{(0.3/1.47)^2 + (0.1/2.5)^2} \]
\[ = \sqrt{[0.0004 + 0.0025]} \]
\[ = 0.053 = 4.5\% \]

**2.1.1.2 Uncertainty in BTE**

The BTE is calculated by using the formula

\[
\text{BTE} = \frac{BP \times 3600 \times 100}{\text{Fuel flow in kg XCV}}
\]

At Full Loading Condition

\[ \Delta \text{BTE}/\text{BTE} = \sqrt{[(\Delta BP/BP)^2 + (\Delta mf/mf)^2]} \]
\[ = \sqrt{[(0.022)^2 + (0.01/1.01)^2]} \]
\[ = 0.024 = 2.4\% \]

At Low Loading Condition

\[ \Delta \text{BTE}/\text{BTE} = \sqrt{[(\Delta BP/BP)^2 + (\Delta mf/mf)^2]} \]
\[ = \sqrt{[(0.045)^2 + (0.01/0.45)^2]} \]
\[ = 0.050 = 5.0\% \]

**2.1.1.3 Uncertainty in SFC**

The SFC is calculated by using the formula

\[
\text{SFC} = \frac{\text{Fuel flow in kg/hr}}{BP}
\]

At Full Loading Condition

\[ \Delta \text{SFC}/\text{SFC} = \sqrt{[(\Delta mf / mf)^2 + (\Delta BP/BP)^2]} \]
= √[(0.01/ 1.01)^2 + (0.02)^2]

= 0.022 = 2.2%

At Low Loading Condition

ΔSFC/SFC = √[(Δmf / mf)^2 + (ΔBP/ BP)^2]

= √[(0.01/ 0.57)^2 + (0.038)^2]

= 0.0418 = 4.18 %

2.1.1.4 Uncertainty in HGas

The HGas is calculated by using the formula

HGas = (ma + mf) x C_{pgas} x (T_{exhaust}-T_{air})

At Full Loading Condition

ΔHGas/HGas = √[(Δma/ma)^2 + (Δmf/mf)^2 + (ΔEGT/EGT)^2]

= √[(0.01/18.52)^2 + (0.01/ 1.01)^2 + (0.01/503.1)^2]

= 0.001127 = 1.12%

At Low Loading Condition

ΔHGas/HGas = √[(Δma/ma)^2 + (Δmf/mf)^2 + (ΔEGT/EGT)^2]

= √[(0.01/23.11)^2 + (0.01/ 0.57)^2 + (0.01/245.27)^2]

= 0.0175 = 1.75%

2.1.1.5 Uncertainty in Calorific Value

The uncertainty in gross calorific value, UHs, shall be calculated by applying the following equation:

UH_s = [Σ(H_i - H_{si})^2 x (U_x/100)^2]^{0.5}

where H_{si} is the gross calorific value on volumetric basis for each component found in the ISO 6976. H_s shall be taken as the mean value of the three test cases.
Table 1.1 Show Calculation results, which are based on test results.

<table>
<thead>
<tr>
<th>Component</th>
<th>(Hs - Hsi)^2 ×(UXi/100)^2</th>
<th>Hs - Hsi (kJ/kg)</th>
<th>Hsi (kJ/kg)</th>
<th>Total expanded uncertainty per. component UXi = (URXi^2 + UCXi^2 + ULX^2)^(0.5) (mole %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>68.049</td>
<td>4 430</td>
<td>37 667</td>
<td>0.1862</td>
</tr>
<tr>
<td>C2</td>
<td>97.563</td>
<td>-23 908</td>
<td>66 005</td>
<td>0.0413</td>
</tr>
<tr>
<td>C3</td>
<td>400.854</td>
<td>-51 757</td>
<td>-93 854</td>
<td>0.0387</td>
</tr>
<tr>
<td>iC4</td>
<td>21.607</td>
<td>-79 205</td>
<td>121 302</td>
<td>0.0059</td>
</tr>
<tr>
<td>nC4</td>
<td>49.356</td>
<td>-79 591</td>
<td>121 688</td>
<td>0.0088</td>
</tr>
<tr>
<td>neoC5</td>
<td></td>
<td>-106 543</td>
<td>148 640</td>
<td>0.0000</td>
</tr>
<tr>
<td>iC5</td>
<td>12.342</td>
<td>-107 145</td>
<td>12.342</td>
<td>0.0033</td>
</tr>
<tr>
<td>nC5</td>
<td>11.223</td>
<td>-107 438</td>
<td>149 535</td>
<td>0.0031</td>
</tr>
<tr>
<td>C6</td>
<td>197.593</td>
<td>-135 316</td>
<td>177 413</td>
<td>0.0104</td>
</tr>
<tr>
<td>N2</td>
<td>179.554</td>
<td>39720</td>
<td>0</td>
<td>0.0318</td>
</tr>
<tr>
<td>CO2</td>
<td>186.566</td>
<td>39720</td>
<td>0</td>
<td>0.0324</td>
</tr>
<tr>
<td>O2</td>
<td></td>
<td>39720</td>
<td>0</td>
<td>0.0000</td>
</tr>
<tr>
<td>Sum</td>
<td>1224.707</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Square root of sum</td>
<td>35.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

U_{H_{s}} (kJ/kg) = 35.0
U_{H_{s}} (% of H_{s}) = 0.08 %

The end result shows in this case an expanded uncertainty of 0.08 % of H_{s}, which is well below the required limit of 0.30 %.
2.1.1.6 Uncertainty in Emission Constituents (Resolution/Range)

\[ \Delta CO/CO (\%) = 0.01/10 = 0.001 = 0.1\% \]

\[ \Delta CO_2/CO_2 (\%) = 0.1/20 = 0.005 = 0.5\% \]

\[ \Delta HC/HC = 1/20000 \text{ (ppm)} = 0.00005 = 0.005\% \]

\[ \Delta O_2/O_2 = 0.01/25 \text{ (\%)} = 0.0004 = 0.04\% \]

\[ \Delta NO_x / NO_x = 1 / 10000 \text{ (ppm)} = 0.0001 = 0.01\% \]

Table 1.2 shows the accuracy of the measurements and the uncertainty of the calculated results.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine speed</td>
<td>± 30 rpm</td>
</tr>
<tr>
<td>Temperatures</td>
<td>± 1°C</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>± 0.03 %</td>
</tr>
<tr>
<td>Hydrocarbon</td>
<td>± 10 ppm</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>± 0.04%</td>
</tr>
<tr>
<td>Time</td>
<td>± 0.5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calculated results</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brake power</td>
<td>± 2.2%</td>
</tr>
<tr>
<td>BTE</td>
<td>± 2.4%</td>
</tr>
<tr>
<td>SFC</td>
<td>± 2.2%</td>
</tr>
<tr>
<td>HGas</td>
<td>± 1.12%</td>
</tr>
<tr>
<td>Crank angle encoder</td>
<td>± 0.5° CA</td>
</tr>
<tr>
<td>( C_V )</td>
<td>0.08%</td>
</tr>
</tbody>
</table>
Table 1.3  Probable errors in the estimation of performance of diesel engine running on POME

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
<th>Probable error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (N)</td>
<td>1500 rpm</td>
<td>30 rpm</td>
</tr>
<tr>
<td>Load (W)</td>
<td>10 kg</td>
<td>0.1 kg</td>
</tr>
<tr>
<td>Fuel flow rate (mf)</td>
<td>1.01 kg/hr</td>
<td>0.01 kg/hr</td>
</tr>
<tr>
<td>Bore (D)</td>
<td>87.5mm</td>
<td>1mm</td>
</tr>
<tr>
<td>Stroke Length (L)</td>
<td>110mm</td>
<td>1mm</td>
</tr>
<tr>
<td>Air flow rate (ma)</td>
<td>23.11 kg/hr</td>
<td>0.01 kg/hr</td>
</tr>
</tbody>
</table>

Table 1.4  Resolution and Range of Gas analyzer for the emission constituents

<table>
<thead>
<tr>
<th>Emissions</th>
<th>Range</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0-10 %</td>
<td>0.01%</td>
</tr>
<tr>
<td>CO₂</td>
<td>0-20 %</td>
<td>0.1%</td>
</tr>
<tr>
<td>HC</td>
<td>0-2000 ppm</td>
<td>1 ppm</td>
</tr>
<tr>
<td>O₂</td>
<td>0-25%</td>
<td>0.01%</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0-10000 ppm</td>
<td>1 ppm</td>
</tr>
</tbody>
</table>
Table 1. 5 shows the accuracy of the exhaust gas emission analyzer

<table>
<thead>
<tr>
<th>NO</th>
<th>Emission Parameters</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CO</td>
<td>+/- 0.03% abs / +/- 3% rel (0-10%) whichever is higher</td>
</tr>
<tr>
<td>2</td>
<td>CO\textsubscript{2}</td>
<td>+/- 0.04% abs or +/- 4% rel, whichever is higher</td>
</tr>
<tr>
<td>3</td>
<td>HC</td>
<td>+/- 10ppm abs or +/- 5% rel (0-2000ppm) accessories</td>
</tr>
<tr>
<td>4</td>
<td>O\textsubscript{2}</td>
<td>+/- 0.1% abs or +/- 3% rel * Sampling Probe</td>
</tr>
<tr>
<td>5</td>
<td>NO\textsubscript{x}</td>
<td>+/- 25ppm abs or +/- 3% rel (0-4000 ppm) * Rubber Hose 7 meter long PU tube</td>
</tr>
</tbody>
</table>

Table 1.6 shows the Range and Accuracy of the pressure sensors

<table>
<thead>
<tr>
<th>S.No</th>
<th>Type of the Sensors</th>
<th>Range</th>
<th>Accuracy/ Resolution/ Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Air flow rate measurement</td>
<td>0-99 m\textsuperscript{3}/hr.</td>
<td>±0.01 m\textsuperscript{3}/hr.</td>
</tr>
<tr>
<td>2</td>
<td>Fuel flow measurement</td>
<td>0-99 kg/hr.</td>
<td>±0.01 kg/hr.</td>
</tr>
<tr>
<td>3</td>
<td>Engine speed</td>
<td>0-9999 rpm</td>
<td>± 2rpm</td>
</tr>
<tr>
<td>4</td>
<td>Combustion pressure measurement</td>
<td>0-100 bar</td>
<td>resolution-0.1psi</td>
</tr>
<tr>
<td></td>
<td>(Piezoelectric)</td>
<td></td>
<td>Sensitivity-1 mV/psi</td>
</tr>
</tbody>
</table>
Table 1.7 shows the various Indian standards used for emission analysis

<table>
<thead>
<tr>
<th>Elements</th>
<th>Indian Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>IS 13270:1992 (reaffirmed 1999)</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>IS 11293:1992</td>
</tr>
<tr>
<td>Hydrocarbon</td>
<td>---</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>IS 11255 – (PART 7) – 2005</td>
</tr>
<tr>
<td>S N o</td>
<td>Investigators</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Bar et al.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Agarwal and Agwarwal</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Suryawanshi</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Dutra et al.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Wirawan et al.</td>
</tr>
<tr>
<td>6</td>
<td>Rakopoulos et al.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Authors and Year</td>
</tr>
<tr>
<td>-----</td>
<td>------------------</td>
</tr>
<tr>
<td>7</td>
<td>Boulifi et al. 2010</td>
</tr>
<tr>
<td>8</td>
<td>Hazar and Ozturk 2011</td>
</tr>
<tr>
<td>9</td>
<td>Venkanna et al. 2009</td>
</tr>
<tr>
<td>10</td>
<td>Subbanah and Rajagopal 2011</td>
</tr>
<tr>
<td>11</td>
<td>Rao et al. 2008</td>
</tr>
<tr>
<td>12</td>
<td>Aydin and Bayindir 2010</td>
</tr>
</tbody>
</table>

- From the above observation in Table 1.8, the chosen test fuel properties and BTE are shown as a constant compression ratio and full load.
- In this study, to improve thermal efficiency of the engine, the compression ratio varies with constant speed at full load condition.
- This may the reason the BTE of the engine was increased for higher CR19 and full load.
APPENDIX 2

Calibration Certificates

The appendix 2 consists of calibration certificates for the multi gas analyzer, smoke meter, pressure sensor & certificate of properties of tested fuels. The multi gas analyzer is made Netel (India) limited, Mumbai. The pressure sensor is of make Kistler Peizotronics.
# CALIBRATION REPORT / CERTIFICATE

Ref No: ARAI/TA(5G-RV)/NETEL/NPM-MGA-2/1088-12  

**Date:** 31-03-12

<table>
<thead>
<tr>
<th>1.0 Component</th>
<th>NETEL 5 Gas Analyzer</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLC equipment model</td>
<td>NPM-MGA-2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.0 FLC Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDU/Mechanical Engineering department</td>
</tr>
<tr>
<td>Kumaraguru college of Technology, Coimbatore - 641049</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Registration No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5454</td>
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</table>

<table>
<thead>
<tr>
<th>3.0 Objective of the test</th>
</tr>
</thead>
<tbody>
<tr>
<td>To carry out Physical check and calibration of gas Analyzer / Smoke meters as per the test procedure specified in Annexure 1 of CMVR / TAP 115-116 Part</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.0 Detailed Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.1 Checking of supply/ setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>4.2 Checking of Accessories</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.3 Span Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Details of span gas concentration:</td>
</tr>
<tr>
<td>CO - 3.28%</td>
</tr>
<tr>
<td>CO₂ - 11.6%</td>
</tr>
<tr>
<td>H₂ - 3077 PPM in Propane</td>
</tr>
<tr>
<td>O₂ - 0.43%</td>
</tr>
<tr>
<td>NOₓ - 462 ppm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Calibration gas cylinder No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGL 238621 &amp; 138927</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Calibration gas cylinder make</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A, Birla Gases Ltd</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. Calibration gas validity date</th>
</tr>
</thead>
<tbody>
<tr>
<td>02-03-138, 30-03-13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.4 Electrical Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.5 Leakage test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passed</td>
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</table>

<table>
<thead>
<tr>
<th>6.0 Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO - 3.28%</td>
</tr>
<tr>
<td>CO₂ - 12.66%</td>
</tr>
<tr>
<td>H₂ - 3077 PPM in Propane</td>
</tr>
<tr>
<td>O₂ - 0.43%</td>
</tr>
<tr>
<td>NOₓ - 462ppm</td>
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</tbody>
</table>

<table>
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<th>7.0 Next Calibration Due Date</th>
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</tbody>
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**NETEL (INDIA) LIMITED**

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Website: www.netel-india.com
### Technical data

- **Pressure range**  
  bar  
  0...100

- **Calibration at 200 °C**  
  bar  
  0...100

- **Sensitivity (±0.5 %)**  
  mV/bar  
  25

- **Frequency range (-3 dB)**  
  Hz  
  0,016...20'000

- **Linearity**  
  %FSO  
  ≤ ± 1

- **Shock**  
  g  
  2000

- **Operating temperature range**  
  mounting location  
  °C  
  -50...300

  Viton cable connection max. °C  
  200

  short overload <1 h °C  
  240

  electronics °C  
  -10...110

- **Sensitivity shift**  
  200 ± 150 °C  
  %  
  ≤ ± 2,5

  200 ± 50 °C  
  %  
  ≤ ± 1

- **Thermo shock**  
  bar  
  ≤ -0,5

  (Kistler testengine 9,5 bar p̄m; 1500 1/min)

- **Time constant**  
  for cylinder measuring  
  s  
  ≈ 5

  for calibration  
  s  
  > 2500

- **Signal output (at 1mA load)**  
  max.  
  V  
  4,4...5

  min.  
  V  
  > 0

- **Signal span**  
  V  
  3,0

- **Zero line**  
  V  
  1,9...2,2

- **Supply voltage**  
  VDC  
  7...32

- **Supply current**  
  mA  
  6

- **Output impedance**  
  Ω  
  100

- **Mounting torque of sensor in adapter**  
  Nm  
  15

- **Connector at sensor 8 pole male**  
  (protection class valid with connected cable)  
  DIN M12x1  
  IP67
APPENDIX 3

Preparation of WCRBME

Pure Biodiesel (WCRBME)
Schematic diagram of VCR engine with input data’s

Emission measurement setup with VCR engine
Panel board with data acquisition system consists of fuel tank and fuel flow measurement