APPENDIX-1

ENGINE SPECIFICATIONS

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Kirloskar Engines Ltd, Pune, India</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>AV1</td>
</tr>
<tr>
<td>Engine Type</td>
<td>Four stroke, single cylinder, constant speed, compression ignition engine</td>
</tr>
<tr>
<td>Rated Power</td>
<td>3.7 kW at 1500 RPM</td>
</tr>
<tr>
<td>Bore</td>
<td>80 mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>110 mm</td>
</tr>
<tr>
<td>Swept Volume</td>
<td>553 cc</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>12 to 21</td>
</tr>
<tr>
<td>Mode of Injection</td>
<td>Direct injection</td>
</tr>
<tr>
<td>Cooling System</td>
<td>Water</td>
</tr>
<tr>
<td>Dynamometer</td>
<td>Eddy current dynamometer</td>
</tr>
</tbody>
</table>
# APPENDIX –II

## NOZZLE SPECIFICATIONS

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameter</th>
<th>Conventional Nozzle</th>
<th>Modified Nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Make</td>
<td>Bosch</td>
<td>Bosch</td>
</tr>
<tr>
<td>2</td>
<td>No of Orifices</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Orifice Diameter (mm)</td>
<td>0.157</td>
<td>0.111</td>
</tr>
<tr>
<td>4</td>
<td>Included Spray Angle</td>
<td>140°</td>
<td>60°</td>
</tr>
</tbody>
</table>
### APPENDIX –III

**GAS ANALYZER SPECIFICATIONS**

(Make: NETEL, Model: NPM-MGA-2)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Gases Measured</th>
<th>Method</th>
<th>Range</th>
<th>Resolution</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HC</td>
<td>NDIR</td>
<td>0-20,000 ppm</td>
<td>1 ppm</td>
<td>+/- 10 ppm abs (or ) +/- 5 % rel</td>
</tr>
<tr>
<td>2</td>
<td>CO</td>
<td>NDIR</td>
<td>0- 9.99%</td>
<td>0.01%</td>
<td>+/- 0.03% abs (or ) +/- 3% rel</td>
</tr>
<tr>
<td>3</td>
<td>CO₂</td>
<td>NDIR</td>
<td>0- 20%</td>
<td>0.1%</td>
<td>+/- 0.04% abs (or ) +/- 4% rel</td>
</tr>
<tr>
<td>4</td>
<td>O₂</td>
<td>Electrochemical</td>
<td>0- 25%</td>
<td>0.01%</td>
<td>+/- 0.1% abs (or ) +/- 3% rel</td>
</tr>
<tr>
<td>5</td>
<td>NOx</td>
<td>Electrochemical</td>
<td>0-10,000 ppm</td>
<td>1 ppm</td>
<td>+/- 25 ppm abs (or ) +/- 3% rel</td>
</tr>
</tbody>
</table>
APPENDIX –IV

SMOKEMETER SPECIFICATIONS

Make : NETEL (INDIA) LTD.,
Model : NPM-SM111B
Display Indication : Light absorption coefficient (K)
Display Range : 0 to 9.99 m⁻¹
Scale Resolution : 0.01 m⁻¹
Linearity : 0.1 m⁻¹
Repeatability : 0.1 m⁻¹
Light Source : 5 mm clear green LED
Response Time : 0.3 seconds
Warm up Time : 3 minutes
Temperature Range : 5 to 50°C
Power Requirement : 230 V AC +/- 10% 50 Hz 200W
APPENDIX- V

ERROR ANALYSIS

All measurements of physical quantities are subjected to uncertainties. Uncertainty analysis is needed to prove the accuracy of the experiments. In order to have reasonable limits of uncertainty for a computed value an expression is derived as follows:

Let, R be the computed result function of the independent measured variables, \( x_1, x_2, x_3, \ldots, x_n \) as per the relation, \( R = f(x_1, x_2, x_3, \ldots, x_n) \) and let error limits for the measured variables or parameters be \( x_1 \pm \Delta x_1, x_2 \pm \Delta x_2, \ldots, x_n \pm \Delta x_n \) and the error limits for the computed result be \( R \pm \Delta R \).

To get the realistic error limits for the computed result, the principle of root-mean square method is used to get the magnitude of error given by Holman [153].

\[
\Delta R = \left[ \left( \frac{\partial R}{\partial x_1} \right)^2 \Delta x_1^2 + \left( \frac{\partial R}{\partial x_2} \right)^2 \Delta x_2^2 + \ldots + \left( \frac{\partial R}{\partial x_n} \right)^2 \Delta x_n^2 \right]^{1/2}
\]

(A1)

A1. UNCERTAINTY ANALYSIS OF COMPUTED PARAMETERS AT FULL LOAD CONDITION FOR BASE ENGINE DIESEL

Using equation (A1) the uncertainty in the computed values such as brake power (BP), brake thermal efficiency (BTE), brake mean effective pressure (BMEP) and mass flow rate of fuel (\( m_f \)) are estimated for base engine diesel. The measured values such as speed (N), fuel consumption time (t), torque (T), volume flow rate of fuel (x) are estimated from their respective uncertainties.
A1.1 Mass Flow Rate of Fuel ($m_f$):

\[ m_f = 2.988 \frac{x}{t} \text{ kg/hr} \]  \hfill (A2)

Where $x$ is volume of fuel consumed (cc)

\[ t \text{ is time for fuel consumption (sec)} \]

\[ x = 12 \pm 0.1 \text{ cc} \]

\[ t = 39 \pm 0.1 \text{ sec} \]

\[ \frac{\partial m_f}{\partial x} = \frac{2.988}{t} = 0.0766 \]

\[ \frac{\partial m_f}{\partial t} = 2.988 \times x \times \left(\frac{-1}{t^2}\right) = -0.02357 \]

\[ \Delta m_f = \sqrt{\left(\frac{\partial m_f}{\partial x} \Delta x\right)^2 + \left(\frac{\partial m_f}{\partial t} \Delta t\right)^2} \]  \hfill (A3)

\[ = \sqrt{(0.0766 \times 0.1)^2 + (-0.02357 \times 0.1)^2} \]

\[ \Delta m_f = 0.008 \text{ kg/hr} \]

Percentage of Error ($% \Delta m_f$) \hfill (A4)

\[ = \frac{\Delta m_f}{m_f} \times 100 \]

\[ = \frac{0.008}{0.93} \times 100 \]

\[ = 0.86\% \]

A1.2 Brake Power (BP):

\[ BP = 1.04719 \times 10^{-4} \times N \times T \text{ kW} \]  \hfill (A5)

Where $N$ is speed of crank shaft \hfill RPM
T is Torque \( \text{N-m} \)

\[ \text{BP} = f(\text{N}, \text{T}) \]

\[ \text{N} = 1500 \pm 10 \text{ (RPM)} \]

\[ \text{T} = 3.5 \pm 0.5 \text{ (N-m)} \]

\[
\frac{\partial \text{BP}}{\partial \text{N}} = 1.04719 \times 10^{-4} \times \text{T} = 2.468 \times 10^{-3}
\]

\[
\frac{\partial \text{BP}}{\partial \text{T}} = 1.04719 \times 10^{-4} \times \text{N} = 0.1570
\]

\[
\Delta \text{BP} = \sqrt{\left(\frac{\partial \text{BP}}{\partial \text{N}} \Delta \text{N}\right)^2 + \left(\frac{\partial \text{BP}}{\partial \text{T}} \Delta \text{T}\right)^2}
\]

\[
= \sqrt{(2.468 \times 10^{-3} \times 10)^2 + (0.1570 \times 0.5)^2}
\]

\[\Delta \text{BP} = 0.082 \text{ kW}\]

Percentage of Error \(\% \Delta \text{BP}\)

\[
= \frac{\Delta \text{BP}}{\text{BP}} \times 100
\]

\[
= \frac{0.082}{3.7} \times 100
\]

\[= 2.22\%
\]

**A1.3 Brake Thermal Efficiency (BTE):**

\[
\text{BTE} = 8.47 \times \frac{\text{BP}}{m_f} \text{ %}
\]

Where BP is Brake Power \(\text{kW}\)

\[m_f \text{ is mass flow rate of fuel kg/hr}\]

\[\text{BP} = 3.7 \pm 0.082 \text{ kW}\]

\[m_f = 0.93 \pm 0.008 \text{ kg/hr}\]

\[
\frac{\partial \text{BTE}}{\partial \text{BP}} = \frac{8.47}{m_f} = 9.107
\]
\[
\frac{\partial BTE}{\partial m_f} = 8.47 \times BP \left(\frac{-1}{m_f^2}\right) = -36.2
\]

\[
\Delta BTE = \sqrt{\left(\frac{\partial BTE}{\partial BP}\Delta BP\right)^2 + \left(\frac{\partial BTE}{\partial m_f}\Delta m_f\right)^2}
\]

\[
= \sqrt{(9.107 \times 0.082)^2 + (-36.2 \times 0.008)^2}
\]

\[
\Delta BTE = 0.08 \% \]

Percentage of Error (% \(\Delta BTE\)) = \[
\frac{\Delta BTE}{BTE} \times 100
\]

\[
= \frac{0.08}{29.6} \times 100
\]

\[
= 0.27 \%
\]

**A1.4 Brake Mean Effective Pressure (BMEP):**

\[
BMEP = 2170 \times \frac{BP}{N} \text{ bar}
\]

Where BP is Brake Power \text{ kW}

\[N \text{ is speed in RPM}\]

\[BP = 3.7 \pm 0.082 \text{ kW}\]

\[N = 1500 \pm 10 \text{ RPM}\]

\[
\frac{\partial BMEP}{\partial BP} = \frac{2170}{N} = 1.4466
\]

\[
\frac{\partial BMEP}{\partial N} = 2170 \times \frac{BP}{N^2} = 3.5684 \times 10^{-3}
\]

\[
\Delta BMEP = \sqrt{\left(\frac{\partial BMEP}{\partial BP}\Delta BP\right)^2 + \left(\frac{\partial BMEP}{\partial N}\Delta N\right)^2}
\]

\[
= \sqrt{(1.4466 \times 0.082)^2 + (-3.5684 \times 10^{-3} \times 10)^2}
\]

\[
\Delta BMEP = 0.123 \text{ bar}
\]
Percentage of Error (\( \% \Delta \text{BMEP} \))

\[
\% \Delta \text{BMEP} = \frac{\Delta \text{BMEP}}{\text{BMEP}} \times 100
\]  \hspace{1cm} (A13)

\[
= \frac{0.123}{5.35} \times 100
\]

\[
= 2.29\%
\]
All the uncertainties of the above parameters are tabulated in Table A1

Table A1 Uncertainties of Measured and Computed Parameters at Full Load

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Parameter</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Speed (N)</td>
<td>0.66</td>
</tr>
<tr>
<td>2</td>
<td>Torque (T)</td>
<td>2.12</td>
</tr>
<tr>
<td>3</td>
<td>Volume flow rate of fuel(x)</td>
<td>0.83</td>
</tr>
<tr>
<td>4</td>
<td>Time for fuel consumption (t)</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>Mass flow rate of fuel (mf)</td>
<td>0.86</td>
</tr>
<tr>
<td>6</td>
<td>Brake power (BP)</td>
<td>2.22</td>
</tr>
<tr>
<td>7</td>
<td>Brake thermal efficiency (BTE)</td>
<td>0.27</td>
</tr>
<tr>
<td>8</td>
<td>Brake mean effective pressure (BMEP)</td>
<td>2.29</td>
</tr>
</tbody>
</table>