APPENDIX 4

ERROR AND UNCERTAINTY ANALYSIS

Errors and uncertainties in the experiments are associated with various primary experimental measurements that may arise from instrument selection, condition, calibration, environment and test planning. Uncertainty analysis is an essential to prove the accuracy of the experimental results.

Table A 4.1 indicates the uncertainty percentage of various measuring instruments.

**Table A 4.1 Uncertainty percentage of measuring instruments**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Instruments</th>
<th>Uncertainty percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gas Analyzer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HC</td>
<td>±0.05</td>
</tr>
<tr>
<td></td>
<td>CO</td>
<td>±0.1</td>
</tr>
<tr>
<td></td>
<td>CO₂</td>
<td>±0.05</td>
</tr>
<tr>
<td></td>
<td>NOₓ</td>
<td>±0.02</td>
</tr>
<tr>
<td>2</td>
<td>Speed measuring unit</td>
<td>±0.1</td>
</tr>
<tr>
<td>3</td>
<td>Load indicator</td>
<td>±0.2</td>
</tr>
<tr>
<td>4</td>
<td>Manometer</td>
<td>±1.0</td>
</tr>
<tr>
<td>5</td>
<td>Burette for fuel measurement</td>
<td>±1.0</td>
</tr>
<tr>
<td>6</td>
<td>Crank angle encoder</td>
<td>±0.2</td>
</tr>
</tbody>
</table>

The uncertainty percentage of various parameters such as, BP, BSFC and BTE are calculated as follows and the values are presented in Table A 4.2.
If an estimated quantity $R$ depends on independent variables like $x_1, x_2, \ldots, x_n$, then the error in the value of “$R$” is given by

$$R = f(x_1, x_2, \ldots, x_n) \quad \text{(A 5.1)}$$

To get the realistic error limits ($\Delta R$), the principle of root mean square method is used as explained by Holman (2003).

$$\Delta R = \sqrt{\left(\frac{\partial R}{\partial x_1} \cdot \Delta x_1\right)^2 + \left(\frac{\partial R}{\partial x_2} \cdot \Delta x_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} \cdot \Delta x_n\right)^2} \quad \text{(A 5.2)}$$

The error limits for the estimated quantity is $R \pm \Delta R$.

The realistic error of BP is computed as follows:

$$BP = f(N, T) \quad \text{(A 5.3)}$$

$$\Delta BP = \sqrt{\left(\frac{\partial BP}{\partial N} \cdot \Delta N\right)^2 + \left(\frac{\partial BP}{\partial T} \cdot \Delta T\right)^2} \quad \text{(A 5.4)}$$

where $\Delta N = 0.1$ and $\Delta T = 0.05$.

The realistic error of BSFC is computed as follows:

$$BSFC = f(TFC, BP) \quad \text{(A 5.5)}$$

$$\Delta BSFC = \sqrt{\left(\frac{\partial BSFC}{\partial TFC} \cdot \Delta TFC\right)^2 + \left(\frac{\partial BSFC}{\partial BP} \cdot \Delta BP\right)^2} \quad \text{(A 5.6)}$$

The realistic error of BTE is computed as follows:

$$E = f(TFC, BP) \quad \text{(A 5.7)}$$
\[
\Delta BTE = \sqrt{\left(\frac{\partial BTE}{\partial TFC} \cdot \Delta TFC\right)^2 + \left(\frac{\partial BTE}{\partial BP} \cdot \Delta BP\right)^2}
\]

where \(\Delta TFC\) and \(\Delta BP\) are calculated as 0.3% and 0.8% respectively.

Table A 4.2 Uncertainty percentage of calculated parameters

<table>
<thead>
<tr>
<th>S.No</th>
<th>Parameters</th>
<th>Uncertainty percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BP</td>
<td>± 0.79</td>
</tr>
<tr>
<td>2</td>
<td>BSFC</td>
<td>± 0.98</td>
</tr>
<tr>
<td>3</td>
<td>BTE</td>
<td>± 0.96</td>
</tr>
</tbody>
</table>

A sample calculation for BTE at 25% load condition with BD is given below:

\[BP = 0.9669\ \text{kW};\ TFC = 0.45\ \text{kg/hr};\ HV = 43,800\ \text{kJ/kg}\]

\[
BTE = \frac{BP \times 3600 \times 100}{TFC \times HV}
\]

\[
BTE = \frac{0.9669 \times 3600 \times 100}{0.45 \times 43800} = 17.66\%
\]

\[
BTE = f(TFC, BP)
\]

\[
\frac{\partial BTE}{\partial BP} = \frac{3600 \times 100}{TFC \times CV} = 18.27
\]

\[
\frac{\partial BTE}{\partial TFC} = \frac{BP \times 3600 \times 100}{(-TFC)^2 \times CV} = 39.25
\]
The uncertainty of BTE is 17.66 ± 0.17. In terms of percentage: 0.96%.

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

\[
\Delta BTE = \sqrt{(18.27 \times 0.0077)^2 + (39.25 \times 0.00286)^2} = 0.17
\]

The uncertainty of BTE is 17.66 ± 0.17.

In terms of percentage: 0.96%.