Appendix-I

A. Sample calculation

Outcomes have obtained by mounting discrete V-pattern baffle in the solar air channel. In this appendix procedure of one sample calculation required for obtaining outcomes has carried out for the raw data of test Run number 20, for roughened channel is given below:

**Data roughened absorber plate**

Relative discrete or gap distance \( \left( \frac{D_d}{L_v} \right) \) = 0.67

Relative discrete or gap width \( \left( \frac{g_w}{H_b} \right) \) = 1.5

Relative baffle height \( \left( \frac{H_b}{H} \right) \) = 0.5

Relative baffle pitch \( \left( \frac{P_b}{H} \right) \) = 1.5

Angle of attack \( \left( \alpha_a \right) \) = 60°

**General data**

Diameter of orifice meter pipe = 80 mm

Diameter of orifice meter = 36 mm

Density of manometric fluid (Isopropyl alcohol) \( \rho_m \) = 786 Kg/m³

**Plate and channel geometrical data**

Width of channel \( (W) \) = 0.3 m

Height of channel \( (H) \) = 0.03 m

Length of test section \( (L_t) \) = 1.2 m
Mean plate Temperature ($T_p$)

The mean temperature of the plate is the average of all temperatures of the heated plate:

$$T_p = \frac{\sum T_{pi}}{N}$$

Average plate temperature is calculated by averaging the temperature indicated by the thermocouples placed on the absorber plate.

$$T_p = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7 + T_8 + T_9 + T_{10} + T_{11} + T_{12}}{21}$$

$$T_p = \frac{T_{13} + T_{14} + T_{15} + T_{16} + T_{17} + T_{18} + T_{19} + T_{20} + T_{21}}{21}$$

$$45.0 + 45.8 + 46.3 + 48.5 + 51.5 + 51.9 + 53.7$$

$$+54.6 + 56.5 + 57.2 + 57.6 + 60.3$$

$$T_p = \frac{+61.8 + 61.5 + 62.4 + 65.8 + 68.3 + 67.4 + 68.0 + 67.8 + 68.2}{21}$$

$$T_p = 58.41 \degree C \text{ Or } 331.41 \text{ K}$$

A.1 Inlet Air Temperature ($T_i$)

Inlet air temperature is determined by:

$$T_i = T_{A1} = 38.4 \degree C \text{ Or } 311.4 \text{ K}$$

A.2 Outlet Air Temperature ($T_o$)

Outlet air temperature is determined by:

$$T_o = (T_{A2} + T_{A3} + T_{A4} + T_{A5} + T_{A6})/5$$

$$T_o = (49.2 + 49.8 + 49.4 + 49.3 + 49.6)/5$$

$$T_o = 49.48 \degree C \text{ or } 322.48 \text{ K}$$

A.3 Mean bulk air temperature ($T_f$)

The mean bulk air temperature $T_f$ is a simple arithmetic mean of the measured data at the inlet and the exit temperature of air streaming through the test section:
\[ T_f = \frac{T_i + T_o}{2} \]

\[ T_f = \frac{38.4 + 49.48}{2} \]

\[ T_f = 43.94 \, ^{\circ}C \, \text{Or} \, 316.94 \, \text{K} \]

**A.4 Air properties**

Thermo-physical properties of air have been calculated by standard correlation provided by (Han, 1998), as given below:

**A.4.1 Kinematics viscosity, (\( \nu \))**

Kinematics viscosity is determined by:

\[ \nu = 1.81 \times 10^{-5} \times (T_f/293)^{0.735} \]

\[ \nu = 1.9175 \times 10^{-5} \, \text{Ns/m}^2 \]

**A.4.2 Specific heat at constant pressure, (\( C_p \))**

Specific heat is determined by:

\[ C_p = 1006 \times (T_f/293)^{0.0115} \]

\[ C_p = 1007.225 \, J/KgK \]

**A.4.3 Thermal conductivity of air, (\( K_a \))**

Thermal conductivity is determined by:

\[ K_a = 0.0257 \times (T_f/293)^{0.86} \]

\[ K_a = 0.0274 \, W/mK \]

**A.4.4 Density of air, (\( \rho_a \))**

Density of air is determined by:

\[ \rho_a = \frac{97500}{287.045 \times T_f} \]

\[ \rho_a = 1.0717Kg/m^3 \]
Appendices

A.5 Mass Stream Rate Measurement ($m_a$)

The $m_a$ of air has been calculated from the pressure drop measurement through the calibrated orifice meter by using the following formula:

$$m_a = C_{do} A_o \left[ \frac{2 \rho_a (\Delta p)_o}{1 - \beta^4} \right]^{0.5}$$

Where,

$$(\Delta p)_o = (\Delta h)_o \times \rho_m \times g$$

$$(\Delta p)_o = 0.06 \times 786 \times 9.81$$

$$(\Delta p)_o = 462.63 \, N/m^2$$

Area of orifice, $A_o = 1.0178 \times 10^{-3} \, m^2$

Coefficient of discharge, $C_{do} = 0.624$

$$m_a = 0.624 \times 1.0178 \times 10^{-3} \left[ \frac{2 \times 1.0717 \times 462.63}{1 - 0.45^4} \right]^{0.5}$$

$$m_a = 0.020 \, kg/s$$

A.6 Velocity of Air through Channel ($V$)

The $V$ is calculated from the knowledge of $m_a$ and the stream as:

$$V = \frac{m_a}{\rho_a WH}$$

$$V = \frac{0.020}{1.0717 \times 0.3 \times 0.03}$$

$$V = 2.073 \, m/s$$

A.7 Equivalent Hydraulic Diameter ($D_{hd}$)

Equivalent Hydraulic Diameter is determined by:

$$D_{hd} = \frac{4. (W \cdot H)}{2. (W + H)}$$
A.8 Reynolds Number (Re)

The Re of air stream in the channel is intended from:

\[
Re = \frac{\rho_a V D_{hd}}{\nu}
\]

\[
Re = \frac{1.0717 \times 2.073 \times 0.05454}{1.9175 \times 10^{-5}}
\]

\[
Re = 6319
\]

A.9 Friction Factor (f_{rs})

The \( f_{rs} \) is determined from the measured data of \((\Delta p)_d\) across the test section length using the Darcy equation as:

\[
f_{rs} = \frac{2(\Delta p)_d D_{hd}}{4\rho_a L_t V^2}
\]

Where,

\[
(\Delta p)_d = (\Delta h)_d \times \rho_m \times g
\]

\[
f_{rs} = \frac{2 \times 12.41 \times 0.054545}{4 \times 1.0717 \times 1.2 \times 2.073^2}
\]

\[
f_{rs} = 0.06124
\]

A.10 Heat Transfer Coefficient (h_t)

The heat transfer rate \( Q_u \) from absorber to the air is given by:

\[
Q_u = m_a \times c_p (T_0 - T_1)
\]

\[
Q_u = 0.020 \times 1007.225 \times (322.48 - 311.4)
\]

\[
Q_u = 223.20 \text{ W}
\]

The \( h_t \) for the heated test section has been calculated as:

\[
D_{hd} = \frac{4 \times (0.3 \times 0.03)}{2 \times (0.3 + 0.03)}
\]

\[
D_{hd} = 0.054545 \text{ m}
\]
A.11 Nusselt Number \((\text{Nu}_{rs})\)

The \(h_t\) can be used to determine the \(\text{Nu}_{rs}\), which is defined as:

\[
\text{Nu}_{rs} = \frac{h_t D_{hd}}{K_a}
\]

\[
\text{Nu}_{rs} = \frac{42.84 \times 0.054545}{0.0274}
\]

\(\text{Nu}_{rs} = 85.28\)
### Appendix-II

Table B1: Specifications of roughened absorber plates

<table>
<thead>
<tr>
<th>Plate. No.</th>
<th>Relative discrete or gap distance ($D_d/L_v$)</th>
<th>Relative discrete or gap width ($g_w/H_b$)</th>
<th>Relative roughness height ($H_b/H$)</th>
<th>Relative roughness pitch ($P_b/H$)</th>
<th>Angle of attack ($\alpha_a$)</th>
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**Appendix-III**

Table C1: Experimental data recorded for plate temperature in roughened channel (Plate no. 20).

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<th>(Δp)₀ (mm)</th>
<th>(Δp)ₐ (mm)</th>
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<th>T₂ (°C)</th>
<th>T₃ (°C)</th>
<th>T₄ (°C)</th>
<th>T₅ (°C)</th>
<th>T₆ (°C)</th>
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</table>
Table C2: Experimental data recorded for air temperature in roughened channel (Plate no. 20).

**Air temperature**

<table>
<thead>
<tr>
<th>Test run</th>
<th>$T_a$(°C)</th>
<th>Air temperature(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inlet</td>
<td>Outlet</td>
</tr>
<tr>
<td></td>
<td>$T_{A1}$</td>
<td>$T_{A2}$ $T_{A3}$ $T_{A4}$ $T_{A5}$ $T_{A6}$</td>
</tr>
<tr>
<td>1</td>
<td>28.6</td>
<td>41.6 65.8 65.1 66.0 65.7 66.2</td>
</tr>
<tr>
<td>2</td>
<td>28.6</td>
<td>40.7 60.3 61.2 60.5 61.2 61.4</td>
</tr>
<tr>
<td>3</td>
<td>28.7</td>
<td>40.1 58.6 58.4 57.9 58.1 58.7</td>
</tr>
<tr>
<td>4</td>
<td>28.8</td>
<td>39.6 51.6 52.2 52.1 51.8 52.0</td>
</tr>
<tr>
<td>5</td>
<td>28.7</td>
<td>38.4 49.2 49.8 49.4 49.3 49.7</td>
</tr>
<tr>
<td>6</td>
<td>28.6</td>
<td>36.5 46.9 47.3 47.1 47.0 46.8</td>
</tr>
<tr>
<td>7</td>
<td>28.8</td>
<td>35.8 44.2 44.8 44.9 44.1 44.3</td>
</tr>
<tr>
<td>8</td>
<td>28.7</td>
<td>34.6 41.2 41.4 41.8 41.9 41.2</td>
</tr>
<tr>
<td>9</td>
<td>28.6</td>
<td>32.9 39.1 39.8 39.2 39.1 39.2</td>
</tr>
<tr>
<td>10</td>
<td>28.7</td>
<td>30.8 35.9 36.4 36.0 36.2 35.9</td>
</tr>
</tbody>
</table>
Appendix D.1 Uncertainties analysis

During experimentation, lots of factors come into play which causes deviation in the data of the measured parameters from the actual data. It is essential to investigate this deviation which might occur due to carelessness during experimentation. Uncertainty analysis provides the maximum possible error in numerical digits. It is based on the random sampling during the experimentation. The uncertainty analysis tells us expected accuracy, not the exact accuracy of the system. To evaluate uncertainty involve in this experiment method suggested by (Kline and McClintock,) is used. If the data of any parameter is calculated using certain measured quantities then error in measurement of “y” (parameter) is given as follows.

\[
\frac{\delta y}{y} = \left[ \left( \frac{\delta y}{\delta x_1} \right)^2 + \left( \frac{\delta y}{\delta x_2} \right)^2 + \left( \frac{\delta y}{\delta x_3} \right)^2 + \cdots + \left( \frac{\delta y}{\delta x_n} \right)^2 \right]^{0.5}
\]

Where \( \delta x_1, \delta x_2, \delta x_3, \ldots \delta x_n \) are possible error in measurement of \( x_1, x_2, x_3, \ldots x_n \), \( \delta y \) is known as absolute uncertainty and \( \frac{\delta y}{y} \) is known as relative uncertainty.

In the present experiment, important parameters considered for uncertainty analysis are Reynolds number, Heat transfer coefficient, Nusselt number, friction factor. The data of measured parameters are given as below:
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Length of test section, $L_t$</td>
<td>1200 mm</td>
</tr>
<tr>
<td>2.</td>
<td>Width of the channel, $W$</td>
<td>300 mm</td>
</tr>
<tr>
<td>3.</td>
<td>Height of channel, $H$</td>
<td>30 mm</td>
</tr>
<tr>
<td>4.</td>
<td>Diameter of pipe, $D_p$</td>
<td>80 mm</td>
</tr>
<tr>
<td>5.</td>
<td>Diameter of orifice meter, $D_o$</td>
<td>36 mm</td>
</tr>
<tr>
<td>6.</td>
<td>Pressure drop across orifice meter, $(\Delta_p)_o$</td>
<td>185 mm</td>
</tr>
<tr>
<td>7.</td>
<td>Pressure drop across test section,$(\Delta_p)_d$</td>
<td>56.2 Pa</td>
</tr>
<tr>
<td>8.</td>
<td>Atmospheric pressure, $P_a$</td>
<td>97500 N/m²</td>
</tr>
<tr>
<td>9.</td>
<td>Outlet air temperature, $T_o$</td>
<td>25.33 °C</td>
</tr>
<tr>
<td>10.</td>
<td>Inlet air temperature, $T_i$</td>
<td>20 °C</td>
</tr>
<tr>
<td>11.</td>
<td>Rise in temperature of air, $\Delta T$</td>
<td>5.33 °C</td>
</tr>
<tr>
<td>12.</td>
<td>Mean bulk air temperature $T_f$</td>
<td>22.66 °C</td>
</tr>
<tr>
<td>13.</td>
<td>Mean plate temperature, $T_p$</td>
<td>33 °C</td>
</tr>
</tbody>
</table>

The thermo-physical properties of air have been determined by following standard correlations:

$$\mu = 1.81 \times 10^{-5} \times \left( \frac{T_f}{293} \right)^{0.735}$$

$$C_p = 1006 \times \left( \frac{T_f}{293} \right)^{0.0155}$$

$$K_a = 0.0257 \times \left( \frac{T_f}{293} \right)^{0.86}$$
Appendices

\[ \rho_a = \frac{97500}{287.045} \times T_f \]

Uncertainty associated with instruments used in various measurements of parameters in the experiment is given in Table D1.

**Table D1: Uncertainty intervals of various measurements**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Measurement</th>
<th>Instrument</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dimensions of channel</td>
<td>Vernier caliper</td>
<td>±0.1 mm</td>
</tr>
<tr>
<td>2</td>
<td>Pressure drop across the channel</td>
<td>Micro-manometer</td>
<td>±0.1 Pa</td>
</tr>
<tr>
<td>3</td>
<td>Pressure drop across the orifice-plate</td>
<td>U-tube manometer</td>
<td>±1 mm</td>
</tr>
<tr>
<td>4</td>
<td>Temperature measurement</td>
<td>Copper-constantan thermocouple</td>
<td>±0.1°C</td>
</tr>
<tr>
<td>5</td>
<td>Orifice plate and throat diameter</td>
<td>Vernier caliper</td>
<td>±0.1 mm</td>
</tr>
</tbody>
</table>

**D.2 Uncertainty in Area of absorber plate (A_p)**

\[ A_p = W \times L_t \]

\[ A_p = \left[ \left( \frac{\delta A_p}{\delta L_t} L_t \right)^2 + \left( \frac{\delta A_p}{\delta W} \delta W \right)^2 \right]^{0.5} \]

\[ \frac{\delta A_p}{A_p} = \sqrt{ \left( \frac{\delta L_t}{L_t} \right)^2 + \left( \frac{\delta W}{W} \right)^2 } \]

\[ \frac{\delta A_p}{A_p} = \left[ \left( \frac{0.1}{1200} \right)^2 + \left( \frac{0.1}{300} \right)^2 \right]^{0.5} \]

\[ \frac{\delta A_p}{A_p} = 0.00034359 \]

**D.3 Uncertainty in Area of flow (A_f)**

\[ A_f = W \times H \]
\[ A_f = \left[ \left( \frac{\delta A_f}{\delta W} \right)^2 + \left( \frac{\delta A_f}{\delta H} \right)^2 \right]^{0.5} \]

\[ \frac{\delta A_f}{A_f} = \left[ \left( \frac{W \times \delta H}{W \times H} \right)^2 + \left( \frac{H \times \delta W}{W \times H} \right)^2 \right]^{0.5} \]

\[ \frac{\delta A_f}{A_f} = \left[ \left( \frac{\delta H}{H} \right)^2 + \left( \frac{\delta W}{W} \right)^2 \right]^{0.5} \]

\[ \frac{\delta A_f}{A_f} = \left[ \left( \frac{0.1}{30} \right)^2 + \left( \frac{0.1}{300} \right)^2 \right]^{0.5} \]

\[ \frac{\delta A_f}{A_f} = 0.00334995 \]

**D.4 Uncertainty in measurement of Hydraulic diameter (D_{hd})**

\[ D_{hd} = \frac{4 \times (W \times H)}{2 \times (W \times H)} = 2(WH)(W + H)^{-2} \]

\[ \frac{\delta D_{hd}}{\delta H} = [2(WH)(-1)(W + H)^{-2}] + [(W + H)^{-1}(2W)] \]

\[ \frac{\delta D_{hd}}{\delta H} = \frac{2W}{(W + H)} - \frac{2WH}{(W + H)^2} \]

\[ \frac{\delta D_{hd}}{\delta H} = \frac{2 \times 300}{(300 + 30)} - \frac{2 \times 300 \times 30}{(300 + 30)^2} = 1.65289 \]

\[ \delta D_{hd} = \left[ \left( \frac{\delta D_{hd}}{\delta W} \delta W \right)^2 + \left( \frac{\delta D_{hd}}{\delta H} \delta H \right)^2 \right]^{0.5} \]

\[ \delta D_{hd} = \left[ \left( \frac{\delta D_{hd}}{\delta W} \delta W \right)^2 + \left( \frac{\delta D_{hd}}{\delta H} \delta H \right)^2 \right]^{0.5} \]

\[ \frac{\delta D_{hd}}{D_{hd}} = \frac{[(1.65289 \times 0.1)^2 + (0.0165289 \times 0.1)^2]^{0.5}}{2(300 \times 30)(300 + 30)^{-1}} \]

\[ \frac{\delta D_{hd}}{D_{hd}} = 0.0030304246 \]
Appendices

D.5 Uncertainty in Area of orifice meter ($A_o$)

\[ A_o = \frac{\pi}{4} D_o^2 \]

\[ \frac{\delta A_o}{A_o} = \frac{2\pi D_o}{4} \]

\[ \delta A_o = \left[ \left( \frac{\delta A_o}{\delta D_o} \right) \right]^{0.5} \]

\[ = \left[ \left( \frac{\pi D_o}{2} \delta D_o \right) \right]^{0.5} \]

\[ = \frac{\pi D_o \times \delta D_o}{2} \]

\[ \frac{\delta A_o}{A_o} = \frac{2 \times \delta D_o}{D_o} = \frac{2 \times 0.1}{42.96} \]

\[ \frac{\delta A_o}{A_o} = 0.0047 \]

D6. Uncertainty in density measurement ($\rho_a$)

\[ \rho_a = \frac{P_a}{R \times T_o} \]

\[ \delta \rho_a = \left[ \left( \frac{\delta \rho a}{\delta P_a} \right) \times 1 \times \delta P_a \right]^2 + \left( \frac{\delta \rho a}{\delta T_o} \right)^2 \]

\[ = \left[ \left( \frac{1}{R \times T_o} \right) \times \left( \frac{\rho_a R T_o}{P_a} \right) \times \delta P_a \right]^2 + \left( \frac{-P_a}{R \times T_o^2} \right) \times \left( \frac{\rho_a R T_o}{P_a} \right) \times \delta T_o \]

\[ \frac{\delta \rho a}{\rho a} = \left[ \left( \frac{\delta P_a}{P_a} \right)^2 + \left( \frac{\delta T_o}{T_o} \right)^2 \right]^{0.5} \]

Taking $P_a = 97500$ Pa

\[ \frac{\delta \rho a}{\rho a} = \left[ \left( \frac{0.1}{97500} \right)^2 + \left( \frac{0.1}{25.33} \right)^2 \right]^{0.5} = 3.94 \times 10^{-3} \]
Appendices

D.7 Uncertainty in mass flow rate measurement (\(m_a\))

\[
m_a = c_{do} A_o \left[ \frac{2 \rho_a (\Delta p)_0}{1 - \beta^4} \right]^{0.5}
\]

\[
m_a = c_{do} \times A_o \times \rho_a^{0.5} \times (\Delta p)_0^{0.5} \times \left[ \frac{2}{1 - \beta^4} \right]^{0.5}
\]

\[
\delta m_a = \left[ \left( \frac{\delta m_a}{\delta c_{do}} \right)^2 + \left( \frac{\delta m_a}{\delta A_o} \right)^2 + \left( \frac{\delta m_a}{\delta \rho_a} \right)^2 + \left( \frac{\delta m_a}{\delta (\Delta p)_0} \right)^2 \right]^{0.5}
\]

\[
\frac{\delta m_a}{m_a} = \left[ \left( \frac{\delta c_{do}}{c_{do}} \right)^2 + \left( \frac{\delta A_o}{A_o} \right)^2 + \left( \frac{\delta \rho_a}{\rho_a} \right)^2 + \left( \frac{\delta (\Delta p)_0}{(\Delta p)_0} \right)^2 \right]^{0.5}
\]

The data of

\[
\frac{\delta c_{do}}{c_{do}} = 1.5\%
\]

The uncertainty in \((\Delta p)_0\), for U-tube manometer is 0.2 mm.

\((\Delta p)_0 = \Delta(H)_o \sin 30^\circ \times \sin 90^\circ = 185\text{mm}
\]

\[
\frac{\delta m_a}{m_a} = \left[ \left( \frac{1.5}{100} \right)^2 + (0.0047)^2 + (0.00394)^2 + \left( \frac{0.2}{185} \right)^2 \right]^{0.5} = 0.016241
\]

D.8 Uncertainty in measurement of air velocity in channel (\(V\))

\[
V = \frac{m_a}{\rho_a \times W \times H}
\]

\[
\frac{\delta V}{V} = \left[ \left( \frac{\delta m_a}{m_a} \right)^2 + \left( \frac{\delta \rho_a}{\rho_a} \right)^2 + \left( \frac{\delta W}{W} \right)^2 + \left( \frac{\delta H}{H} \right)^2 \right]^{0.5}
\]

\[
\frac{\delta V}{V} = \left[ (0.016241)^2 + (0.00394)^2 + \left( \frac{0.1}{300} \right)^2 + \left( \frac{0.1}{30} \right)^2 \right]^{0.5} = 0.017044
\]

D.9 Uncertainty in useful heat gain (\(Q_u\))

\[
Q_u = m_a c_p (T_0 - T_i) = m_a c_p \Delta T
\]
Uncertainty in specific heat is 0.1

So, equation becomes

$$\frac{\delta Q_u}{Q_u} = \left[ \left( \frac{\delta m_a}{m_a} \right)^2 + \left( \frac{\delta c_p}{c_p} \right)^2 + \left( \frac{\delta \Delta T}{\Delta T} \right)^2 \right]^{0.5}$$

D.10 Uncertainty in heat transfer coefficient (h_t)

$$h_t = \frac{Q_u}{A_p \times (T_p - T_f)} = \frac{Q_u}{A_p \times \Delta T_f}$$

$$\frac{\delta h_t}{h_t} = \left[ \left( \frac{\delta Q_u}{Q_u} \right)^2 + \left( \frac{\delta A_p}{A_p} \right)^2 + \left( \frac{\delta \Delta T_f}{\Delta T_f} \right)^2 \right]^{0.5}$$

$$\frac{\delta h_t}{h_t} = \left[ (0.02481)^2 + (0.00034359)^2 + \left( \frac{0.1}{22.66} \right)^2 \right]^{0.5} = 0.0252017$$

D.11 Uncertainty in Nusselt number (Nu.rs)

$$Nu.rs = \frac{h_tD_{hd}}{K_a}$$

$$\frac{\delta Nu.rs}{Nu.rs} = \left[ \left( \frac{\delta D_{hd}}{D_{hd}} \right)^2 + \left( \frac{\delta h_t}{h_t} \right)^2 + \left( \frac{\delta K_a}{K_a} \right)^2 \right]^{0.5}$$

$$\frac{\delta Nu.rs}{Nu.rs} = \left[ (0.0030304246)^2 + (0.0252017)^2 + \left( \frac{0.0001}{0.02529} \right)^2 \right]^{0.5} = 0.0394161$$

D.12 Uncertainty in Reynolds Number (Re)

$$Re = \frac{V.D_{hd}}{\nu} = \frac{\rho_a V D_{hd}}{\mu}$$

$$\frac{\delta Re}{Re} = \left[ \left( \frac{\delta D_{hd}}{D_{hd}} \right)^2 + \left( \frac{\delta V}{V} \right)^2 + \left( \frac{\delta \rho_a}{\rho_a} \right)^2 + \left( \frac{\delta \mu}{\mu} \right)^2 \right]^{0.5}$$
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\[
\frac{\delta Re}{Re} = \left[ (0.0030304246)^2 + (0.17044)^2 + (0.00394)^2 + \left( \frac{0.001 \times 10^{-5}}{1.87 \times 10^{-5}} \right)^2 \right]^{0.5}
\]

\[
\frac{\delta Re}{Re} = 0.01776
\]

D.13 Uncertainty in friction factor (f_{rs})

\[
f_{rs} = \frac{2(D_p D_{hd})}{4\rho_a L_t V^2}
\]

\[
\frac{\delta f_{rs}}{f_{rs}} = \left[ \left( \frac{\delta D_{hd}}{D_{hd}} \right)^2 + \left( \frac{\delta V}{V} \right)^2 + \left( \frac{\delta L_t}{L_t} \right)^2 + \left( \frac{\delta \rho_a}{\rho_a} \right)^2 + \left( \frac{\delta (D_p)}{D_p} \right)^2 \right]^{0.5}
\]

\[
\frac{\delta f_{rs}}{f_{rs}} = \left[ (0.0030304246)^2 + (0.17044)^2 + \left( \frac{0.1}{1200} \right)^2 + (0.00394)^2 + \left( \frac{0.1}{56.2} \right)^2 \right]^{0.5}
\]

\[
\frac{\delta f_{rs}}{f_{rs}} = 0.01784
\]

D.14 Uncertainty in thermohydraulic performance parameter (\eta_p)

\[
\eta_p = (Nu_{rs}/Nu_{ss})/(f_{rs}/f_{ss})^{0.33}
\]

\[
\frac{\delta \eta_p}{\eta_p} = \left[ \left( \frac{\delta Nu_{rs}}{Nu_{rs}} \right)^2 + \left( \frac{\delta f_{rs}}{f_{rs}} \right)^2 \right]^{0.5}
\]

\[
\frac{\delta \eta_p}{\eta_p} = [(0.0394161)^2 + (0.01784)^2]^{0.5}
\]

\[
\frac{\delta \eta_p}{\eta_p} = 0.043265 = 4.3265\%
\]

As the uncertainty calculation was done on a single test run (constant Reynolds number), the uncertainty analysis for complete test run for single geometry (complete set of Reynolds number) was carried out and outcomes are given as below.
### Parameters and Error Range

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameters</th>
<th>Error range, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mass flow rate ($m_a$)</td>
<td>1.597 – 2.033</td>
</tr>
<tr>
<td>2.</td>
<td>Velocity of air ($V$)</td>
<td>1.653 – 1.811</td>
</tr>
<tr>
<td>3.</td>
<td>Useful heat gain ($Q_u$)</td>
<td>2.131 – 3.267</td>
</tr>
<tr>
<td>4.</td>
<td>Heat transfer coefficient ($h_t$)</td>
<td>2.213 – 3.732</td>
</tr>
<tr>
<td>5.</td>
<td>Nusselt number ($Nu_{rs}$)</td>
<td>3.378 – 4.667</td>
</tr>
<tr>
<td>6.</td>
<td>Friction Factor ($f_{rs}$)</td>
<td>1.283 – 2.331</td>
</tr>
<tr>
<td>7.</td>
<td>Reynolds Number ($Re$)</td>
<td>1.43 – 3.76</td>
</tr>
<tr>
<td>8.</td>
<td>Thermohydraulic performance parameter ($\eta_p$)</td>
<td>3.675 – 5.221</td>
</tr>
</tbody>
</table>