Chapter - 3

EXPERIMENTAL DETAILS

3.1 INTRODUCTION

In Section 2.5, outline of the present work is given in detail. The research work involves experimental and numerical analysis of heat transfer augmentation from a single dimple. In this chapter, the description of the experimental set up and instrumentation used, along with the experimental procedure and data reduction is presented. The main objective of the experimentation is to obtain experimental data pertaining to heat transfer and fluid flow over a single dimple surface for various air flow rates through the channel and at various heat loads.

3.2 REQUIREMENTS OF EXPERIMENTAL SET UP

It is required to create a uniform air flow over a dimpled portion of test set up with the provision of uniform heating from the bottom of the test section with provision of temperature and flow parameters measurement at the required locations. A bell mouth entry along with honeycomb structure is used to provide uniform air flow. Two cartridge heaters are used at the bottom of the test surface for uniform heating of test plate. The experimental set up required to study the heat transfer enhancement from a single dimple consist of following components

1) Bell mouth entry 2) Honeycomb structure
3 ) Settling section 4) Test section
5) Exit section 6) Orifice meter
7) Flexible pipe 8) Blower
3.3 EXPERIMENTAL SET UP

The schematic diagram of the experimental set up is shown in Fig.3.1, while the photograph is shown in Fig. 3.2. The open loop type set up consists of the following components connected to the suction side of the blower:

1) Development section
2) Test section
3) Exit section
4) Flow measurement section
5) Blower coupled to electric motor.

The air first enters the bell mouth entry ensuring smooth flow of air, followed by honeycomb section to get uniform flow of air throughout the cross section of duct. This is followed by settling section which helps to develop the flow. Before the test duct the total development section is of 100 x 25 mm$^2$ in cross section and 1000 mm in length. This gives a length to equivalent diameter ratio of about 30. This is adequate for obtaining hydrodynamically developed air flow prior to the test section. The development section is followed by test section. In the test section heat is added to the flow by the forced convection from bottom side.

The heated air is then mixed thoroughly in the exit section with the help of an air mixing chamber. The flow rate of the air is measured with the help of a standard orifice meter connected to U tube water manometer shown in Fig.3.3. A flow control valve is provided to control the volume flow rate of air. The test facility is connected to the suction side of the blower used to generate desired air flow. The selected blower shown in Fig.3.4 having following specifications:
Capacity - 1000 m$^3$/hr, Power - 1.5kW and Speed-2880 rpm:

The apparatus is connected on suction side of the blower so that a steady air flow can be obtained. The specifications of experimental set up are given in Table 3.1.
Fig. 3.1: Schematic diagram of experimental setup

Fig. 3.2: Photograph of experimental setup
Fig. 3.3: Photograph of orifice with U tube manometer

Fig. 3.4: Photograph of blower
### Table 3.1 Specifications of experimental set up

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Particulars</th>
<th>Dimensions</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Height of test-section</td>
<td>25mm</td>
</tr>
<tr>
<td>2</td>
<td>Width of test duct</td>
<td>100mm</td>
</tr>
<tr>
<td>3</td>
<td>Aspect ratio of the duct</td>
<td>4</td>
</tr>
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<td>4</td>
<td>Hydraulic diameter of duct</td>
<td>40 mm</td>
</tr>
<tr>
<td>5</td>
<td>Entrance section length</td>
<td>150 mm</td>
</tr>
<tr>
<td>6</td>
<td>Honey comb section length</td>
<td>50 mm</td>
</tr>
<tr>
<td>7</td>
<td>Settling section length</td>
<td>800 mm</td>
</tr>
<tr>
<td>8</td>
<td>Test section length</td>
<td>160 mm</td>
</tr>
<tr>
<td>9</td>
<td>Exit section length</td>
<td>250 mm</td>
</tr>
<tr>
<td>10</td>
<td>Diameter and length of PVC pipe</td>
<td>52 mm diameter, 1000 mm</td>
</tr>
<tr>
<td>11</td>
<td>Orifice plate</td>
<td>β=0.7, t=3 mm</td>
</tr>
<tr>
<td>12</td>
<td>Vertical U tube water manometer</td>
<td>L.C.=1 mm</td>
</tr>
<tr>
<td>13</td>
<td>Digital differential micro manometer</td>
<td>L.C.=1 Pascal</td>
</tr>
<tr>
<td>14</td>
<td>Air Blower (suction type)</td>
<td>1.5 kW, 1000 m³/hr, 2880 rpm</td>
</tr>
</tbody>
</table>
3.4 COMPONENT DETAILS

3.4.1 Test Section

The test section shown in Fig. 3.5 has two parts: test air duct and test plate assembly. The test air duct is of 100 x 25 x 160 mm³ and has flanges on both sides to connect developing and exit section. At the bottom of the test air duct there is slot of 100 x 100 mm² to accommodate test plate. The top of the test duct acts as a shroud. Two thermocouples are fixed on the shroud and two on the sides of air duct to measure the heat loss. The test plate is housed with two cartridge heaters of size φ12mm x 100 mm and capacity of 300 W. The test plate is heated by stabilized power input to heaters through a dimmerstat. In order to reduce heat loss, the bottom of the test plate is mounted on insulating (asbestos) sheet of 4 mm thickness and silica wool insulation of 40 mm thickness. The assembled test section is housed in Bakelite box of size 160 x 160 x 62 mm³. All sides of the test plate are insulated with silica wool of thickness 12 mm. The bakelite box is clamped to test air duct and sealed to avoid the air leakage. For realistic temperature measurement of the test plate fourteen calibrated Cu-Constantan (36 gauge) thermocouples are used. The whole test section is covered with 50 mm silica wool insulation to reduce heat loss. The development and exit sections are attached on either side of the test section.

3.4.2 Dimple Surface

The dimple surface is manufactured from aluminum block of size 100 x 100 x 32 mm³ shown in Fig 3.6 and Fig.3.7 (a) to Fig.3.7 (d). The composition of aluminum is given in Appendix A.2. The dimpled surface is formed within the aluminum block by CNC machining. The dimple print diameter is 50 mm kept constant through out the study. Three dimple depths of 10mm, 15mm and 20mm are studied in the experimentation to get δ/D ratio 0.2, 0.3 and 0.4. There are two φ12mm x 100 mm drilled passages are provided in the aluminum block for cartridge heaters. The locations of thermocouples are shown in Fig. 3.8. There are fourteen thermocouples rooted in the test plate by drilled passages below the test surface, so that thermocouples wire do not disturb the flow. The dimple surface is housed in the bakelite box and clamped to test duct. The various parameters studied during the experimentation are given in Table 3.2.
3.4.3 Development Section and Exit Section

The test section is preceded and followed by a long rectangular development section and followed by the exit section. Both of them are made of 2mm M.S. sheet and have the same cross sectional area of 100 x 25 mm². The 1000 mm long development section includes 250 mm inlet section and 50 mm honey comb structure. This length ensures a hydrodynamically developed air flow prior to the test section. The exit section is 175 mm long and housed with perforated baffles of size 12mm x 100mm, which direct the air flow in upward and downward direction and help to mix air thoroughly as shown in Fig.3.9. The temperature of exit air is then measured by three thermocouples placed 25 mm apart from each other so as to get an average temperature.

3.5 INSTRUMENTATION

The various physical parameters required to be measured during the tests are;

1. Air flow rate
2. Heater input
3. Temperature and
4. Pressure drop across the test plate and across the flow measuring device

3.5.1 Air Flow Rate

The air flow rate is measured with the help of a standard ASME orifice meter fitted with 52mm PVC pipe. The orifice plate with β=0.7 having 3mm thickness is designed to cover entire range of mass flow rates up to 200 kg/hr investigated. The orifice plate is held concentric with the pipe by means of flanges. The pressure taps are provided for differential pressure measurement (at $D_p$ and $D_p/2$) and pressure drop is measured using U tube water manometer. Since all the ASME norms for orifice design are observed, the standard ASME calibration curves are used for the flow measurement calculations. Other orifice meter details are given in Appendix A.2.
Fig. 3.5: Enlarged cross-sectional view of test duct

Fig. 3.6: Schematic diagram of dimple surface
Fig. 3.7: Top view of test surface (a) Flat plate (b) Dimple depth $\delta/D=0.2$
(c) Dimple depth $\delta/D=0.3$ (d) Dimple depth $\delta/D=0.4$
Fig. 3.8: Thermocouple locations on test plate

(All dimensions are in mm)

Fig. 3.9: Exit chamber consist of mixing device

(All dimensions are in mm)
Table 3.2: The range of parameters varied during the experimentation

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameter</th>
<th>Nomenclature</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dimple Print Diameter</td>
<td>D</td>
<td>50mm (Constant)</td>
</tr>
<tr>
<td>2.</td>
<td>Channel height to dimple print diameter</td>
<td>H/D</td>
<td>0.5 (Constant)</td>
</tr>
<tr>
<td>3.</td>
<td>Channel aspect ratio</td>
<td>α</td>
<td>4 (Constant)</td>
</tr>
<tr>
<td>4.</td>
<td>Dimple depth to hydraulic diameter ratio</td>
<td>δ/Dh</td>
<td>0.25, 0.375 and 0.5 (---)</td>
</tr>
<tr>
<td>5.</td>
<td>Reynolds number based on hydraulic diameter</td>
<td>Re_{Dh}</td>
<td>10000 to 35000 (---)</td>
</tr>
<tr>
<td>6.</td>
<td>Heat Load</td>
<td>Q_{in}</td>
<td>25,50,60 and 75 W</td>
</tr>
</tbody>
</table>
The free end of downstream pipe is connected to blower through flexible hose pipe and pressure reducer. The free end of the upstream pipe is connected to the free end of exit section by means of a reducer. The desired flow rate through the test section is obtained by controlling the opening of a gate valve provided prior to flexible pipe.

3.5.2 Heat Input

The heater input is directly measured with the help of a calibrated digital watt meter whose accuracy is checked against a standard voltmeter and an ammeter in the standard laboratory of Gaurav Enterperises, Pune. The accuracy of the wattmeter is found to be +/- 0.5 % of overall range. The control panel consist of wattmeter, dimmerstat, voltage stabilizer and millivoltmeter (temperature indicator) shown in Fig. 3.10.

3.5.3 Temperature

Temperatures at different locations are measured with the help of calibrated 36 SWG copper constant thermocouples. The thermocouple wires are braided with fiberglass insulation so as to have both wires as a single unit. There are 14 thermocouples on test plate. One thermocouple is used for measuring inlet air temperature and three thermocouples for measuring exit air temperature after exit section. Besides these, four thermocouples are mounted on inner surfaces of the body structure to check the body wall temperature. The emf developed by thermocouples is measured with millivoltmeter and temperature is noted referring IS: 2056-1962 Table. All thermocouples are made from the same pool of wire. Randomly chosen thermocouples are calibrated using hypsometer for the steam point and thermos flask for distilled water ice point. The error in the temperature is applied to all the thermocouples used in the investigations referring to IS2056:1962.

3.5.4 Pressure Drop

The pressure drop across the orifice meter is measured with a U tube water manometer of least count 1mm. The pressure drop across the test plate is measured with the help of digital micro manometer manufactured by M/s Ajay Sensors, Bangalore with least count of 0.1 mm of water column(1 Pascal) shown in Fig.3.11. Appendix A.2 gives the calibration certificate.
Fig. 3.10: Photograph of control panel

Fig. 3.11: Photograph of micromanometer
3.6 EXPERIMENTAL PROCEDURE

Prior to testing, the test surface is housed in bakelite box and clamped to test duct. Care is taken so that the dimple surface is located in the middle of test duct. The test procedure adopted for carrying out the experimental investigated in the present study is as follows.

3.6.1 Heat Transfer Data

1. The delivery valve should be closed while starting the blower.
2. The valve should be gradually opened and the air flow rate adjusted to the required value in U tube manometer. The valve should be controlled to maintain required flow rate.
3. The heater should be switched ‘ON’ and set to the desired value and heater input maintained throughout the run.
4. The few representative thermocouples on the test plate and in the air stream to be selected and reading to be noted down after every 15 minutes. Wait till the thermocouples read more or less the same value for two or three successive observations. This is an indication that steady state has been reached.
5. All thermocouple readings should be noted down.
6. The wattmeter, orifice manometer and micro manometer reading should also be noted.

Typically it takes approximately four to five hours to reach the first steady state and two hours for every subsequent steady state. Many test runs are repeated to ensure repeatability of test observations.

3.6.2 Friction Factor Data

This study is conducted under ambient conditions without wall heating. Six different flow rates are used to get six different Reynolds Numbers ranging from 10000 to 35000. The pressure drop in the test section is measured in the beginning of each experiment before the heater is switched on.
The procedure adopted is as follows:

1. The delivery valve closed and the blower started.
2. The valve opened fully and the blower to run for half an hour.
3. The discharge adjusted to required value and set the flow conditions.
4. The micro manometer and orifice manometer readings noted.

The above procedure is used during the experimentation of dimple surface at \( \text{Re}_{Dh} \) varying from 10000 to 35000.

### 3.7 DATA REDUCTION

The main parameters of interest in this study are the heat transfer coefficient and the friction factor under fully developed condition.

The assumptions made during the data reduction are listed below.

1) Air is assumed as an incompressible gas.
2) Power input to the heaters is same as the heat supplied to the dimple surface.
3) The heat flux is calculated based on projected area.

The following procedure/formulae are used to calculate these parameters.

#### 3.7.1 Mass Flow Rate of Air (\( \dot{m}_{m} \))

Mass flow rate of air is calculated as per following relation;

\[
\dot{m}_{m} = C_d \rho_a \frac{\pi}{4} d^2 v \sqrt{2gh_a} \sqrt{1 - \beta^4}
\]

(3.1)

The properties of air are evaluated at orifice temperature, while the density of water is taken at the ambient conditions.

#### 3.7.2 Heat Loss from the Test Channel (\( Q_l \))

Preliminary tests are performed on the test set up to estimate the heat loss from the test section [26]. The total heat supplied to the test plate is divided as given in Equation 3.2.

\[
Q_{in} = Q_u + Q_l
\]

(3.2)

where, \( Q_{in} \) is heater input, \( Q_u \) is useful convective heat gain and \( Q_l \) is total loss from the test channel.

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A part of heat supplied is utilized to increase the enthalpy of air and remaining heat is lost to atmosphere through natural convection and radiation. The following procedure is adopted to determine the heat loss.

The test section is made air tight and is well insulated from surroundings. The flat plate is used for finding out heat loss. A fixed amount of heat input (W) is given to the heaters in the test plate and surface temperature allowed to attain a steady state. Tests are performed for six different power inputs. The data generated in this manner is plotted as shown in Fig.3.12. The heat loss is plotted against the parameter \(T_{bs} - T_{ai}\).

where, \(T_{bs}\) represents average surface temperature of the channel.

The parameter \(T_{bs}\) is defined as

\[
T_{bs} = \frac{(T_w + T_s)}{2}
\]  

(3.3)

The following correlations are developed using excel programming;

The heat loss \((Q_i)\) is correlated against \((T_{bs} - T_{ai})\) is plotted as shown in Fig.3.12.

\[
Q_i = 0.8356 (T_{bs} - T_{ai}) - 0.0035 (T_{bs} - T_{ai})^2 - 1.2311
\]  

(3.4)

The above equation is used to predict the net heat loss.

3.7.3 Energy Balance Check

An energy balance check is carried out by comparing the increase in enthalpy of the air stream i.e. \(m \cdot C_p \cdot (T_{ae} - T_{ai})\) with the electrical energy input from which the heat loss is subtracted, i.e. \((Q_{in} - Q_i)\). In most of the cases the balance is within \(\pm 6\%\).

3.7.4 Air Bulk Mean Temperature

\[
T_{bm} = \frac{T_{ai} + T_{ae}}{2}
\]  

(3.5)

3.7.5 Reynolds Number

\[
\text{Re}_{Dh} = \frac{V D_h}{\mu_a}
\]  

(3.6)

3.7.6 Heat Transfer Coefficient

It is necessary to have knowledge of the mechanism of heat transfer before evaluating the heat transfer coefficient. The mechanism of the heat transfer is shown in Fig.3.13.
Fig. 3.12: Heat loss estimation based on base surface temperature

Fig. 3.13: Mechanism of Heat transfer for Flat test Channel
It can be seen from test set up conditions heat entering into the duct ($Q_u$) is transferred to the air by forced convection.

a) Mostly from heated surface (1) and
b) Partly from unheated surfaces (2), (3) and (4) which receive heat from (1) by radiation and conduction

$$Q_u = m_a \times C_p (T_{ae} - T_{ai})$$  \hspace{1cm} (3.7)

$$h = \frac{Q_u}{A(T_w - T_{bm})}$$  \hspace{1cm} (3.8)

3.7.7 Equivalent Diameter

$$D_h = \frac{4A_c}{P}$$  \hspace{1cm} (3.9)

3.7.8 Nusselt Number

$$Nu = \frac{hDh}{K_a}$$  \hspace{1cm} (3.10)

The properties of air are evaluated at the bulk mean temperature.

3.7.9 Friction Factor

$$f = \frac{\Delta P Dh}{2\rho_a l_p \left[ \frac{m_a}{\rho_a A_c} \right]^2}$$  \hspace{1cm} (3.11)

The properties of air used in the calculations were taken from air table corresponding to mean bulk air temperature.