CHAPTER 5
DESIGN OF TEST SECTION

5.1 INTRODUCTION

It is found essential to validate experimentally the heat-transfer characteristic in the developed porous (Rigimesh) material and the effect of nitrogen cooling through the capillary tortuous flow passage with the aid of applied pressure differential. Hence a simple set up is designed and presented here with. For the design of various components ASME and Bureau of Indian Standard are followed. Fig. 5.1 illustrates the complete set-up designed and used for experimentation. A number of assumptions are made to proceed the design as follows:

1. Flow through the duct is in equilibrium condition
2. The material of the duct and the wall thickness are designed to withstand the internal pressure sufficiently and can maintain structural rigidity throughout the experiment.
3. No moving parts are included in the set-up
4. Thermal conductivity of the material selected for the test set-up is very low.
5. No heat is permitted to leak (heat-transfer from specimen to the duct) in the test specimen mounting compartment, i.e. insulation is proper.
6. Measurements are taken when flow of cooling gas is in laminar, steady and stable.

Data:

\[ P = 400 \times 10^4 \text{ N m}^2 \]

\[ V = 18 \text{ m s}^{-1} \text{ (maximum)} \]

\[ D_d = 26 \times 10^{-3} \text{ m} \]

Permissible safe stress in the duct material, (mild steel)

\[ \sigma_t = 3900 \times 10^4 \text{ N m}^2 \]

\[ = 39 \text{ MN m}^2 \]
5.2 WALL THICKNESS OF CYLINDRICAL MAIN DUCT, $t_d$

$$t_d = \frac{pd}{2\sigma t} + C \quad (5.1)$$

Where

- $p$ = pressure in N m$^{-2}$
- $d$ = diameter in m
- $\sigma_t$ = safe stress for the duct material
- $C$ = a constant which varies according to material.

The present case for mild steel is $3$ mm.

Substituting the values in equation (5.1) above

$$t_d = \frac{400 \times 10^4 \times 26 \times 10^{-3}}{2 \times 39 \times 10^6} + 3 \text{ mm}$$

$$= 0.0013 \text{ m} = 1.3 + 3$$

$$= 4.3 \text{ mm}$$

Standard product of wall thickness of 5.0 mm used.

5.3 RATE OF FLOW COOLANT GAS THROUGH THE DUCT:

$$G_c = \rho A V \quad (5.2)$$

Where

- $G_c$ = flow of gas though the duct in kg s$^{-1}$
- $\rho$ = density of the flowing gas in kg m$^{-3}$
- $A$ = area of cross section in m$^2$
- $V$ = velocity of flow in m s$^{-1}$

$$\therefore \, G_c = 1.165 \times \frac{\pi}{4} (0.026)^2 \times 18$$

$$= 11.13 \times 10^{-3} \text{ kg s}^{-1}$$
54. DESIGN OF FLANGE THICKNESS, \( t_r \)

\[
\begin{align*}
  t_r &= 1.5 t + 0.3 \text{ mm} \quad (5.3)
\end{align*}
\]

Where
\[
\begin{align*}
  t &= \text{thickness of the wall of the main duct} \\
  t_r &= 1.5 \times 5 + 0.3 = 7.8 \text{ mm}
\end{align*}
\]

Adopted a standard thickness of flange as 8 mm

The effective diameter on which the fluid pressure acts is just at the point of leaking that is the diameter of circle touching the bolt holes. Let this diameter be, \( D_i \). If \( d_i \), the diameter of the bolt hole and, \( D_{pc} \), is the pitch circle diameter, then

\[
\begin{align*}
  D_i &= D_{pc} - d_i \quad (5.4)
\end{align*}
\]

Force trying to separate the flange,

\[
\begin{align*}
  F &= A \times P \quad (5.5)
\end{align*}
\]

Where
\[
\begin{align*}
  A &= \text{area of cross-section of the diameter touching the fastener. ie } D_i, \\
  F &= \frac{\pi}{4} D_i^2 \times P \quad (5.6)
\end{align*}
\]

If \( n = \) the number of bolts
\( d_c = \) core diameter of fixing bolts
\( \sigma_{lb} = \) permissible stress of the bolt material
then resistance of the bolt

\[
\begin{align*}
  &= \frac{\pi}{4} (d_c)^2 \times \sigma_{lb} \times n \quad (5.7)
\end{align*}
\]

for the nominal diameter of the bolts

\[
\begin{align*}
  d &= 0.75 \times t + 1 \text{ mm} \quad (5.8)
\end{align*}
\]
where
\[ t = \text{the thickness of the flange in mm} \]

\[ \therefore d = 0.75 \times 8 + 1 = 7.0 \text{ mm} \]

Adopted a standard bolt of nominal diameter 8 mm

Core diameter of the bolt \( = \) nominal diameter - twice the depth of thread
\[ d_c = 8.00 - (2 \times 0.767) = 6.466 \text{ mm} \]

Adopt core diameter of bolt is \( = 6.5 \text{ mm} \)

A convenient and suitable pitch circle diameter of flange is selected as 66 mm.

\[ D_t = D_{pc} - d \]
\[ = 66 - 8 = 58 \text{ mm} \] (5.9)

As mentioned earlier total force on the bolt \( = \frac{\pi}{4} (D_t)^2 x P_r \)

Where,
\( P_r \) is the pressure of the flowing fluid in the pipe
ie., \( 400 \times 10^4 \text{Nm}^{-2} \)

\[ F_{\text{total}} = \frac{\pi}{4} x (0.058)^2 x 400 \times 10^4 \]
\[ = 10.56 \text{ kN} \] (5.10)

Number of bolts \( n \) required for bolting the flanges
\[ n = 0.275 \times D_d + 1.6 \] (5.11)

where
\( D_d = \text{Main duct diameter in mm} \)

Substituting in eqn, (5.11),
\[ n = 0.275 \times 26 + 1.6 = 8.75 \]
Adopted 8 numbers of bolts which is convenient to mark and drill the holes at 45° apart.

\[
\text{force on one bolt} = \frac{F_r}{n} = \frac{10.56}{8} = 1.32kN
\]  

Check:

\[
F = \frac{\pi}{4} d^2 \times \sigma_t
\]  

where

\[
\sigma_t = \text{permissible tensile stress in N m}^{-2}
\]

\[
= 3900 \times 10^4 \text{ N m}^{-2}
\]

\[
= 39 \text{ MN m}^{-2}
\]

\[
1.32 \times 10^3 = \frac{\pi}{4} d^2 \times 39 \times 10^6
\]

\[
d = \sqrt{\frac{1.32 \times 10^3}{\frac{\pi}{4} \times 39 \times 10^6}} = 65mm
\]

Adopted a standard commercial precision stainless steel bolt of nominal diameter 8.00 mm.

Outside diameter of the flange, \(D_{fo}\)

\[
D_{fo} = D_d + 2t_f + 2 \times 2.5d \text{ in mm}
\]

where

\[
D_{fo} = \text{Outside diameter in flange in mm}
\]

\[
D_d = \text{Diameter of main duct in mm}
\]

\[
t_f = \text{Thickness of duct flange in mm}
\]

\[
d = \text{Diameter of bolt in mm}
\]
Substituting the values in the above relation
\[
D_{fo} = 26 + 2 \times 8 + 2 \times 2.5 \times 8
\]
\[
= 82 \text{ mm}
\]

Outside diameter of the flange is adopted as 90 mm. This is to accommodate the integral orifice plate between the flanges.

Pitch circle Diameter, \(D_{pc}\) of flange
\[
D_{pc} = D_d + 2t_r + 2d + 8 \text{ mm}
\]
\[
= 26 + 2 \times 8 + 2 \times 8 + 8 \text{ mm}
\]
\[
= 66 \text{ mm}
\]

Strengthening of the pipe near the specimen assembly
\[
= \frac{t + t_r}{2} + 3.5 \text{ mm}
\]
\[
= \frac{5 + 8}{2} + 3.5 = 10 \text{ mm}
\]

Outside diameter of the specimen mount cabin
\[36 + 18 = 54 \text{ mm}\]

5.5 BENDING MOMENT IN THE BOLTED FLANGE

The bending moment about the section XX which is tangential to the outside of the pipe. Width of the segment is obtained by measuring the distance from the drawing shown in Fig.5.2(a). Distance form section XX from the Centre of the bolt:
\[
y = \frac{D_{pc}}{2} - \left( \frac{D_d}{2} + t_f \right)
\]
\[
= \frac{66}{2} - \left( \frac{26}{2} + 8 \right)
\]
\[
= 12 \text{ mm} = 12 \times 10^{-3} \text{ m}
\]

Working stress in the flange.
Fig. 5.2 (a) Geometrical construction for dimension 'X'.

Fig. 5.2 (b) Expansion factor for orifice.
Let $\sigma_b$ be the working stress in the flange. Bending moment on each bolt due to force $F_t$

\[
F_t \times y = \frac{10.56 \times 10^3 \times 1.2 \times 10}{8} = 15.84 \text{ N m}
\]

Resisting moment on the flange of the main duct

\[
= \sigma_b \times Z_f
\]

where

\[
Z_f = \text{the section modules of the flange}
\]

\[
= \frac{1}{6} \times (t_f)^2
\]

where

\[
X = 0.042 \text{ meter}
\]

\[
t_f = 0.008 \text{ meter}
\]

Substituting

\[
= \sigma_b \times \frac{1}{6} \times 0.042 \times (0.008)^2
= \sigma_b \times 4.48 \times 10^{-7} \text{ N m}^{-2}
\]

Equating the moments

\[
15.84 = \sigma_b \times 4.48 \times 10^{-7}
\]

\[
\sigma_b = \frac{15.80}{4 \times 10^{-6}} = 39.5 \times 10^4 \text{ N m}^{-2}
\]

\[
= 35.35 \text{ MN m}^{-2}
\]
The stress, $\sigma_{th}$, arrived for mild steel for the main duct and the associated components design for sweat cooling experiment is well below the adopted design stress. Hence the designed components for the sweat cooling experiment is found all right [86,87].

5.6 DESIGN OF ORIFICE FLOW METER

(D and D/2 tappings)

Data:

Medium of experiment is gaseous nitrogen

Maximum flow rate, $G_e = 11 \times 10^{-3}$ kg s$^{-1}$

Maximum upstream pressure, $P_1 = 1.4458$ MN m$^{-2}$

Down stream pressure, $P_2 = 1.2803$ MN m$^{-2}$

The basic co-relations for an isentropic, compressible gas flow through an orifice can be stated as [86,88]:

$$G_e = \frac{C_d A_p Z}{\sqrt{RT}} \quad (5.21)$$

If $(P_2/P_1) \leq \text{critical pressure ratio}, \text{i.e;}

$$Z \leq \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma - 1}{\gamma - 1}}$$

then

$$Z = \sqrt{\frac{2}{\gamma + 1}} \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma - 1}} \quad (5.22)$$

If $(P_2/P_1) > \text{critical pressure ratio}$

$$Z = \frac{2\gamma}{\gamma - 1} \left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma - 1}} - \left(\frac{P_2}{P_1}\right)\right] \quad (5.23)$$

Where

$G_e = \text{Weight flow rate of gas, kg s}^{-1}$
A = Area of cross-section of orifice, m²

\( P_1 \) = Gas pressure in the upstream of orifice, N m⁻²

\( P_2 \) = Gas pressure, downstream of orifice in N m⁻²

R = Gas constant, 8314.3 kJ kg⁻¹ mole⁻¹ K⁻¹

\( T \) = Gas temperature upstream of orifice, 300 K

Z = Compressibility factor

\( \gamma \) = Ratio of specific heats i.e. 1.4 for GN₂

\( C_d \) = Flow coefficient, a function of design configuration and flow Reynolds number

\( g \) = Gravitational constant 9.81 m s⁻²

In the present case

Critical pressure ratio = \( \left( \frac{2}{2.4} \right)^{\frac{14}{3}} \) = 0.528

and \( \left( \frac{P_2}{P_1} \right) = \frac{1.2803 \times 10^6}{1.4458 \times 10^6} = 0.8855 \) which is higher than critical pressure ratio 0.528. Hence another relation for, Z according to equation (5.23)

\[
Z = \sqrt{\frac{2 \times 9.81 \times 1.4}{1.4 - 1}} \left[ \left( \frac{1.2803}{1.4458} \right)^{\frac{2}{14}} - \left( \frac{1.2803}{1.4458} \right)^{\frac{24}{14}} \right]
\]

\[
Z = 2.58
\]

Check:

From Fig.5.3 also the value of Z indicate the same as 2.58.

Compressibility Factor, Z

The compressibility factor, \( Z \), is the measure of deviation from ideal gas behaviour. It is defined as:

\[
Z = \frac{PV}{RT} \quad (5.24)
\]
Fig. 5.3 COMPRESSIBILITY FACTOR CURVE
For an ideal gas \( Z = 1 \) for all pressures and temperatures. Thus the above equation (5.25) is a modification of the ideal gas equation in which the value of the quantity \( \frac{Z - 1}{Z} \) represents the relative deviation from the ideal gas behaviour. (Engineering Thermodynamics by Dwight C. Look, Jr & Harry J. Savet).

In the present work compressibility factor, \( Z \), is obtained from the pressure ratio relation, which has also introduced in the flow meter calibration and fluid flow measurement (NASA SP 125).

A coefficient of discharge, \( C_d \) is assumed as 0.60 (BS 1042). Therefore substituting all the values in equation (5.21) above

\[
10 \times 10^{-3} = \frac{0.60 \pi d^2 \times 1.4458 \times 10^6 \times 2.58}{4 \sqrt{8314.3 \times 288}}
\]

\[
d = \sqrt{\frac{10 \times 10^{-3} \times 1547.43}{0.60 \times 0.7854 \times 1.4458 \times 10^{6.258}}}
\]

\[
d = 2.95 \times 10^{-3} \text{ m}
\]

Adopted a diameter of orifice = 2.87 mm to suit the standard bores of readily available orifice from “Taylor Instruments” calibrated in Taylor Flow Laboratory.

\( C_d \) for gaseous Nitrogen = 0.605

Accuracy = ± 0.5% rate of flow

Thickness, \( t_0 \), of the orifice plate = 0.1 \( D_o \)

\[
= 0.1 \times 26 = 2.6 \text{ mm}
\]

Adopted a thickness = 3.0 mm
Square edged thickness $= 0.05 \times D_o$ \hspace{1cm} (5.26)

$= 0.05 \times 26$

$= 1.30 \text{ mm}$

Angle to downstream side $= 30^\circ$ minimum

Fig. 5.4 illustrate the designed orifice with all dimensions.

In order to avoid turbulence caused by the orifice plate, the pressure measurement tapings are kept at a standard distance from the orifice plate [88,89,90].

Upstream side $= D_o$ to $1.1 \times D_o$ from the orifice plate \hspace{1cm} (5.27)

$= 26 \text{ mm to } 29 \text{ mm}$

Downstream side $= 0.4 \times D_o$ to $0.5 \times D_o$ \hspace{1cm} (5.28)

$= 10 \text{ mm to } 13 \text{ mm}$

Material selected for the orifice plate is AISI 304 stainless steel.

Bleed holes are necessary in orifice plates. In gas flow measurement, these holes would be at the bottom to allow liquid if any remaining in the duct to pass [90,91]. 1.5 mm diameter holes are generally allowed. The following relation can be used to arrive the bleed hole diameter.

$$d = d_m \left[ 1 + 0.55 \left( \frac{d_h}{d_m} \right)^2 \right] \hspace{1cm} (5.29)$$

Where

$$d_m \quad = \quad \text{Measured diameter}$$

$$d_h \quad = \quad \text{bleed hole element}$$

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Fig. 5.4 ORIFICE FLOW METER
Van Der Waals equation of state for real gas,

\[(P + \frac{a}{v^2}) (v - b) = RT \tag{5.30}\]

where

- \(P\) is the up-stream pressure in MN m\(^{-2}\)
- \(a\) and \(b\) are Van Der Waals constants for nitrogen gas
  - \(a = 137450 \text{ N m}^4 \text{ kg}^{-2} \text{ mole}^{-2}\)
  - \(b = 0.0387 \text{ m}^3 \text{ kg}^{-1} \text{ mole}^{-1}\)
- \(v\) = specific volume of the fluid in m\(^3\) kg\(^{-1}\)
- \(R\) = Universal gas constant, 8314.3 kJ kg\(^{-1}\) mole\(^{-1}\) K\(^{-1}\)
- \(T\) = critical temperature of the fluid, ie. 126.2 K

for nitrogen

Applying Van Der Waals equation for,

\[P = \frac{RT}{v - b} - \frac{a}{v^2} \tag{5.31}\]

Substituting

\[P = \frac{8314.3 \times 126.2}{0.84 - 0.0387} - \frac{137450}{0.84^2}\]

\[P = 1.1146 \text{ MN m}^{-2}\]

The pressure indicated by the application of Van Der Waals equation of state (5.31) in the present case is comparable with other published data.

Comparison

With Van Der Waals equation the pressure effect is 1.1146 MN m\(^{-2}\). Rate of flow through the orifice meter with the reduced pressure.

\[G_c = \frac{0.605 \times 0.7854 \times 2.95^2 \times 10^{-6} \times 1.1146 \times 10^6 \times 2.58}{\sqrt{8314.3 \times 288}} \]

\[= 7.6845 \times 10^3 \text{ kg s}^{-1}\]
The difference between the two equations (ideal and Van Der Waal's equation) for the same pressure,

\[
10 - 7.6845 = 2.3155 \text{ gm} 
\]

This difference is due to inaccuracy of the equation of state for ideal gas.

5.7 DESCRIPTION OF TEST EQUIPMENTS

Sweat cooling experimental set-up (P&I diagram) is shown schematically in Fig.5.5. It consists of four basic sub-systems:

(i) Oxy-acetylene torch and its control system
(ii) Gaseous nitrogen cooling system and its control
(iii) Test specimen mounting compartment with water cooling arrangement
(iv) System instrumentation

5.7.1 OXY-ACETYLENE TORCH AND ITS CONTROL SYSTEM

An oxy-acetylene station with torch facility is used as heat source for the present studies. Two gases are mixed in the correct proportion in the welding torch and burned at the end of the torch tip. The orifice size of the torch determines the amount of oxygen and acetylene fed to the flame, the orifice therefore determines the amount of heat produced by the torch. The larger the orifice the greater amount of heat generated.

5.7.2 GASEOUS NITROGEN COOLING SYSTEM AND ITS CONTROL

Gaseous nitrogen in cylinders is used as transpiration cooling gas during the experiment. This is showed in photo-plates of the experimentation. Pressure regulators are used to control the gas pressure in the duct. A solenoid valve is introduced in the flow line to control flow of gas to the main duct. Two pressure gages P1 and P2 are provided at the down stream and up stream sides of the orifice respectively, to monitor the drop in pressure in the orifice to estimate the coolant gas flow.
SUPPLY O2 H2

FUEL REGULATOR

TEST SECTION

T/C

T/C

T/C

GLOBE VALVE

MASS FLOW MEASUREMENT

ORIFICE PLATE

P2

P1

FILTER

DIFFERENTIAL

PRESSURE

MEASUREMENT

COOLING WATER

PRESSURE STEP DOWN REGULATOR

PRESSURE GUAGE

FLOW CONTROL VALVE

SOLENOID VALVE

N2 SUPPLY

Fig. 5.5: SCHEMATIC DIAGRAM OF SWEAT COOLING EXPERIMENT

(P·I DIAGRAME)
5.7.3 TEST SPECIMEN COMPARTMENT WITH WATER COOLING ARRANGEMENT

The test section is the place where the specimen is mounted for conducting sweat-cooling experiment. This section is made two parts. First part is the bottom portion where the specimen pocket is held. This pocket is made in such a way as to hold the specimen with heat insulator rings and cylinders. Behind the specimen pocket there is a button with threaded insulator cup and cone with a disc, is incorporated for taking out the thermocouple lead wires safely. It is sealed with magnesium oxide and sodium silicate cements. A flange with holes is provided to hold the upper part. The second part is the portion consisting of a conical section at the end of the duct. This is to safeguard the oxy-acetylene flame from spreading out. Inside the conical portion, a spiral fluid path is provided to pass cooling water inorder to take away the radiation heat if any emitted from high temperature flame. This is illustrated in the test bed, Fig. 5.1. The bottom of the upper portion has built-in inlet and outlet insulation rings to locate and compress the flanges in position.

5.7.4 SYSTEM INSTRUMENTATION

The temperature measurement on the surface of the sweat-cooled specimen has been carried out by means of a chrom-Alumal thermocouple. The leads of the thermocouple are connected to a datalogger with accuracy of ± 0.1°C. Two thermocouples are installed in the specimen [74]. For the flame side thermocouple installation, 2 holes of 2 mm diameter are drilled and the bottom is flattened, leaving a surface thickness of 0.5mm. The thermocouple lead wires was forced in the drilled holes and the beads are welded at the bottom flat surface by capacitor discharging method. This method of thermocouple installation is illustrated in Fig. 5.6. Small diameter ceramic sleeves are provided in side the drilled holes as insulator for thermocouple lead wires. After these the thermocouple lead wires are taken out through a button provided in the test section which is sealed after with thermal cement. It is then connected with the datalogger. This method of installing the thermocouple was found highly effective. Because of good
Fig. 5.6 TYPICAL THERMOCOUPLE INSTALLATION
contact between the thermocouple bead and the porous specimen metal, it is considered that a reliable measurement of the porous test specimen temperature very near to the surface is obtained by this technique. Photo-plates 5.1 and 5.2 illustrates the installation of thermocouples in the test specimen on either sides.

5.8 FLOW CALIBRATION WITH ORIFICE PLATE FLOW METER

The orifice designed for a maximum flow rate of $11 \times 10^{-3}$ kg s$^{-1}$ of gaseous nitrogen in ambient temperature and pressure is purchased from M/s. Taylor Instruments Company (India) Limited. The integral type orifice is an accurate flow metering element capable of being close coupled with differential pressure gauges on D and D/2 tapings to make a complete, compact flow metering system assembling. M/s. Taylors Flow Laboratory calibrated orifice provides easier, lower cost and simplified installation between flanges, for handling accurate gas flow metering for the present work.

Specifications:

<table>
<thead>
<tr>
<th>Type of bore</th>
<th>concentric sharp edged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside diameter of duct</td>
<td>26 mm</td>
</tr>
<tr>
<td>Orifice opening diameter</td>
<td>2.87 mm</td>
</tr>
<tr>
<td>Coefficient of discharge</td>
<td>0.605</td>
</tr>
<tr>
<td>Method of mounting</td>
<td>between flanges with liner rings</td>
</tr>
</tbody>
</table>

Accuracy:

Calibrated with gaseous nitrogen : ± 0.5% of rate

5.8.1 TEMPERATURE EFFECT

An expansion factor is obtained from the pressure ratio graph which also is introduced in the final flow measuring relation. [87] Refer Fig 5.2 (b) & 5.3 and description in sec. 5.6.
Photo Plate 5.2 Test Specimen Thermocouple Installation for Temperature Measurement (Coolant Side)

Photo Plate 5.1 Test Specimen Thermocouple Installation for Temperature Measurement (Flame Side)
5.8.2 CHECK FOR FLOW CALIBRATION OF ORIFICE FLOW METER

The experimental value of flow coefficient of the orifice meter is 0.61. This value was validated by substituting the relevant design data in following equation (5.21).

\[ G_c = \frac{C_d A P_1 Z}{\sqrt{R T}} \]

Where

\( A \) = Area of cross-section of the orifice, m²
\( P_1 \) = Upstream pressure N m⁻²
\( Z \) = The compressibility factor [87]
\( G_c \) = The flow rate, kg s⁻¹
\( R \) = The Gas constant
\( T \) = The absolute temperature, K

Substituting,

\[ C_d = \frac{10 \times 10^{-3} \sqrt{8314.3 \times 288}}{6.469 \times 10^{-6} \times 1.4458 \times 10^6 \times 2.58} \]

\[ = 0.641 \]

The value of coefficient of discharge provided by M/s Taylor Instrument Company is comparable with the theoretical values, substituting the design parameters in equation (5.21). The variation of coefficient of discharge is only 0.036 (ie. 5 %) which is within the tolerable limit and further, a detailed calibration was carried out in the calibration set-up at LPSC, Valiamala, as described below.

5.9 CALIBRATION METHOD

A flow diagram of the test set-up for the orifice calibration is shown in Fig 5.7. This consists of a water storage tank having provision for pressurisation and delivery of water. The orifice is connected in the flow line and its location is clearly illustrated in the diagram. The time of flow of water through the orifice is controlled by an electronic timer and a solenoid valve circuit. The upstream pressure of the orifice can be read from
Fig. 5.7 EXPERIMENTAL SET UP FOR ORIFICE CALIBRATION
the pressure gauge, $P_2$ as shown. Also for the redundant measurement of upstream pressure, a pressure transducer is also incorporated in the flow line and the output monitored on a digital panel meter. A high precision digital electronic weighing scale (resolution 10 mg) is used for the determination of the weight of water collected during the experiment in the collecting jar.

5.9.1 PROCEDURE

The gas cylinder valve is opened, pressurised the water tank for a known pressure by adjusting the pressure regulator. The solenoid valve is opened for a predetermined time by setting the electronic timer. The mass of water flown through orifice (as shown in diagram) is collected in a beaker. The weight of water collected is also recorded by an electronic weighing scale as mentioned earlier.

5.9.2 CALCULATIONS

Mass of water collected, $W = 1540$ gm

Time taken for collecting, $t = 5$ sec

$\therefore$ Mass flow rate through the orifice (water)

$$G_w = \frac{1540}{5} = 308 \times 10^3 \text{ kg s}^{-1}$$

For calculating the discharge coefficient for gaseous nitrogen:

$$Gc_{N_2} = \frac{C_dA\rho_{N_2}}{\sqrt{\frac{2g\Delta P}{\rho_{N_2}}}}$$

$$Gc_w = \frac{C_dA\rho_w}{\sqrt{\frac{2g\Delta P}{\rho_w}}}$$

(5.30)

$\Delta P$ and $A$ are same for both nitrogen and water.
In the above relation, except GC\(_{N2}\), all other values are known for water and nitrogen. \(Y\) is the expansibility factor for different pressure ratios and diameter ratios (orifice diameter to pipe inside diameter) and it can be read from the graph. (Fig. 5.2b, Page 110) \(\rho_{N2}\) and \(\rho_w\) are the densities of nitrogen and water respectively.

Equating the values:

\[
\frac{GC_{N2}}{GC_w} = \left( \frac{\rho_{N2}Y}{\rho_w} \right) \left( \frac{\rho_w}{\rho_{N2}} \right) = (5.31)
\]

Where

\[
GC_{N2} = 8.482 \times 10^{-3} \text{ kg s}^{-1}
\]

The value of coefficient of discharge obtained in the experiment is very close to Taylors value (0.605) and compares well with theoretical value. The difference between these values are \((0.608 - 0.605) = 0.003\). The difference is 0.49% which is within the tolerable limit and hence the validity of coefficient of discharge is verified as (0.605) and the same introduced for the present sweat cooling experiment as flow metering element.