Bangladesh University of Engineering and Technology

ME 224 (IPE)

Level -3 Term -1

Fluid Mechanics and Machinery Sessional

Credit Hour: 1.5 Cr. Hr. Contact Hour: 3 Hrs

Name of Experiments:

Exp. 1: (a) Verification of Bernoulli's Principle.
(b) Study of pipe friction.
Exp. 2: (a) Study of flow meters.
(b) Study of Minor losses.
Exp. 3: Study of flow through a circular pipe.
Exp. 4: (a) Study and performance test of a Pelton wheel.
(b) Identification of various parts of a hermetically sealed compressor.
Exp. 5: Performance test of a centrifugal pump.
Exp. 6: Study and performance test of a submersible pump.
Exp. 7: Study and performance test of a positive displacement pump.
Exp. 8: (a) Study of centrifugal pumps in series and parallel connections.
(b) Dismantling and assembling of a centrifugal pump.

Experiment No.1

(a) Verification of Bernoulli’s Principle.

(b) Study of pipe friction.

Experiment Outcomes

The objective of this experiment is to verify Bernoull’s equation and investigate the viscous fluid flow through a circular pipe flow, study the flow regimes and determine the friction factor. On completion of the experiment, the students should be able to

1. demonstrate the relationship between pressure head and kinetic head
2. determine the friction factors using the Moody diagram
3. estimate the head loss in a pipe flow

Bernoulli's principle

Bernoulli’s equation for an ideal (inviscid or frictionless) incompressible (density does not change with applied pressure) fluid, irrotational (zero vorticity) and steady flow (does not change the flowrate with time) is given by

$$\frac{P}{\gamma}+\frac{V^2}{2g}+Z=Total\,head\,(H)=\text{Constant}$$

Where, P = pressure

V = fluid velocity

γ = specific weight of fluid

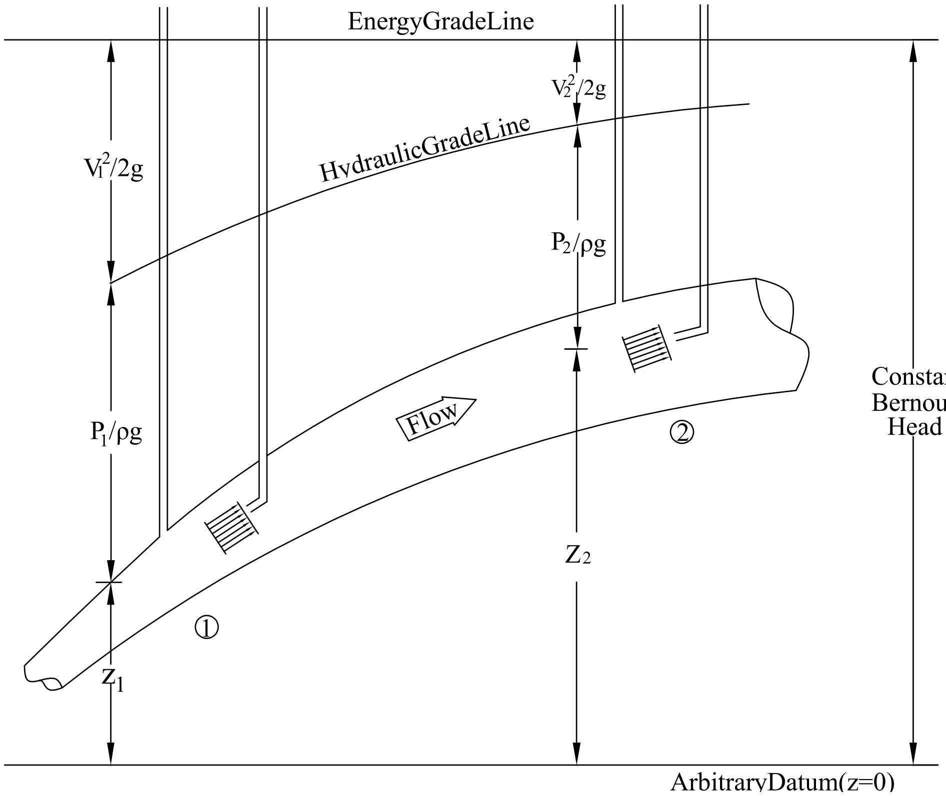
Z = datum head

If there is a head loss H_f, duet to friction, Bernoulli’s equation in this case becomes

$$\frac{P_i}{\gamma}+\frac{V_i^2}{2g}+Z_i=\frac{P_j}{\gamma}+\frac{V_j^2}{2g}+Z_j+H_f$$

Where, subscript i, j indicate the quantities at point i and j in the fluid flow field.

A piezometer tube records the pressure head $\frac{P}{\gamma}$ at the channel centerline. If the datum head is Z, the piezometer tube record $\left(\frac{P}{\gamma}+Z\right)$ above the datum base line. A curve joining the piezometer levels constitutes the hydraulic gradient line. Addition of the total velocity head $\frac{V^2}{2g}$ to the piezometer readings results in the total energy for the incompressible flow.



In more general flow conditions, the EGL (Energy Gradient Line) will drop slowly due to friction losses and will drop sharply due to a substantial loss (a valve or obstructions) or due to work extraction (to a turbine). The EEGL can rise only if there is work addition (as from a pump or propeller). The HGL (Hydraulic Grade Line) generally follows the behavior of the EGL with respect to losses or work transfer, and it rises and/or falls if the velocity decreases and/or increases.

Friction Factor

In fluid dynamics, the head is a concept that relates the energy in an incompressible fluid to the height of an equivalent static column of that fluid. In the case of flow over or through a solid surface (for example: pipe flow), head loss is obvious. This is due to the viscous action (friction) between the fluid and solid surfaces. The viscosity of fluid (μ) is responsible for head loss. This loss is known as *major loss*. Although the head loss represents a loss of energy, it does not represent a loss of total energy of the fluid. The *total energy* of the fluid is conserved. The part of energy which is lost is utilized by the flow to overcome the skin friction drag. In a fully developed laminar pipe flow, the head loss is given by:

$$h_f = \frac{32\mu LV}{\rho g D^2} = \left(\frac{64\mu}{\rho VD}\right)\frac{L}{D}\frac{V^2}{2g} = f\,\frac{L}{D}\frac{V^2}{2g} \tag{1}$$

where, h_f = the head loss (m), f = Darcy friction factor, L = the pipe length (m), D = the hydraulic diameter of the pipe (m), g = the constant for gravitational acceleration (m/s^2) and V = the mean flow velocity (m/s). In this equation, f is the ***Darcy-Weishbach friction factor*** (or commonly known as "*friction factor*") which is given by:

$$f = \frac{64\mu}{\rho VD} = \frac{64}{\mathrm{Re}}$$

where, Re is the Reynolds number giving the ratio of inertia force to viscous force in a flow and frequently defined by:

$$\mathrm{Re} = \frac{\rho VD}{\mu}$$

where, ρ = density of fluid (kg/m3) and μ is the molecular (laminar) viscosity of fluid (Pa.s)

Equation (1) may also be rearranged as

$$h_f = \frac{32\mu LV}{\rho g D^2} = 4\left(\frac{16\mu}{\rho VD}\right)\frac{L}{D}\frac{V^2}{2g} = 4f^{'}\frac{L}{D}\frac{V^2}{2g} \tag{2}$$

In equation (2), f' is the **Fanning friction factor** given by

$$f^{'} = \frac{16\mu}{\rho VD} = \frac{16}{\mathrm{Re}} = \frac{1}{4}f$$

Both Darcy-Weisbach (f) and Fanning friction factors (f') are either read from **Moody diagram** or calculated using various correlations such as **Colebrook equation**.

Experiment 1(a)

Verification of Bernoulli’s Equation

OBJECTIVES

The objective of the experiment is to verify Bernoulli’s equation by demonstrating the relationship between pressure head and kinetic head

Apparatus

i. Bernoulli’s apparatus is used to examine the flow of water through a two-dimensional Perspex convergent-divergent passage of rectangular cross-section with piezometer tubes along its length
ii. A constant level inlet tank to maintain a steady flow and a variable head outlet tank with a control valve
iii. Discharge collection bucket
iv. Stopwatch
v. Platform scale

Schematic Diagram of Experimental Set-up

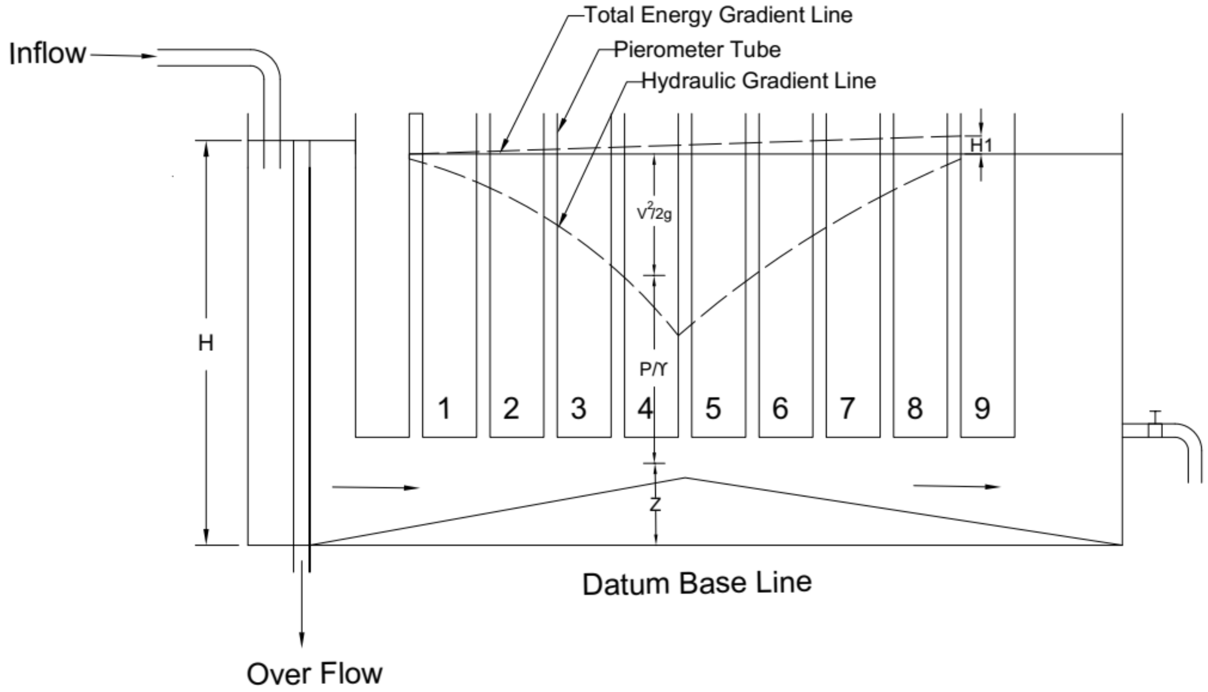


Figure 1.1: Experimental setup of verification of Bernoulli’s equation

Procedure

i. The cross-sectional areas of the channel below the piezometer tubes are measured.
ii. A sheet of paper is placed at the back side of the piezometer tubes.
iii. Set up the apparatus to give a differential head between inlet and outlet tanks.
iv. The flow steadiness is obtained by adjusting the valves. When steady flow occurs the water heads in the piezometer tubes remain constant.
v. The water heads in the inlet and outlet tanks and also the height of the water level in the piezometer tubes are recorded on the paper sheet.
vi. Now water is collected in a bucket for a particular time. Then the weight of the bucket and water is noted from the platform scale.
vii. Take a number of observations by varying the rate of discharge of water.

Data Collection

(Use γ_{water} = 9810 kg/m^3)

Table 1: Data collection for measuring flow rate

Observation No	Weight of empty bucket	Weight of bucket filled with water	Weight of water collected, W	Time of collection of water, t (sec)	Flow rate, $Q = \frac{W}{\gamma t}$ (m^3/s)
1					
2					
3					
4					
5					
6					
7					
8					
9					

Calculation

Table 2: Calculation for estimating total head

Tube position	Cross-sectional area, A (m^2)	Velocity, $V = \frac{Q}{A}$ (m/s)	Velocity head, $\frac{V^2}{2g}$ (m)	Piezometer head, $\frac{P}{\gamma} + Z$, (m)	Total head, $H = \frac{P}{\gamma} + Z + \frac{V^2}{2g}$ (m)
1					
2					
3					
4					
5					
6					
7					
8					
9					

Sample Calculations:

Observation no:

1. Cross sectional area, A =
2. Velocity, $V = \frac{Q}{A} =$
3. Velocity head, $\frac{V^2}{2g} =$
4. Piezometer head, $\frac{P}{\gamma} + Z =$
5. Total head, $H = \frac{P}{\gamma} + Z + \frac{V^2}{2g} =$

Graphical Presentation of Result

Plot the hydraulic gradient and total energy gradient lines. The closeness of total energy at different sections in the channel implies the validity of Bernoulli's equation although it is theoretically valid for steady and ideal flow conditions.

Discussions

The following points need to be addressed accordingly-

- Variation of the total energy line along the flow
- Effect of friction
- Sources and effects of errors in measurements
- Sources and effects of the deviations in calculations
- Improvements required to reduce the discrepancies

EXPERIMENT 1 (b)
Study of pipe friction

OBJECTIVES

The objectives of the experiment are to

- i. measure head loss in a pipe flow at various Reynolds number, Re
- ii. find Darcy-Weisbach friction factor and Fanning friction factor from Moody diagrams and estimate the corresponding head loss
- iii. calculate the hydraulic gradient (h_f/L)

EXPERIMENTAL SET UP

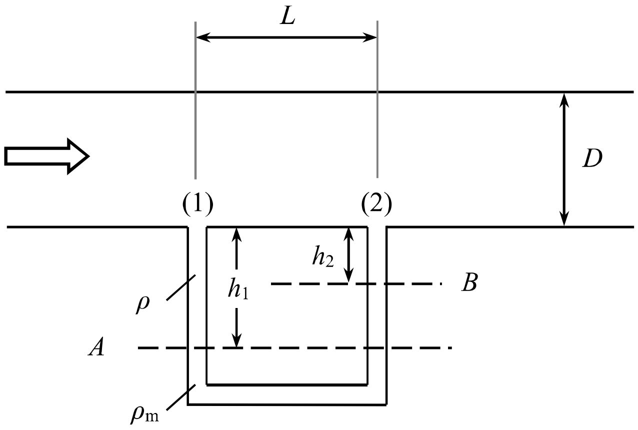


Figure 1.2: Experimental setup for study of pipe friction

DATA COLLECTION

Given data:

Length of the pipe, L =

Diameter of the pipe, D =

Room Temperature, T =

Sp. weight of the flowing fluid, γ =

Sp. weight of the manometric fluid, γ_m =

Density of the flowing fluid, ρ =

Viscosity of the flowing fluid, μ =

Experimental Data:

Table 1. Data for determination of head loss

No. of Obs.	Mass of Water Collected (kg)	Time of Collection (s)	Mass flow rate, (kg/s)	Manometer reading for head loss			Measured head loss, h_f (m of H_2O)
				Left Column (m)	Right Column (m)	Net deflection, h (m)	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Table 2. Data for variation estimating head loss using Moody diagrams

No. of Obs.	Volume flow rate, Q (m^3/s)	Mean velocity, V (m/s)	Reynolds Number, Re	Friction factor from Moody diagram		Estimated head loss, h_f (m of H_2O)	Hydraulic gradient h_f/L
				Darcy	Fanning		
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Sample calculations:

Observation no.:

1. Measured head loss, $h_f = h\left(\frac{\gamma_m}{\gamma} - 1\right) =$

2. Reynolds number, $\mathrm{Re} = \frac{\rho V D}{\mu} =$

   Darcy friction factor, $f =$

   Fanning friction factor, $f_f =$

3. Estimated head loss using Darcy friction factor, $h_f = f\frac{L}{D}\frac{V^2}{2g} =$

4. Estimated head loss using Fanning friction factor, $h_f = 2f_f\frac{L}{D}\frac{V^2}{g} =$

5. Hydraulic gradient, $i = h_f/L =$

GRAPHICAL PRESENTATION OF RESULTS

i) Plot experimentally determined head loss against estimated head loss.

ii) Plot hydraulic gradient (h_f/L) versus velocity (V) in a log-log graph and hence find the value of exponent n to velocity V.

DISCUSSION

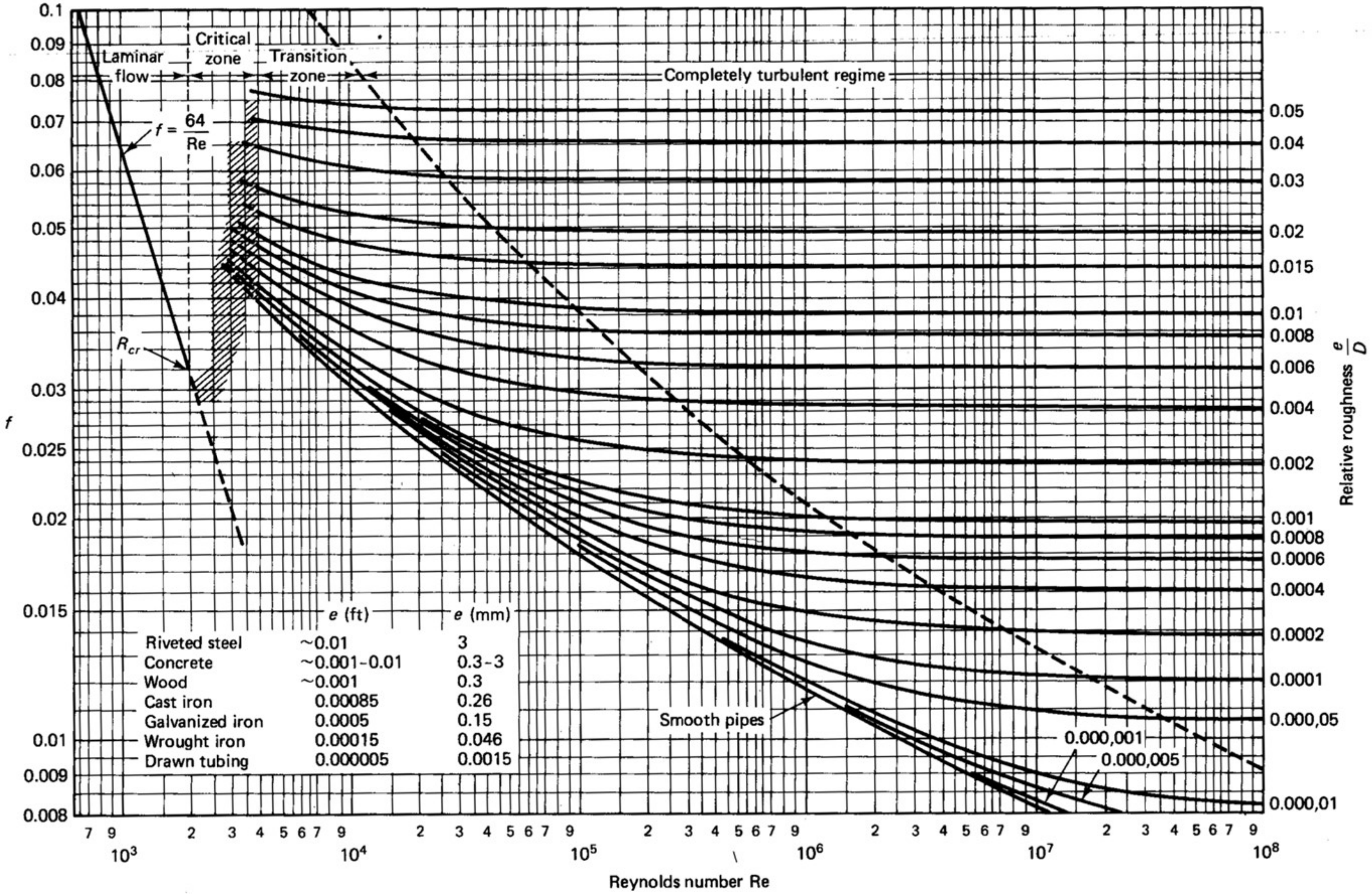
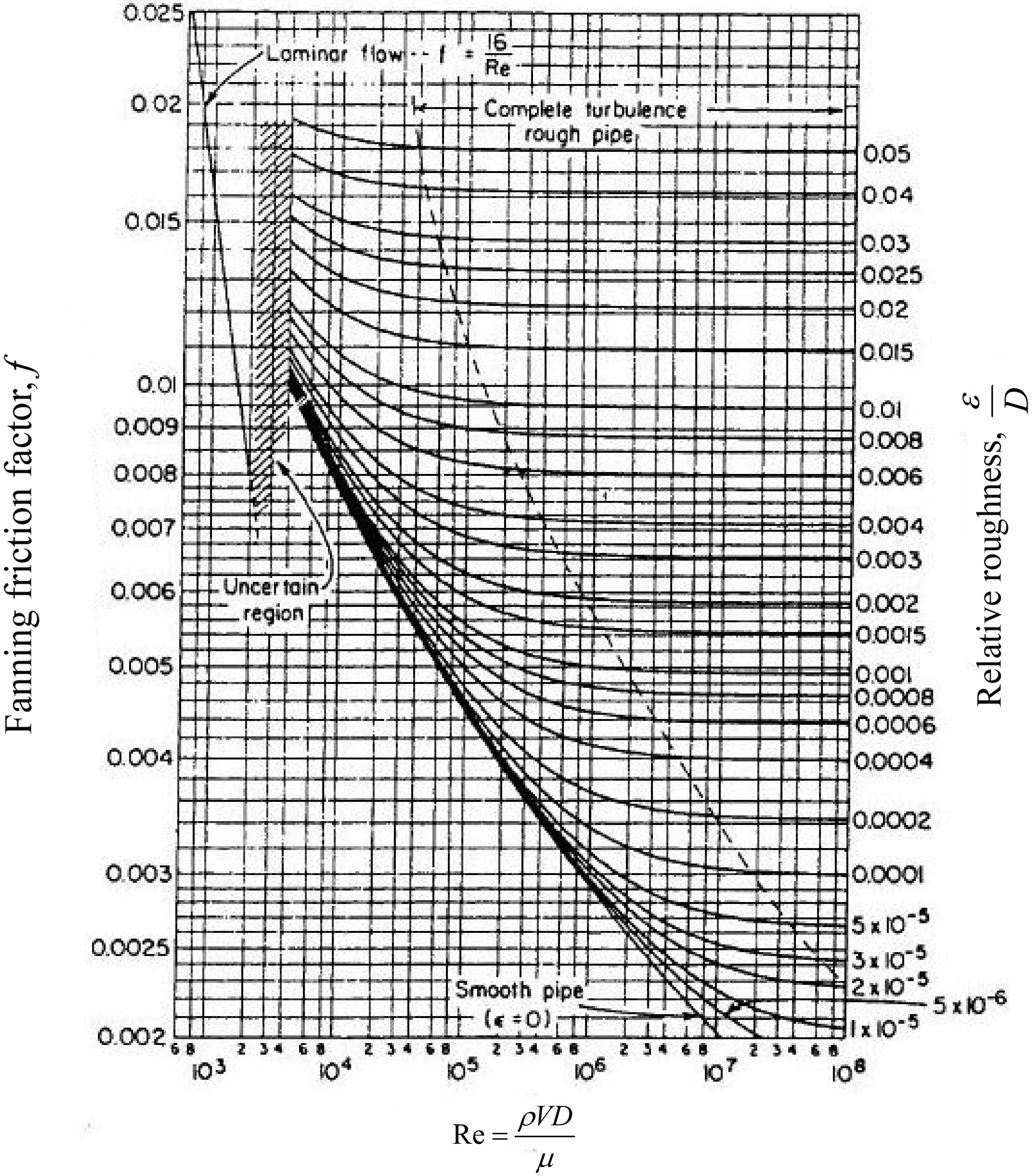


Figure 7.13 Moody diagram. (From L. F. Moody, *Trans. ASME*, Vol. 66, 1944.)


Fanning friction factor, f
Relative roughness, $\frac{\varepsilon}{D}$
$\mathrm{Re} = \frac{\rho V D}{\mu}$
Laminar flow $f = \frac{16}{Re}$
Complete turbulence rough pipe
Uncertain region
Smooth pipe ($\epsilon = 0$)
0.025
0.02
0.015
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.0025
0.002
0.05
0.04
0.03
0.025
0.02
0.015
0.01
0.008
0.006
0.004
0.003
0.002
0.0015
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
5×10^{-5}
3×10^{-5}
2×10^{-5}
5×10^{-6}
1×10^{-5}
10^3
10^4
10^5
10^6
10^7
10^8
6 8 2 3 4 6 8

Experiment No. 2

(a) Study of flow meters

(b) Study of minor losses

Experiment Outcomes

The objective of this experiment is to make students familiar with different types of flow meters and understand the minor losses in a fluid flow. On completion of the experiment, the students should be able to

1. Understand the principle of flow measurement in a pipe flow
2. Calibrate flow meters such as orifice meter
3. Determine the *K* factor for sudden contraction

Principles of flow measurement:

There are many types of flow meters: turbine-type flow meter, rotameter, orifice meter, and venturi meter, etc. In turbine flow meters, a rotor is placed in a flow. The rpm of the rotor varies with flow rate and by measuring the rpm, the flow rate is determined. Rotameters are suitable for measuring flow rate through a vertical pipe. The location of the float in a rotameter depends on the flow rate. Thus, the flow rate is determined by measuring the vertical displacement of the float. The orifice meter is known as pressure-based flow meter (*obstruction type*). This meter reduces the flow area and creates pressure differential which depends on flow rate. Thus, flow rate is determined by measuring the pressure drop.

Minor loss:

Minor losses in a pipe flow come from the change in flow area and (or) direction by different types of fittings. Pipe fittings are always required to complete a hydraulic piping system; for example - sudden contraction, sudden expansion, valves, reducers, bends, elbows, crosses, T-joints, etc. Some of them are shown in figure below:

Minor losses are different from the major losses because these come from the viscous (friction) action between the fluid and the pipe wall. If the pipe is long and the number of pipe fittings is small, the minor loss is small compared to the major loss and may, therefore, be neglected. Even though they are termed “minor”, the losses can be greater than the major losses. For example, when a valve is almost closed, the loss can be almost infinite or in a short pipe with large number of fittings, the minor loss may dominate over the major loss.

Minor losses are directly related to the velocity head in a flow, meaning that the higher the velocity head the greater the losses will be. Unit for minor loss is feet or meters of a fluid column. For any fittings, the minor losses (h_L) are related to the velocity head ($V^2/2g$) by introducing loss coefficients, K as shown below:

$$h_L = K\frac{V^2}{2g}$$

About the experiment

A venturi meter, a orifice meter and a rotameter are arranged in series in the test bench. A compressor is used to flow air through the flow measuring devices. The flow rate is controlled by a gate valve located at the discharge side of the compressor. Pressure drops in orifice meter as well as in the Venturi meter are measured by water manometers and the theoretical flow rates are calculated from these pressure drops. The orifice meter and venturi meter are calibrated comparing the measured flow rate (theoretical) with the actual flow rate measured by the pre-calibrated rotameter.

The same test rig contains arrangement for measurement of pressure drop across a reducer (sudden contraction) as well as across an enlarger (sudden expansion). Head losses across these fittings are calculated from the measured pressure drops. The velocity head is calculated from the flow rate and flow area. The K factors of these fittings are determined from the measured head losses and velocity heads.

EXPERIMENT 2(a)
Study of flow through an orifice meter

OBJECTIVES

The objectives of the experiment are to

1. understand the working principle of orifice meter
2. calculate the mean C_d for orifice meter
3. verify the relation between flow rate and pressure drop in orifice meter by plotting the flow rate against manometer reading (pressure drop) in log-log graph paper.

EXPERIMENTAL SET UP

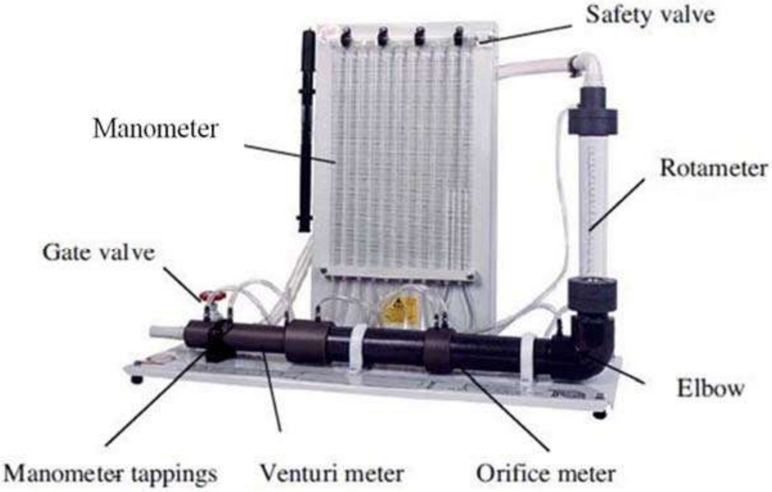


Figure 2.1: A typical test bench for flow measurement device

NECESSARY EQUATIONS

Theoretical flow rate for orifice meter, $Q_T = k_1\sqrt{H_m} = A_o\sqrt{\dfrac{2g\left(\dfrac{\gamma_m}{\gamma}-1\right)}{1-C_C\left(\dfrac{D_o}{D_1}\right)^4}}\sqrt{H_m}$

Actual flow rate, $Q_a = kH^n$

Coefficient of Discharge, $C_d = \dfrac{Q_a}{Q_T}$

Data Collection

Given Data:

Pipe diameter, D_1 =

Orifice diameter, D_0 =

Room Temperature, T_r =

Rotameter absolute pressure, P_R = 1000 mm Aq G

Rotameter absolute temperature, T_R = 303 K

Experimental Data:

Specific weight of mercury =

Specific weight of water =

Specific weight of air =

Table 1: Manometer and Rotameter readings

No. of Observation	Air temp. inside the pipe, Ta (°C)	Manometer reading						Flow rate from rotameter, Q_R, (m^3/min)
		flow pressure in the pipe (Hg manometer)			across the orifice (water manometer)			
		Left column (mm)	Right column (mm)	Net deflection $H_{m,\,Hg}$ (mm of Hg)	Left column (mm)	Right column (mm)	Net deflection $H_{m,\,O}$ (mm of water)	
1								
2								
3								
4								
5								

CALCULATION AND RESULT

Table 2: Calculation of C_d for Orifice meter

No of Obs.	p_a (Pa)	T_a (K)	k_1	Manometric deflection, $H_{m.O}$ (m)	Theoretical flowrate, Q_T (m^3/s)	Actual flowrate, Q_a (m^3/s)	$C_d = \frac{Q_a}{Q_T}$	Mean C_d	From graph	
									n	C_d
1										
2										
3										
4										
5										

Sample calculation for orifice meter:

Observation no:

1. Flow pressure, $p_a = \rho_{Hg} g H_{m,Hg} + p_{atm} =$

2. $k_1 = A_o \sqrt{\dfrac{2g\left(\dfrac{\gamma_m}{\gamma} - 1\right)}{1 - C_C\left(\dfrac{D_o}{D_1}\right)^4}} =$

(assume $Cc = 1.0$)

3. Theoretical flow rate, $Q_T = k_1\sqrt{H_{m,O}} =$

4. Actual flow rate, $Q_a = \dfrac{Q_R \times p_R}{60 \times T_R} \times \dfrac{T_a}{P_a} \times 0.8 =$

where 0.8 is correction factor and p_R = 1000 mm AqG $+p_{atm}$

5. Coefficient of discharge, $C_d = \dfrac{Q_a}{Q_T} =$

GRAPHICAL PRESENTATION OF RESULTS

(i). **Relation between flow rate and pressure drop across a flow meter:**

Draw the Q_a vs H_m curve in log-log graph paper for both orifice meter

Results:

Value of C_d for orifice meter =

DISCUSSION

EXPERIMENT 2(b)

Study of minor losses

OBJECTIVES

The objectives of this experiment are

1. to measure the minor loss in a sudden contraction fittings
2. to determine the loss coefficients or *K* factors for the sudden contraction

EXPERIMENTAL SET UP

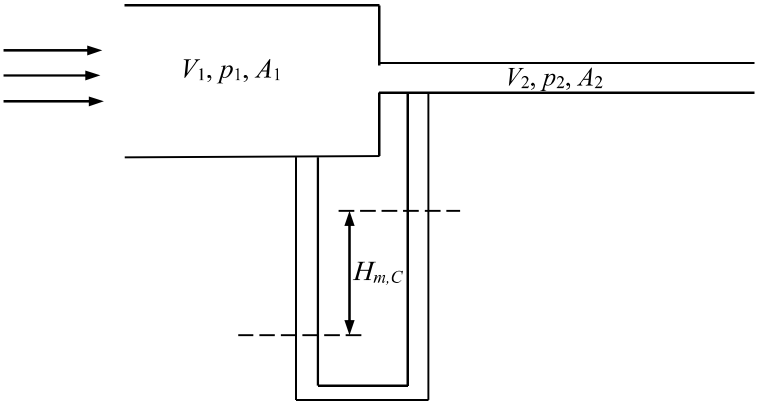


Figure 2.2: Sudden contraction

Experimental data:

Pipe diameter at inlet, $D_1 =$

Pipe diameter at contraction, $D_2 =$

Room temperature, $T_r =$

Absolute pressure at Rotameter, $p_R = 1000$ mm Aq G

Absolute temperature at Rotameter, $T_R = 303$ K

Table 4: Manometer and Rotameter readings for pipe fittings

No. of Observation	Air temp. inside the pipe, *Ta* (˚C)	Manometer reading						Flow rate from rotameter, Q_R, (m^3/min)
		flow pressure in the pipe (Hg manometer)			across the contraction (water manometer)			
		Left column (mm)	Right column (mm)	Net deflection $H_{m, Hg}$ (mm of Hg)	Left column (mm)	Right column (mm)	Net deflection $H_{m, C}$ (mm of water)	
1								
2								
3								
4								
5								

Calculation and Result

Table 5: Determination of *K* factor for sudden contraction

No. of Observation	P_a (Pa)	T_a (K)	P_a (kg/m^3)	Actual flow rate Q_a (m^3/s)	$V^2_1/2g$ (m of H_2O)	$V^2_2/2g$ (m of H_2O)	h_L, contraction	*K* factor
1								
2								
3								
4								
5								

Sample calculation:

Observation No.

1. Flow pressure, $p_a = \rho_{Hg} g H_{m,Hg} + p_{atm} =$

2. Density of air at T_a, $\rho_a =$

3. Actual flow rate, $Q_a = \dfrac{Q_R \times p_R}{60 \times T_R} \times \dfrac{T_a}{P_a} \times 0.8 =$

where 0.8 is correction factor and p_R = 1000 mm AqG $+p_{atm}$

4. Velocity at section 1, $V_1 = \dfrac{Q_a}{\dfrac{\pi}{4} D_1^2} =$

   Velocity head at section 1 = $V_1^2/2g =$

5. Velocity at section 2, $V_2 = \dfrac{Q_a}{\dfrac{\pi}{4} D_2^2} =$

   Velocity head at section 2 = $V_2^2/2g =$

6. Head loss due to sudden contraction, $h_{L,contraction} = H_{m,C}\left(\dfrac{\rho_w}{\rho_a} - 1\right) + \dfrac{V_1^2 - V_2^2}{2g} =$

7. K factor for contraction =

GRAPHICAL PRESENTATION OF RESULTS

(i) **Determination of *K* factor from graph:**

Plot on a log-log paper head loss against velocity head for sudden contraction. Determine the *K* factors from the slopes of the curves.

(ii) Compare the *K* factors calculated in Table 5 with those obtained from the graphs.

DISCUSSION

Experiment No. 3

Study of Flow through a Circular Pipe

EXPERIMENT OUTCOMES

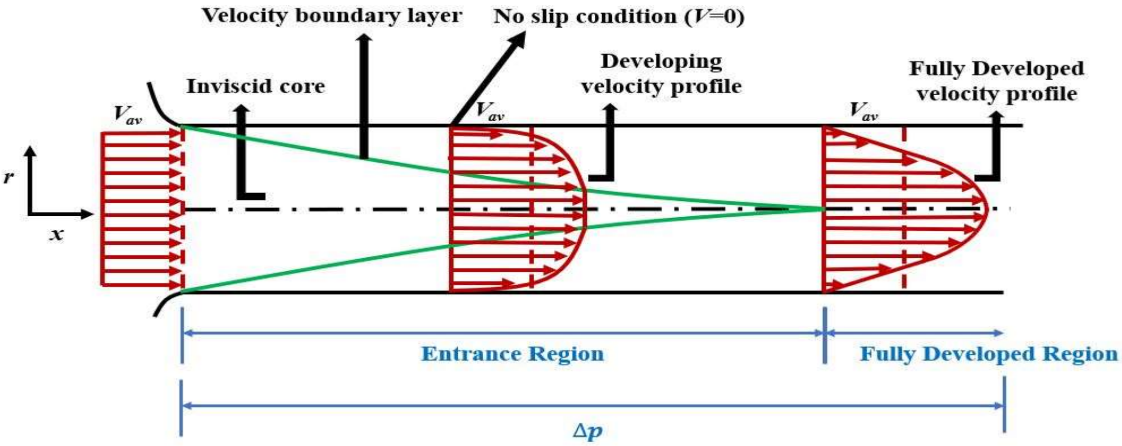
The objective of this experiment is to demonstrate the velocity variation at throat and different radii of a circular pipe when air flows through that pipe. On completion of the experiment, the students should be able to

- Understand physical description of internal flow and the velocity boundary layer.
- Visualize the velocity distribution around a circular pipe due to the fluid flow.
- The concept of laminar and turbulent flow in a circular pipe.

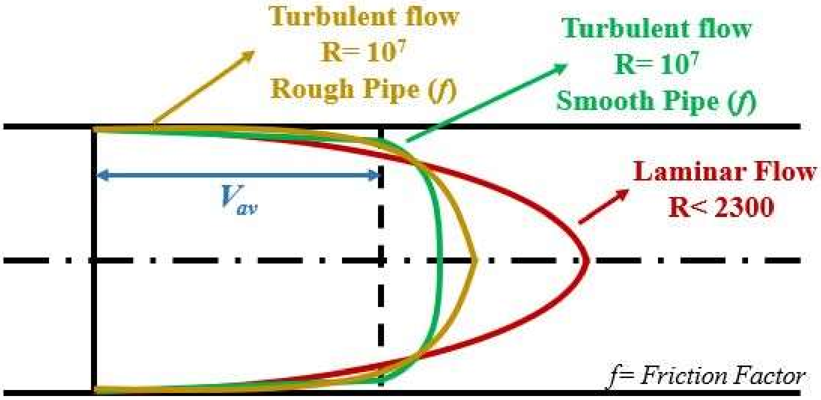
FLOW THROUGH A CIRCULAR PIPE

Concept of Velocity Boundary layer

For an internal flow as such the current study, when a fluid enters a circular pipe at a uniform velocity, the fluid particles at the boundary of the pipe come to a complete rest because of the no-slip condition. As a result, the fluid particles in the adjacent layers slow down gradually due to friction. To keep the mass flow rate through the pipe constant, the velocity of the fluid at the midsection of the pipe increases to make up for the velocity reduction. Thus, a velocity gradient develops along the pipe. The region of the flow in which the effects of the viscous shearing forces caused by fluid viscosity are felt is called the velocity boundary layer. The hypothetical boundary surface divides the flow in a pipe into two regions: the boundary layer region, in which the viscous effects and the velocity changes are significant, and the inviscid (core) flow region, in which the frictional effects are negligible and the velocity remains essentially constant in the radial direction. The region from the pipe inlet to the point at which the boundary layer merges at the centerline is called the hydrodynamic entrance region.



The region beyond the entrance region in which the velocity profile is fully developed and remains unchanged is called the hydrodynamically fully developed region. The velocity profile in the fully developed region is parabolic in laminar flow and somewhat flatter (or fuller) in turbulent flow due to eddy motion and more vigorous mixing in the radial direction. However, in fluid flow, it is convenient to work with an average velocity V_{av}, which remains constant in incompressible flow when the cross-sectional area of the pipe remains constant and fluid properties evaluated at some average temperature are also treated as constants.



Criteria:

Fluid flow regime is mainly characterized by the ratio of inertial forces to viscous forces in the fluid. This ratio is called the Reynolds number and is expressed for internal flow in a circular pipe as

$$Re = \frac{intertia\ force}{viscous\ force} = \frac{\rho V_{av} D}{\mu}$$

where V_{av} = average flow velocity (m/s), D = characteristic length of the geometry (diameter in this case, in m), and μ/ρ = kinematic viscosity of the fluid (m^2 /s).
As a general criterion, for flow through smooth pipes,
Re < 2300 signifies the flow to be laminar
Re > 4000 signifies the flow to be turbulent.
At large Reynolds numbers, the inertial forces are large relative to the viscous forces, and thus the viscous forces cannot prevent the random and rapid fluctuations of the fluid. At small or moderate Reynolds numbers, however, the viscous forces are large enough to suppress these fluctuations and to keep the fluid "in line." Thus, the flow is turbulent in the first case and laminar in the second.

ABOUT THE EXPERIMENT

In this experiment, ambient air driven primarily by a pressure difference is passed through a parabolic nozzle to the circular pipe. Velocity of the flowing fluid at the throat of the parabolic nozzle is then calculated from the manometric deflection of the water manometer (For the constant operating speed of 3800 rpm). Further down the circular pipe a pitot traverse is located in a perspex box. Linear distance travelled by the traverser after each full revolution represents the radial location in the circular pipe and a corresponding manometric deflection is obtained from the inclined water manometer connected to the pitot tube. Thus, velocity profile in circular pipe is obtained.

Study of flow through a circular pipe

OBJECTIVES

The objectives of the experiment are to

i) To measure the velocity of flowing fluid
  - At the throat of the inlet nozzle
  - At various radii of the circular pipe.

ii) To find the flow rate of flowing fluid.

iii) To compare the discharge obtained graphically (V vs r^2) with that obtained through the parabolic nozzle.

APPARATUS

Apparatus used in this experiment are:

i) A smooth long pipe
ii) A parabolic nozzle at the inlet of the pipe
iii) A suction fan at the outlet of the pipe
iv) Three (air-water) manometers one at nozzle and other at pitot tube
v) Pitot tube with traverse mechanism
vi) Static pressure tube at various distances

EXPERIMENTAL SET UP

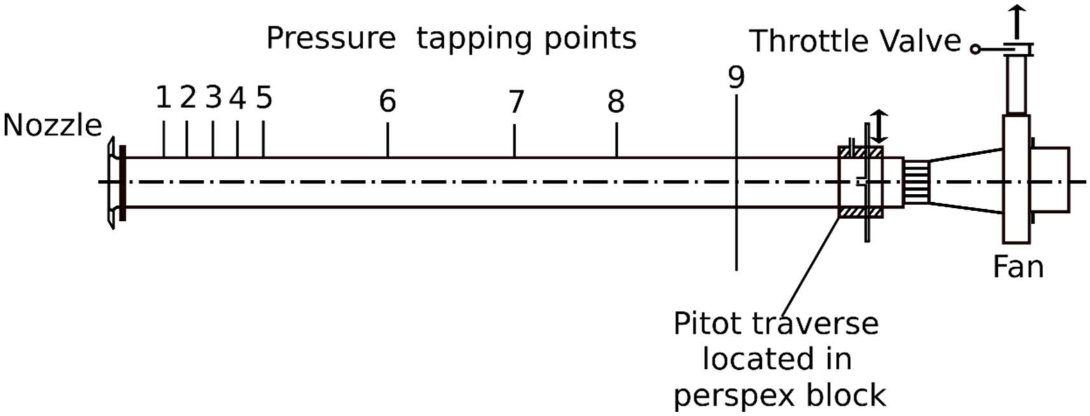


Figure: Experimental set-up of flow through a circular pipe

DATA COLLECTION

Given Data:

Nozzle throat diameter = 2 inch = 5.08 $*10^{-2}$ m

Pipe diameter = 3.1 inch = 7.87$*10^{-2}$ m

Pitot tube diameter = 1.2$*10^{-2}$ m

Linear distance travelled by the traverser after one full revolution= 0.1 inch = 2.54 mm

Co-efficient of discharge of the nozzle, C_d = 0.98

Universal gas constant, R = 287 Nm/KgK

Barometric pressure, P (Pa) =

Room temperature, T (K) =

Density of air, ρ_{air} (kg/m^3) =

Viscosity of air, μ_{air} (N.s/m^2) =

Specific weight of water γ_w (N/m^3) =

Experimental Data:

Table 1. Data for Velocity of Flowing Fluid at the Throat of the Parabolic Nozzle (For the constant operating speed of 3800 rpm)

Observation Position	Manometric Deflection, H_w (m of water)	Velocity of Air, V_{th} (m/s)
Throat		

Table 2. Data for Velocity Profile in Circular Pipe (Measuring with pitot tube)

No. of Observations	No. of Revolutions	Radial Location ,r (mm)	r^2 (mm^2)	Manometric Deflection, (m of water)	Velocity of Air (m/s)
1					
2					
3					
4					
5					
6					
7					
8					
9					

10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					

CALCULATIONS AND RESULTS

Sample Calculation:

Observation no.

Manometric deflection, H_w (m of water), at throat =

Manometric deflection, H_w (m of water), using pitot tube =

Throat velocity, $V_{th} = \sqrt{\frac{2\Delta P}{\rho_{air}}} = \sqrt{\frac{2H_w\,\gamma_w}{\rho_{air}}} =$

Nozzle throat cross-sectional area, $A_{th} = \pi\frac{(throat\ dia.)^2}{4} =$

Flow rate of nozzle, $Q_{nozzle} = C_d * A_{th} * V_{th}$

$=$

Velocity at a radial location , $V_r = \sqrt{\frac{2H_w \gamma_w}{\rho_{air}}}$ =

Discharge obtained graphically, Q_{graph} = π * area under the curve (V vs r^2)

= (using Trapezoidal rule)

=

Cross sectional area of the pipe, $A_p = \pi \frac{(pipe\ dia.)^2}{4}$ =

Average velocity, $V_{av} = \frac{Q_{nozzle}}{A_p}$ =

Reynolds number, $Re = \frac{\rho D V_{av}}{\mu}$ =

% of error in flow rate = $\left|\frac{Q_{nozzle} - Q_{graph}}{Q_{nozzle}}\right| * 100\%$ =

GRAPHICAL PRESENTATION OF RESULTS

i) Plot the velocity profile along the radius of the circular pipe (*r* vs *V)*.

DISCUSSION

Experiment no. 4(a)

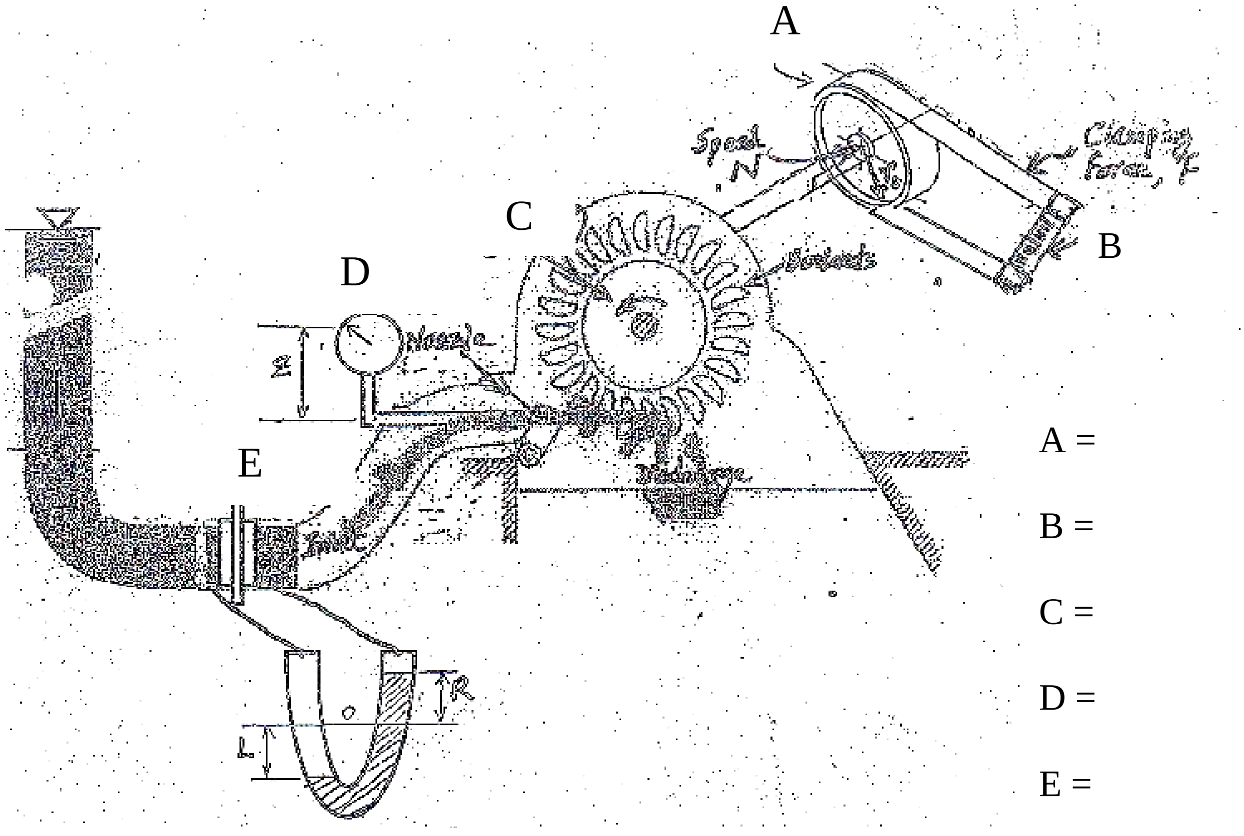
Name of the Experiment: Study and Performance test of a Pelton Wheel.

Objectives:

- To study the working principle of a Pelton wheel.
- To determine the performance parameters of the Pelton wheel.
- To plot efficiency vs speed, discharge vs speed, P_{out} vs Speed, efficiency vs P_{out} curve of a Pelton wheel.
- To calculate the specific speed of a Pelton wheel.

Apparatus:

Schematic diagram:



A =

B =

C =

D =

E =

Fig. Experimental set up of performance test of a Pelton wheel.

Data from the experiment:

No. of obs.	Manometer Reading			Spring Scale Reading (Kg)	Force, F (N)	Speed of the Pelton wheel (N)	
	Left (L) inch	Right (R) inch	Net Deflection (inch)			rpm	Rad/s

Data Obtained from calculation:

No. of obs.	Torque (T) Nm	Power output (Po) Watt	Pressure Head (h) m	Discharge (Q) (Cusec × 102) m ^{3}/hr	Efficiency (η)%

Sample calculations:

Dynamometer wheel radius, r = 4 inch = m

Pressure Head correction, Z = 1.1 m

Pelton wheel rotor radius, R =

Pelton wheel speed, N = rpm

$$\omega = \frac{2\pi N}{60} \text{ rad/s}$$

Torque, T = F×r Nm

Output power, $P_o = T\omega$

Pressure head, h=P/γ psi + Z (m)

= (P×144/62.4)/3.28 +Z (m)

Discharge, Q = 0.024×√(L+R) cusec

=

= m^3/hr

Input hydraulic Power, $P_i = \Upsilon Q h$

Efficiency, $\eta = \frac{Po}{Q\Upsilon H} \times 100$ %

Speed ratio, $\phi = \frac{\omega R(peripheral\ velocity\ of\ rotor)}{Cv\sqrt{2gh}(fluid\ velocity\ at\ nozzle\ tip)}$

Specific Speed, $N_s = \frac{N\sqrt{Pout}}{H^{5/4}}$ where, N (rpm), P_{out} (KW), H(m)

- **Plot the characteristic curve of the Pelton wheel.**

Discussion:

Experiment no: 4(b)

Experiment Name: Identification of Various Components of a Hermetically Sealed Compressor.

Introduction:

A compressor is a mechanical device that increases the pressure of a gas by reducing its volume. Compressors are similar to pumps in the aspect that both increase the pressure on a fluid and both can transport the fluid through a pipe. Compressors can be of positive displacement or rota-dynamic type.

The compressor in this experiment is a positive displacement type reciprocating compressor. This type of compressors is typically used in household refrigerators. The intake gas enters the suction manifold, then flows into the compression cylinder where it gets compressed by a piston driven in a reciprocating motion via a crankshaft, and is then discharged. The compressor is generally driven by an electric motor. In a hermetically sealed compressor, the motor compressor assembly is packed in an air-tight compartment.

Fig.1 : Various components of a hermetically sealed compressor

1. Housing with connectors and baseplates	**2.** Top cover	**3.** Blocks with a stator bracket	**4.** Stators (with screws)
5. Rotors	**6.** Valve units (screws, cylinder cover, gaskets, valve plate)	**7.** Crankshafts with grommet	**8.** Connecting rods with a piston
9. Oil pickup tubes	**10.** Springs with suspensions	**11.** Internal discharge tubes (screw, washer, gasket)	**12.** Start equipment (PTC device, cover, cord relief)

Objectives:

1. To observe different components of a hermetically sealed compressor.
2. To understand the working principal of these parts and identify them.

Report Writing:

1. Identify and write down the function of the various components of the hermetically sealed compressor shown in the lab.
2. Differentiate between components of figure no. 01 and the hermetically sealed compressor shown in lab.
3. Find out any missing components of hermetically sealed compressor that you think should be there in lab.

Experiment no. 5

Name of the experiment: Performance test of a centrifugal pump

Experiment no. 5

Name of the experiment: Performance test of a centrifugal pump

Objectives:

To study the performance characteristics of the pump at constant speed when varying the flowrate.

Apparatus:

Schematic diagram:

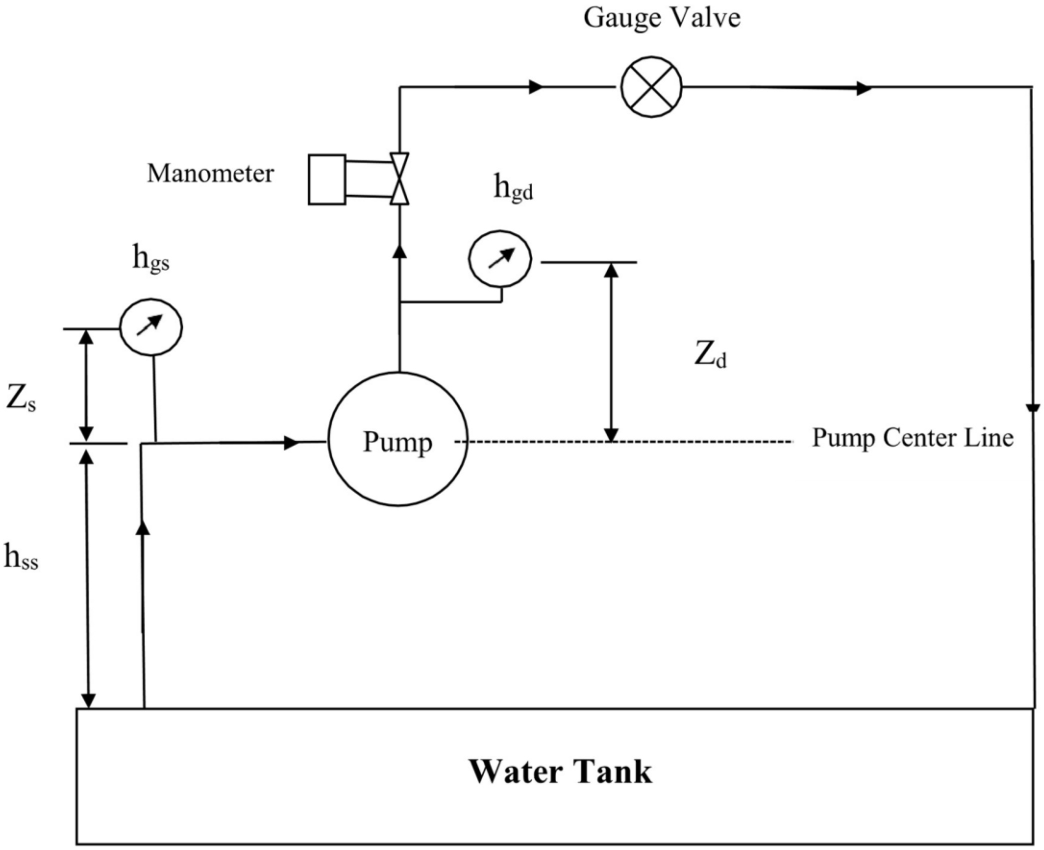


Figure 5: Schematic Diagram of Centrifugal Pump Test

Data Collection:

Operating speed, N = rpm

Suction pipe dia. d_s = m

Delivery pipe dia. d_d = m

No of Obs.	Suction Pressure, $h_{g,s}$		Delivery Pressure, $h_{g,d}$		Total Head (m of H_2O)	Manometer reading			Flow rate, Q (m^3/s)
	inch Hg	m of H_2O	Kg/cm^2	m of H_2O		Left, L (cm)	Right, R (cm)	Net deflection, ΔH (m)	

Calculation:

Manometer Net Deflection, $\Delta H = L + R =$ (cm)

$=$ (m)

Flow rate, $Q = 0.015 \times \sqrt{\Delta H}$ (m^3/s) =

Here,

Pressure gauge reading in suction side, $h_{g,\,s}$ =

Pressure gauge reading in delivery side, $h_{g,\,d}$ =

h_s = vertical distance of the pressure gauge in the suction side from the pump horizontal centerline = Z_S = m

h_d = vertical distance of the pressure gauge in the delivery side from the pump horizontal centerline = Z_d = m

Velocity at the suction side, $v_s = \dfrac{Q}{\frac{\pi d_s^2}{4}}$

Velocity at the delivery side, $v_d = \dfrac{Q}{\frac{\pi d_d^2}{4}}$

Total Head, $H_t = \left(h_{g,d} + \dfrac{v_d^2}{2g} + h_d\right) - \left(h_{g,s} + \dfrac{v_s^2}{2g} + h_s\right)$

Input Power, $P_i =$

Output Power, $P_o = Q\gamma H_t$

Efficiency, $\eta = \dfrac{P_o}{P_i} \times 100\%$

Calculation Table:

Obs. No.	N (rpm)	Total head, H (m)	Discharge, Q (m^3/s)	Input power, P_i (Watt)	Output power, P_o (Watt)	Efficiency, η

Discussions:

(Discuss the experimental pump characteristic curve. Also, compare it with ideal pump characteristic curve. Discuss the possible source of deviations in your results.)

Experiment No. 6

Name of the Experiment: Study and performance test of a submersible pump

Experiment No. 6

Name of the Experiment: Study and performance test of a submersible pump

Objectives:

- To study the working principle of a submersible pump.
- To determine the performance parameters of a submersible pump.
- To plot the characteristic curve of a submersible pump and find its duty point.
- To calculate the specific speed of a submersible pump.

Apparatus:

Schematic diagram:

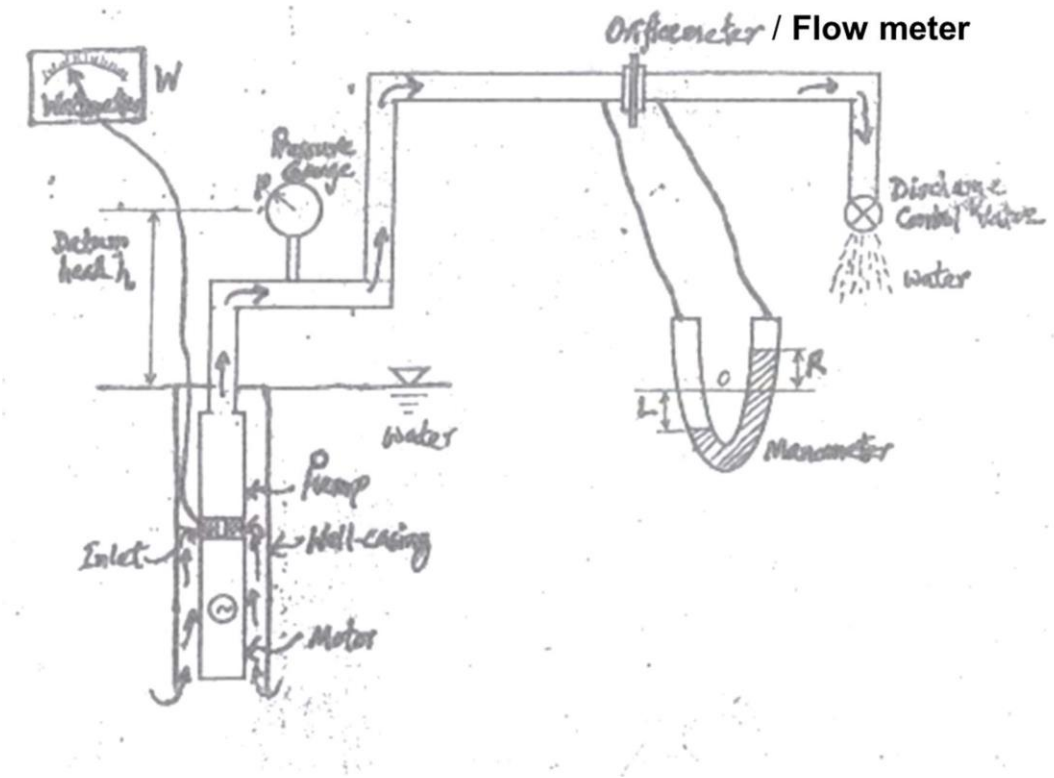


Figure 6: Schematic diagram of a submersible pump test

Experimental measurement data:

Datum Head of the PG (Pressure Gauge), H_0 = (m)
PG calibration Equation:
Flowmeter calibration equation:
Wattmeter calibration equation:

No. of Obs.	Flow meter reading		Pressure gauge reading (Psi)	Input power, P_{in} Wattmeter reading (kW)
	Vol (lit)	Time (s)		

Calculated data:

No. of Obs.	Flow rate/discharge, Q		Head, H (m)	Input power, P_{in} (kW)	Output power, P_{out} (kW)	Overall efficiency, η (%)
	lit/min (lpm)	m^3/s (cumec)				

Sample calculation:

1. Discharge, Q = vol/time = lit/s

= lit/min

Actual discharge, Q = lit/min [use calibration equation]

Actual discharge, Q = m^3/s

2. Head, $H = \frac{p}{y^{0}} + H$ = m of Water [use calibration equation]

3. Input Power, P_{in} = kW [from Wattmeter]

Actual Input Power, P_{in} = kW [use calibration equation]

4. Output power, P_{out} = yQH kW

5. Overall efficiency, η = $\frac{P_{out}}{P_{in}} \times 100$ %

6. Specific speed (at best efficiency point), $N_s = \frac{N\sqrt{Q}}{H^{3/4}}$

Graphical presentation:

Plot the characteristics curve of a submersible pump (H, P_{in}, η vs. Q) and find its duty point at maximum efficiency, η_{max}.

Experiment No. 7

Name of the Experiment: Study and performance test of a positive displacement pump

Experiment No. 7

Name of the Experiment: Study and performance test of a positive displacement pump

Objective:

To find the pump performance for a range of delivery pressures (varied load) at a constant speed.

Apparatus:

Experimental Setup:

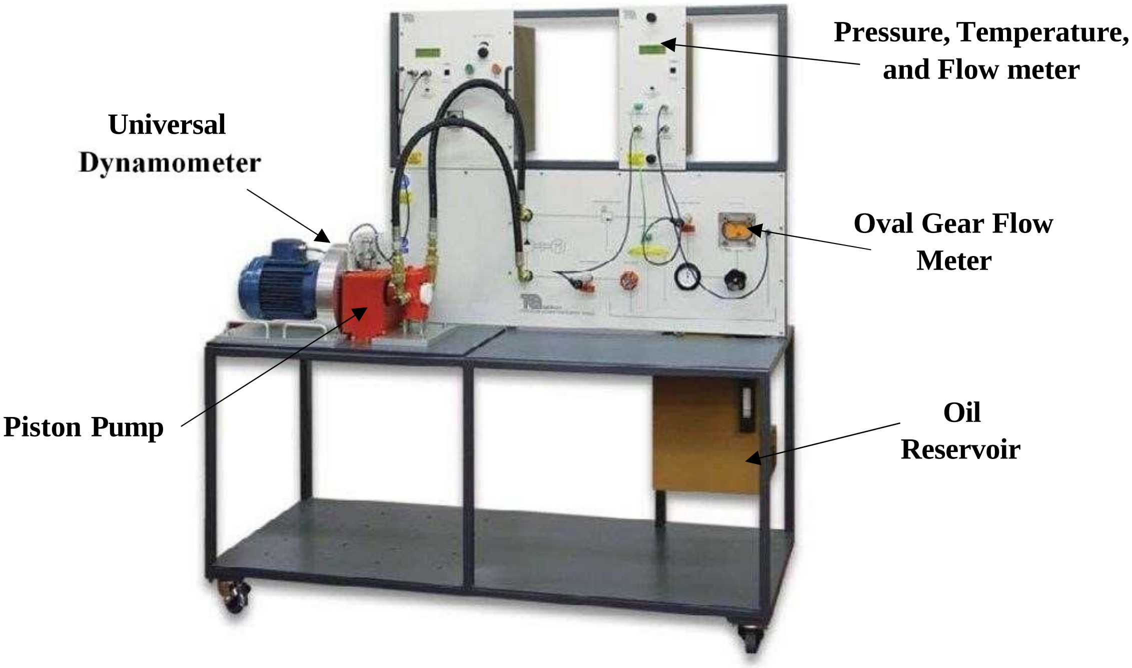


Figure 7(a): Positive displacement pump module

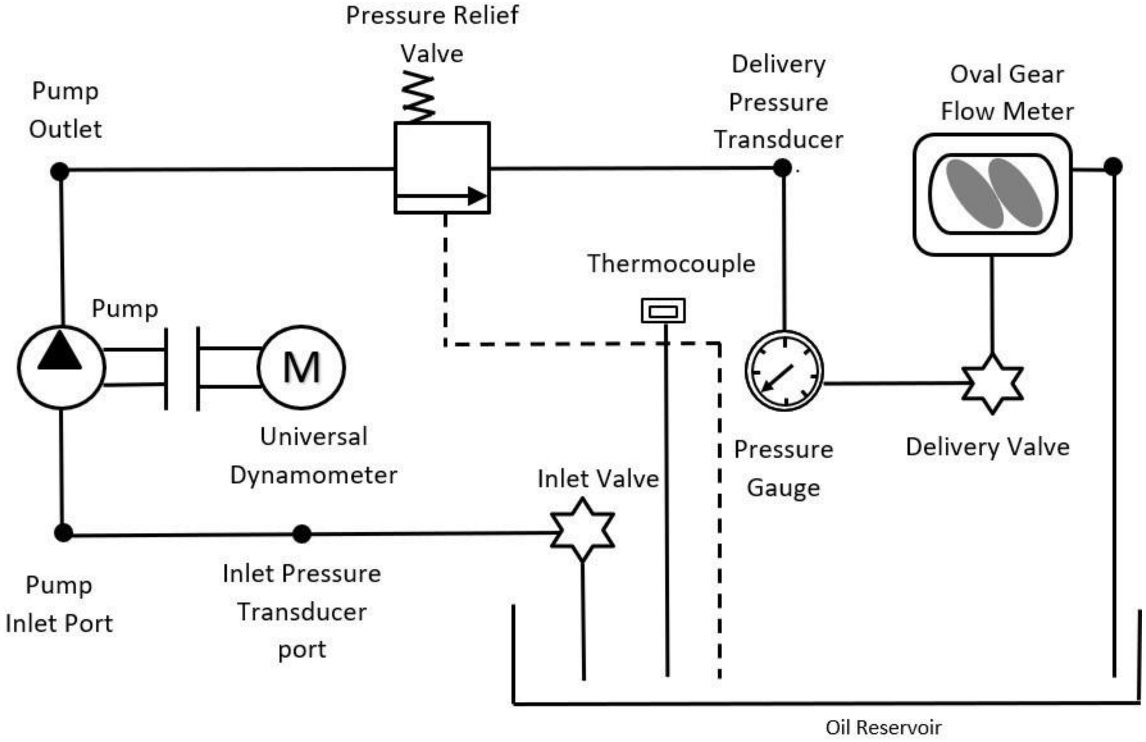
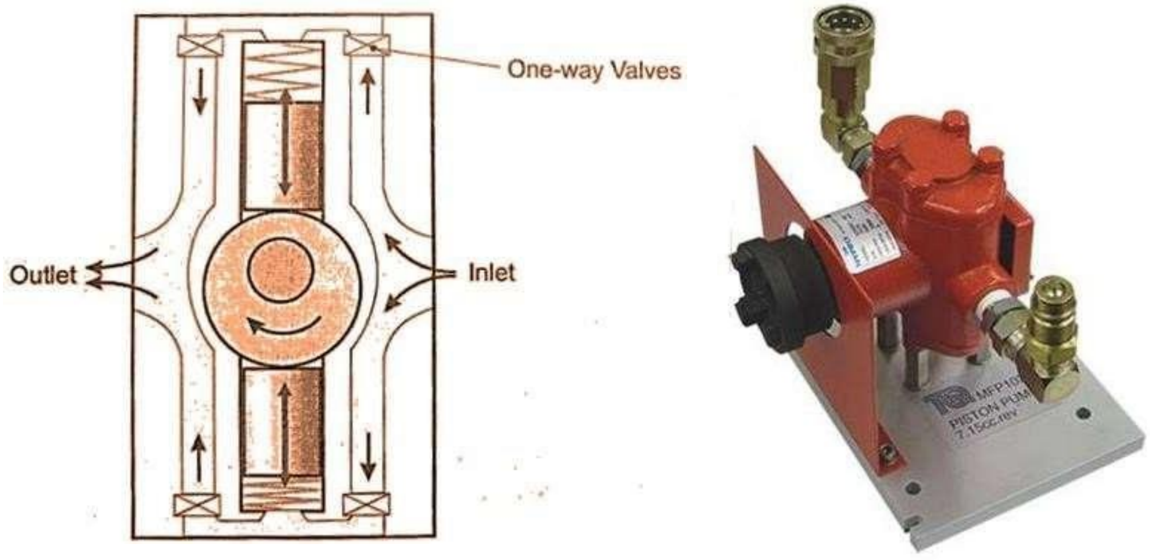


Figure 7(b): Schematic diagram of piston pump setup



Piston Pump Working Action

Piston Pump (TQ MFP103a)

Figure 7(c): Piston pump

Experiment: 7(a)

Experiment Name: Effect of delivery pressure at constant speed

Experiment: 7(a)

Experiment Name: Effect of delivery pressure at constant speed

Objective:

To find the pump performance for a range of delivery pressures (varied load) at a constant speed.

Procedure:

- Fit the pump according to the instructions (i.e., video).
- Fully open inlet and delivery valves.
- Use button on the pressure display to zero all the pressure readings.
- Zero the torque reading of the MFP100 Universal Dynamometer.
- Press the start button on the Motor Drive and run the speed to 1600 rpm (+/- 5 rpm) for at least five minutes and monitor the oil temperature until it stabilizes. Check that any air bubbles have moved away from the flowmeter.
- Record the speed and oil temperature.
- Slowly shut the delivery valve and maintain the speed until the delivery pressure reaches 2 bar. Allow a few seconds for conditions to stabilize. Record the indicated flow and pressures.
- Continue increasing the delivery pressure in 1 bar steps (while keeping the speed constant) to a maximum of 15 bar. At each step, allow a few seconds for conditions to stabilize and record the indicated flow and pressures.
- (Optional) Repeat the test at two other lower speeds (1200 rpm and 800 rpm are recommended)

Data from experiment:

Swept Volume, $V_s = 0.00715$ L/rev

Speed, $N_P =$ rpm,

Expected Flow = L/min

Oil Temperature, $T_1 =$ (at Start), (at end)

Data Table:

Obs. No	Delivery Pressure P_2 (bar)	Inlet Pressure P_1 (bar)	Pressure Difference ΔP, (Bar)	Pressure Difference ΔP, (Pa)	Flow Rate Q_v, (L/min)	Shaft Power W_D, (W)	Hydraulic Power W_P, (W)	Overall Efficiency η_P, (%)	Volumetric Efficiency η_v, (%)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									

Calculation:

1. Mechanical Power (into the pump), W_D =

2. Hydraulic Power (from the pump), $W_P = (P_2 - P_1)\, Q_v$ =

3. Overall Pump Efficiency, η_P =

4. Swept Volume V_S =

5. Expected Volume Flow rate = $V_S \times N_p$ =

6. Volumetric Efficiency, $\eta_V = Q_v / (V_S \times N_p) \times 100$ =

Discussion:

- Compare the Flow rate, Shaft power, Volumetric efficiency, and Overall efficiency with Pressure difference.
- Create one chart with two vertical axes, one for flow rate and other one for volumetric efficiency, overall efficiency, and shaft power.
- Discuss the individual parameters behavior with the change of pressure difference.
- If the test is run at other speeds, repeat the above discussions, and compare them.

Experiment: 7(b)

Experiment Name: Effect of speed at constant speed delivery pressure

Experiment: 7(b)

Experiment Name: Effect of speed at constant speed delivery pressure

Objective:

To find the pump performance for a range of speeds at a constant delivery pressure (load).

Procedure:

- Fit the pump according to the instructions (i.e., video).
- Fully open inlet and delivery valves and use button on the pressure display to zero all the pressure readings.
- Zero the torque reading of the MFP100 Universal Dynamometer.
- Press the start button on the Motor Drive and run the speed to 1600 rpm (+/- 5 rpm) for at least five minutes and monitor the oil temperature until it stabilizes.
- Wait for any trapped air bubbles to move from the flowmeter.
- Slowly shut the delivery valve and maintain the speed until the delivery pressure reaches 15 bar.
- Allow a few seconds for conditions to stabilize. Record the speed, oil temperature, the indicated flow (from display) and pressures.
- Reduce the speed by 100 rpm while adjusting the delivery pressure to keep it constant at 15 bar. Allow the conditions to stabilize and record the indicated flow and pressures.
- Continue decreasing the speed in 100 rpm steps (while keeping the pressure constant) until you reach 800 rpm. At each step, record the indicated flow and pressure.
- (Optional) Repeat the test at two other fixed delivery pressures (10 bar and 5 bar are recommended).

Data from experiment:

Swept Volume, V_s = 0.00715 L/rev

Delivery Pressure, P_2 = bar

Oil Temperature, T_1 = (at start), (at end)

Data Table:

Obs. No	Speed, N_P (rpm)	Inlet Pressure P_1, (bar)	Pressure Difference ΔP, (Pa)	Flow rate Q_v, (L/min)	Expected Flow, (L/min)	Shaft Power W_D, (W)	Hydraulic Power W_P, (W)	Overall Efficiency η_P,(%)	Volumetric Efficiency η_v, (%)
1									
2									
3									
4									
5									
6									
7									
8									
9									

Calculation:

1. Mechanical Power (into the pump), W_D =

2. Hydraulic Power (from the pump), $W_P = (P_2 - P_1)\ Q_v$ =

3. Overall Pump Efficiency, η_P =

4. Swept Volume V_S =

5. Expected Volume Flow rate = $V_S \times N_p$ =

6. Volumetric Efficiency, $\eta_V = Q_v / (V_S \times N_p) \times 100$ =

Discussion:

- Compare the Flow rate, Shaft power, Volumetric efficiency, and Overall efficiency with Pump speed.
- Create one chart with two vertical axes, one for flow rate and other one for volumetric efficiency, overall efficiency, and shaft power.
- Discuss the individual parameters behavior with the change of pump speed.
- If the test is run at other delivery pressures, repeat the above discussions, and compare them.

Experiment: 7(c)

Experiment Name: Effect of inlet pressure on pump performance

Experiment: 7(c)

Experiment Name: Effect of inlet pressure on pump performance

Objective:

To show how reduced inlet pressures affect pump performance and cause cavitation.

Procedure:

- Fit the pump according to the instructions (i.e., video).
- Fully open inlet and delivery valves.
- Use button on the pressure display to zero all the pressure readings.
- Zero the torque reading of the MFP100 Universal Dynamometer.
- Press the start button on the Motor Drive and run the speed to 1600 rpm (+/- 5 rpm) for at least five minutes and monitor the oil temperature until it stabilizes.
- Wait for any trapped air bubbles to move from the flowmeter.
- Slowly shut the delivery valve and maintain the speed until the delivery pressure reaches 2 bar.
- While keeping the speed and delivery pressure constant, use the inlet valve to reduce the inlet pressure to the nearest 0.1 bar.
- Allow a few seconds for conditions to stabilize, then record the speed, the oil temperature, the indicated flow, and pressures.
- Continue decreasing the inlet pressure in 0.1 bar steps (while keeping the delivery pressure and speed constant) until you can hear a change in sound from the pump (cavitation). At each step, record the indicated flow and pressures.

Data from experiment:

Swept Volume, V_s = 0.00715 L/rev,

Pump Speed, N_P = rpm,

Expected Flow = L/min

Delivery Pressure, P_2 = bar

Oil Temperature, T_1 = (at Start), (at end)

Data Table:

Obs. No	Inlet Pressure P_1, (bar)	Pressure Difference ΔP, (Pa)	Flow rate Q_v, (L/min)	Shaft Power W_D, (W)	Hydraulic Power W_P, (W)	Overall Efficiency η_P, (%)	Volumetric Efficiency η_v, (%)
1							
2							
3							
4							
5							
6							
7							
8							

Calculation:

1. Mechanical Power (into the pump), W_D =

2. Hydraulic Power (from the pump), $W_P = (P_2 - P_1)\, Q_v$ =

3. Overall Pump Efficiency, η_P =

4. Swept Volume V_S =

5. Expected Volume Flow rate = $V_S \times N_p$ =

6. Volumetric Efficiency, $\eta_V = Q_v / (V_S \times N_p) \times 100$ =

Discussion:

- Compare the Flow rate, Shaft power, Volumetric efficiency and Overall efficiency with inlet pressure.
- Create one chart with two vertical axes, one for flow rate and other one for volumetric efficiency, overall efficiency and shaft power.
- Discuss the individual parameters behavior with the change of pump speed.
- Comment on how low the inlet pressures (that can cause cavitation) affect the performance of the pump.

Experiment no. 8(a)

Name of the experiment: Study of centrifugal pumps in series and parallel connection

Experiment no. 8(a)

Name of the experiment: Study of centrifugal pumps in series and parallel connection

Objective:

To study the flow rate and head characteristics of two centrifugal pumps in series and parallel connections.

Apparatus:

Schematic diagram (connection circuit):

Pump 2 off and Pump 1 running	**Pump 1 off and Pump 2 running**
Both pumps in series connection	**Both pumps in parallel connection**

Data collection:

For pump 2 off pump 1 running:

No of Obs.	Suction Pressure, $P_{s,1}$		Delivery Pressure, $P_{d,1}$		Total Head (m of H_2O)	Manometer reading			Flow rate, Q (m^3/s)
	inch Hg	m of H_2O	Kg/cm^2	m of H_2O		Left, L (cm)	Right, R (cm)	Net Deflection, ΔH (m)	

For pump 2 off pump 1 running:

No of Obs.	Suction Pressure, $P_{s,2}$		Delivery Pressure, $P_{d,2}$		Total Head (m of H_2O)	Manometer reading			Flow rate, Q (m^3/s)
	inch Hg	m of H_2O	Kg/cm^2	m of H_2O		Left, L (cm)	Right, R (cm)	Net Deflection, ΔH (m)	

For pumps is series connection:

No of Obs.	Suction Pressure, $P_{s,3}$		Delivery Pressure, $P_{d,3}$		Total Head (m of H_2O)	Manometer reading			Flow rate, Q (m^3/s)
	inch Hg	m of H_2O	Kg/cm^2	m of H_2O		Left, L (cm)	Right, R (cm)	Net Deflection, ΔH (m)	

For pumps is parallel connection:

No of Obs.	Suction Pressure, $P_{s,4}$		Delivery Pressure, $P_{d,4}$		Total Head (m of H_2O)	Manometer reading			Flow rate, Q (m^3/s)
	inch Hg	m of H_2O	Kg/cm^2	m of H_2O		Left, L (cm)	Right, R (cm)	Net Deflection, ΔH (m)	

Calculation:

1. Suction pressure, P_s = (inch Hg)

   = (m of H_2O)

2. Delivery pressure, P_d = (kg/cm^2)

   = (m of H_2O)

3. Total head = $P_d - P_s$ = (m of H_2O)

4. Manometer net deflection, $\Delta H = L + R$ = (cm)

   = (m)

5. Flow rate, $Q = 0.015 \times \sqrt{\Delta H}$ (m^3/s) =

Discussion:

Experiment No. 8(b)

Name of the Experiment: Dismantling and assembling of a centrifugal pump

Experiment No. 8(b)

Name of the Experiment: Dismantling and assembling of a centrifugal pump

Introduction:

Centrifugal pumps are devices that are used to transport fluids by the conversion of rotational kinetic energy to the hydraulic energy of the fluid flow. The kinetic energy typically comes from an electric motor. Centrifugal pumps are used in more industrial applications than any other kind of pumps.

Working principle:

Fluid enters the pump axially through the suction pipe to the eye of impeller (low pressure area) which rotates at high speed. As the impeller blades rotate, they transfer momentum to incoming fluid. The fluid accelerates radially outward, and a vacuum is created at the impellers eye that continuously draws more fluid into the pump. As the fluid's velocity increases its kinetic energy increases. Fluid of high kinetic energy is centrifugally forced out of the impeller area and enters the volute. In the volute, the fluid flows through a continuously increasing cross sectional area, where the kinetic energy is converted into fluid pressure according to Bernoulli's principle. The main parts of a centrifugal pump include the suction pipe, impeller, volute casing, shaft, packing seals, bearing etc. The impeller may be open, semi open, or closed type depending on the fluid to be handled.

Activities:

1. Dismantle a centrifugal pump using the tools provided.
2. Identify and observe each of the components.
3. Take photographs of various components and attach them with the report.
4. Study the components and energy flow sequence.
5. Assemble all components to form the pump again.

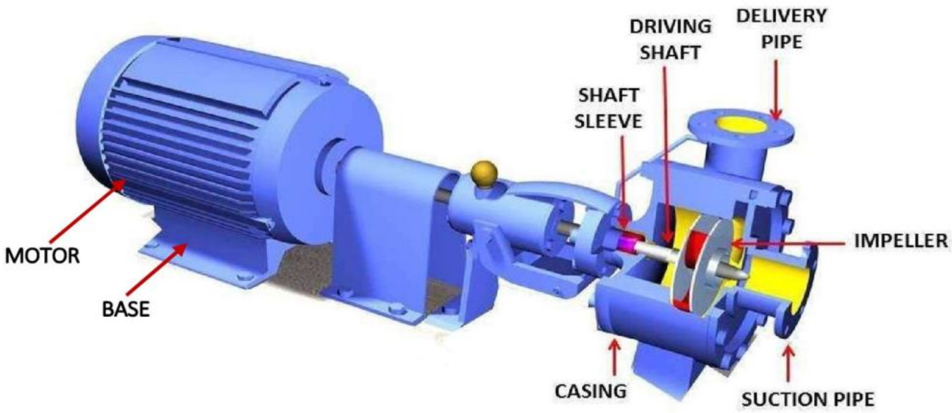
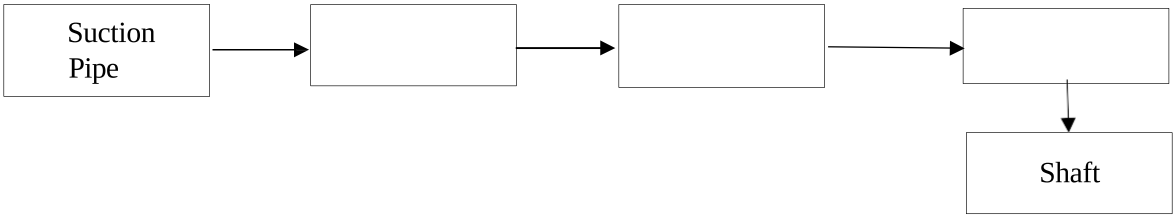
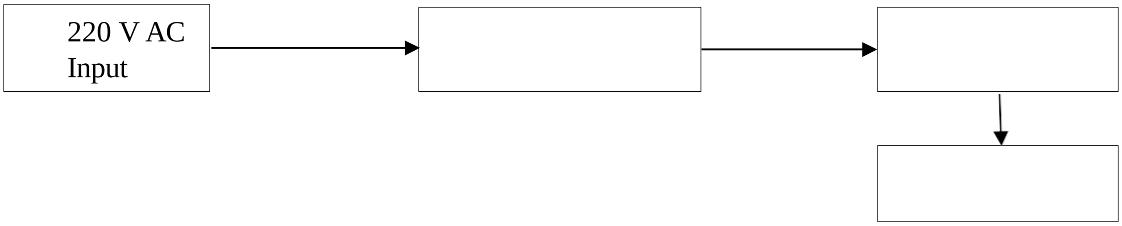


Figure 8 (b): Centrifugal pump and its components.

Pump Components Sequence:



Energy Conversion Sequence:



Question and answer:

1. Where are the gaskets placed?

2. Why gland packing seals are used?