Experiment No. 1

STUDY OF BERNOULLI'S THEOREM

General

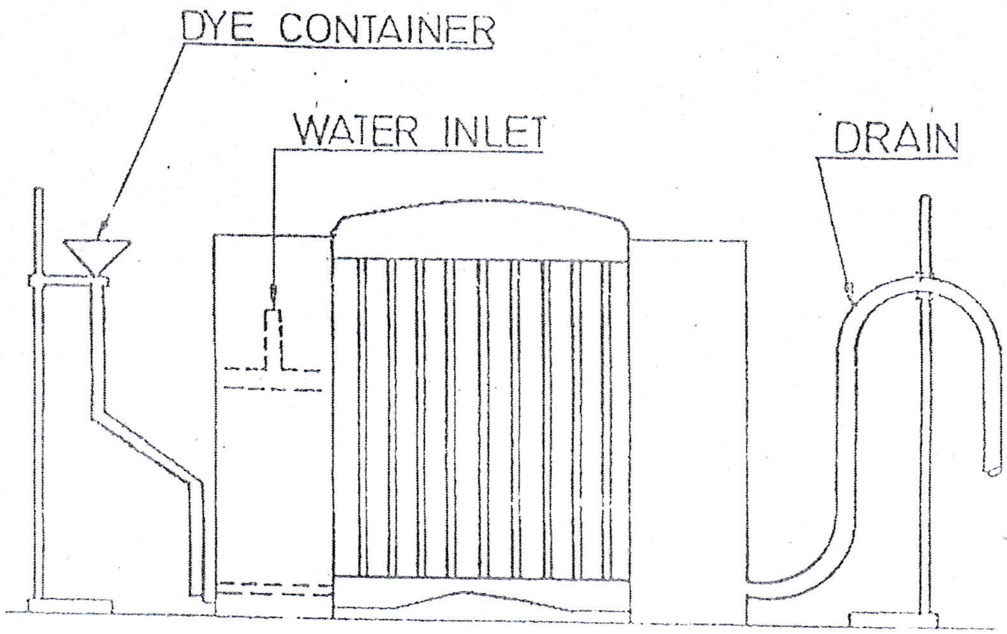
Energy is the ability to do work. It manifests in various forms and can change from one form to another. This various forms of energy present in fluid flow are elevation, kinetic, pressure and internal energies. Internal energies are due to molecular agitation and manifested by temperature. Heat energy may be added to or subtracted from a flowing fluid through the walls of the tube or mechanical energy may be added to or subtracted from the fluid by a pump or turbine. Daniel Bernoulli in the year 1738 stated that in a steady flow system of frictionless (or non-viscous) incompressible fluid, the sum of pressure, elevation and velocity heads remains constant at every section, provided no energy is added to or taken out by an external source.

Practical application

Bernoulli's Energy Equation can be applied in practice for the construction of flow measuring devices such as venturimeter, flow nozzle, orifice meter and Pitot tube. Furthermore, it can be applied to the problems of flow under a sluice gate, free liquid jet, radial flow and free vortex motion. It can also be applied to real incompressible fluids with good results in situations where frictional check is very small.

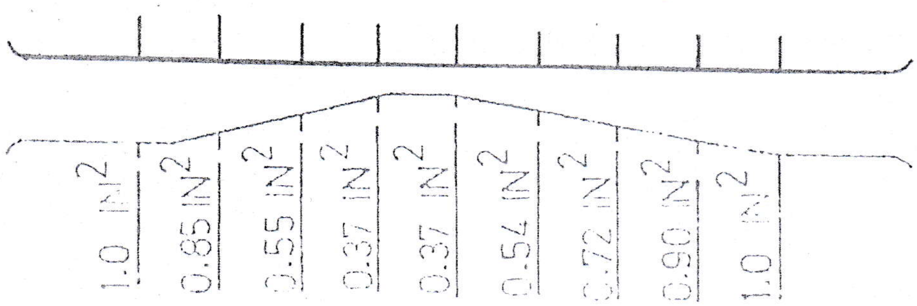
Description of apparatus

The unit is constructed as a single Perspex fabrication. It consists of two cylindrical reservoirs inter-connected by a Perspex Venturi of rectangular cross-section. The Venturi is provided with a number of Perspex piezometer tubes to indicate the static pressure at each cross-section. An engraved plastic backboard is fitted which is calibrated in British and Metric units. This board can be reversed and mounted on either side of the unit so that various laboratory configurations can be accommodated. The inlet vessel is provided with a dye injection system. Water is fed to the upstream tank through a radial diffuser from the laboratory main supply. For satisfactory results, the main water pressure must be nearly constant. After flowing through the venture, water is discharged through a flow-regulating device. The rate of flow through the unit may be detrimental either volumetrically or gravimetrically. The equipment for this purpose is excluded from the manufacturer's supply. The apparatus has been made so that the direction of flow through the venture can be reversed for demonstration purpose. To do this the positions of the dye injector and discharge fitting have to be interchanged.



SKETCH OF APPARATUS

TUBES AT 1'' CENTRES



VENTURI DETAILS

Governing Equation

Assuming frictionless flow, Bernoulli's Theorem states that, for a horizontal conduit

$$\frac{p_1}{\gamma}+\frac{V_1^2}{2g}=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}=\frac{P_3}{\gamma}+\frac{V_3^2}{2g}=\ldots\ldots\ldots\ldots$$

where, $P_1 P_2$ = pressure of flowing fluid at sections 1 and 2

γ = unit weight of fluid

V_1, V_2 = mean velocity of flow at sections 1 and 2

g = acceleration due to gravity.

The equipment can be used to demonstrate the validity of this theory after an appropriate allowance has been made for friction losses.

For actual condition there must be some head loss in the direction of flow. So if the head loss between section 1 and 2 is h_L Bernoulli's theorem is modified to

$$\frac{p_1}{\gamma}+\frac{V_1^2}{2g}=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+h_L$$

Procedure

1. The apparatus should be recurrently leveled by means of screws provided at the base.
2. Connect the water supply to the radial diffuser in the upstream tank.
3. Adjust the level of the discharge pipe by means of the stand and clamp provided to a convenient position.
4. Allow water to flow through the apparatus until all air has been expelled and steady flow conditions are achieved. This can be accomplished by varying the rate of inflow into the apparatus and adjusting the level of the discharge tube.
5. Readings may then be taken from the piezometer tubes and the flow through the apparatus measured.
6. A series of readings can be taken for various through flows.

Objective

1. To calculate the total head loss $h_L = h_I - h_{II}$
2. To plot the static head, velocity head and total head against the length of the passage in one plain graph paper.
3. Verification of total head loss by plotting head loss in each passage or segment.
4. To plot the total head loss h_L, against the inlet kinematics head, $V^2/2g$, for different in- flow conditions in plain graph paper.

Practice Question

1. What are the assumptions underlying the Bernoulli's energy equation?
2. Do you need any modification (s) of Eqn (1) when (a) the frictional head loss is to be considered, and (b) the conduit is not horizontal?

Experiment No. 1

STUDY OF BERNOULLI'S THEOREM

Experimental Data Sheet

Course no.: **Student ID no.:**

Group no.: **Date:**

Collection time = ____________________

Volume of water = ____________________

Discharge Q = ____________________

Both inlet and outlet is open:

Piezometer tube no.	1	2	3	4	5	6	7 **(Pitot tube)**	8
A								
V=Q/A								
$V^2/(2g)$								
p/γ								
$h=p/\gamma+v^2/(2g)$								

Head loss in each segment	0	$h_{2-1} = h_1 - h_2$	h_{3-1}	h_{4-1}	h_{5-1}	h_{6-1}	h_{7-1}	h_{8-1}
h_L	0							

____

Signature of the teacher

Experiment No.: 2

FLOW THROUGH VENTURIMETER

General

The converging tube is an efficient device for converting pressure head to velocity head, while the diverging tube converts velocity head to pressure head. They two may be combined to form venturi tube. As there is a definite relation between the pressure differential and the rate of flow, the tube may be made to serve as metering device.

Venturimeter consists of a tube with a constricted throat that produces an increased velocity accompanied by a reduction in pressure followed by a gradual diverging portion in which velocity is transformed back into pressure with slight frictions loss.

Practical application

The venturimeter is used for measuring the rate of flow of both compressible and incompressible fluids.

The venturimeter provides an accurate means for measuring flow in pipelines. Aside from the installation cost, the only disadvantage of the venturimeter is that it introduces a permanent frictional resistance in the pipelines.

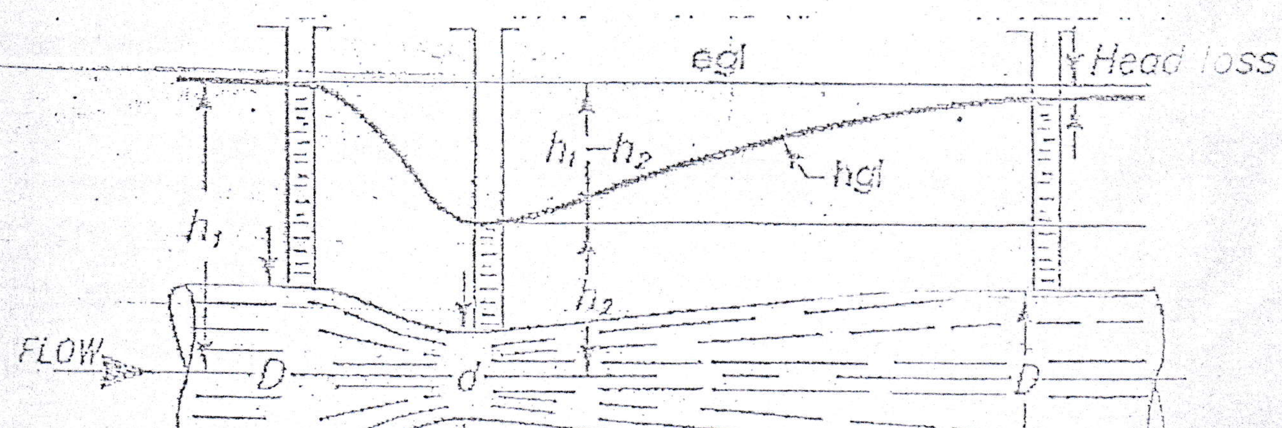


Fig. Venturimeter

Theory

Consider the Venturimeter shown in the above figure. Applying the Bernoulli's equation between Point 1 at the inlet and point 2 at the throat, we obtain.

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}=\frac{P_2}{\gamma}+\frac{V_2^2}{2g} \quad \text{.......(1)}$$

Where P_1 and V_1 are the pressure and velocity at point 1, P_2 and V_2 are the corresponding quantities at point 2, γ is the specific weight of the fluid and g is the acceleration due to gravity from continuity equation, we have.

$$A_1V_1 = A_2V_2 \text{..........}(2)$$

Where, A_1 and A_2 are the cross sectional areas of the inlet and throat respectively since

$$A_1 = \frac{\pi}{4}D_1^2, A_2 = \frac{\pi}{4}D_2^2$$

From Equations (1) and (2), we have

$$V_1 = \sqrt{\frac{2g}{\left(\frac{D_1}{D_2}\right)^4 - 1}\frac{(P_1 - P_2)}{\gamma}}$$

$$= K_1H^{1/2} \text{..............}(3)$$

Where,

$$K_1 = \sqrt{\frac{2g}{\left(\frac{D_1}{D_2}\right)^4 - 1}}$$

And, $H = \dfrac{(P_1 - P_2)}{\gamma}$

The head H is indicated by the piezometer tubes connected to the inlet and throat.

The theoretical discharge, Q_t is given by

$$Q_t = A_1V_1 \text{............}(4)$$

$$= KH^{1/2}$$

Where,

$$K = K_1A_1 \text{...............}(5)$$

Coefficient of discharge

Theoretical discharge is calculated from theoretical formula neglecting loses, friction losses. For this season we introduce a coefficient named coefficient of discharge which is the ratio of actual discharge to theoretical discharge.

Now, if C_d is the coefficient of discharge (also known as the meter coefficient) and Q_a is the actual discharge then,

$$C_d = \frac{Q_a}{Q_t}$$

$$Q_a = C_dQ_t$$

$$= C_d K H^{1/2}$$

$$= CH^n \;............ (6)$$

The value of C_d may be assumed to be about 0.99 for large meter and about 0.97 or 0.98 for small ones provided the flow is such as to give reasonably high Reynolds number.

Calibration

One of the objectives of the experiment is to find the values of C and n for aparticular meter so that in future we can measure actual discharge only by measuring H. Here C and n are called calibration parameters.

For five sets of actual discharge and H data we plot Q_a vs. H in log-log paper and draw a best –fit straight line.

The Equation of line

$\log Q_a = \log CH^n$

$\log Q_a = \log C + n\log H$

Now from the plotting we take two points on the straight line say (H_1, Q_{a1}) and (H_2, Q_{a2})

So from the equation (3) we get

$\log Q_{a1} = \log C + n \log H_1$

$\log Q_{a2} = \log C + n \log H_2$

$$Solving, n = \frac{\log \frac{Q_{a1}}{Q_{a2}}}{\log \frac{H_1}{H_2}}$$

C= antilog [anti log Q_{a1} – n $\log H_1$]

So the calibration equation is $Q_a = CH^n$

Now $C = C_d K$

$C_d = C/K$

Now from the calibration equation we can calculate actual discharge for different H and plot on a plain graph paper. In practice we can use the plot to find actual discharge for any H. Thus the venturimeter is calibrated.

Objective

1. To find C_d for the Venturimeter.
2. To plot Qa against H in log-log paper and to find (a) exponent of H and(b) C_d.
3. To calibrate the Venturimeter.

EXPERIMENT NO.: 2
FLOW THROUGH A VENTURIMETER

DATA AND CALCULATION SHEET

Course no.: Student ID no.: Group no.: Date:

Cross sectional area of the measuring tank, A= ____________

Pipe diameter, D_1= ____________ Area of the pipe, A_1= ____________

Throat diameter D_2= ____________ Area of the throat, A_2= ____________

Temperature of water, t= ____________ Kinematic viscosity of water v= ____________

Initial point gage reading= ____________ Final point gage reading = ____________

No of obs	Height of Water, h	Volume of Water v	Collection time T	Actual Dis-charge Q_a	Piezometer reading			k_1	k	Theoretical discharge Q_t	$C_d = \frac{Q_a}{Q_t}$	$V_2 = \frac{Q_a}{A_2}$	Reynolds number R_e
					Left h_1	Right h_2	Diff. H						

Group No					
Actual discharge Qa					
Head difference H					
Coefficient of discharge					
Reynolds number					

Signature of the Teacher ____________

Experiment No.: 03
FLOW OVER A V – NOTCH

General

The most common types of sharp-crested weir are the rectangular weir and the triangular weirs.

The triangular or V-notch weir is preferable to the rectangular weir for the measurement of widely variable flows. In the case of a rectangular weir, the total weighted perimeter does not vary directly with the head, as the length of the base is the same for all heads. Therefore, the coefficient of contraction, which depends on the wetted perimeter, is not constant for all heads. But in case of a V-notch there is no base to cause contraction which will be due to the sides only. The coefficient of contraction will therefore, be a constant for all heads. For this reason, the V-Notch is the most satisfactory type for flow measurement in canals.

Practical application

The V-notch weir is preferred when small discharges are involved, because the triangular cross-section of the flow 'nappe' leads to a relatively greater variation in head. V-notch Weir has the advantage that it can function for a very small flows and also measure reasonably larger flows as well.

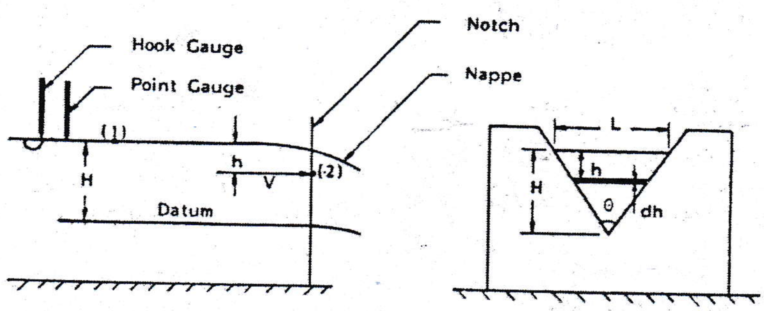


Fig.Flow over a V-Notch

Theory

Consider the V-notch shown in the figure. Let H be the height of water surface and θ be the angle of notch. Then width of the notch at the water surface is given by,

$$L = 2H\tan\frac{\theta}{2} \quad ....(1)$$

Consider a horizontal strip of the notch of thickness dh under a head h. Then, width of the strip,

$$W = 2(H-h)\tan\frac{\theta}{2} \quad ....(2)$$

Hence, the theoretical discharge through the strip

dQ_t = area of the strip x velocity =2(H-h) tan $\frac{\theta}{2} dh\sqrt{2gh}$ ....(3)

Integrating between the limits 0 and H and simplifying, the total theoretical discharge over the notch is given by

$$Q_t = \frac{8}{15}\sqrt{2g}\ \tan\frac{\theta}{2} H^{5/2} \ ....(4)$$

$$= KH^{5/2} \ ....(5)$$

Where,

$$K = \frac{8}{15}\sqrt{2g}\ \tan\frac{\theta}{2} \ ....(6)$$

Let Q_a be the actual discharge, then the coefficient of discharge, Cd is given by

$$C_d = \frac{actual discharge}{theoretical discharge} = \frac{Q_a}{Q_t} \ ....(7)$$

$$Q_a = KC_dH^{5/2} \ ....(8)$$

The co-efficient of discharge depends on relative head (H/P), relative height (P/B) and angle of the notch (θ)

From hydraulic point of view a weir may be fully contracted at low heads while at increasing head it becomes partially contracted. The flow regime in a weir is said to be partially contracted when the contractions along the sides of the V-notch are not fully developed due to proximity of the walls and bed of approach channel. Whereas a weir which has an approach channel and whose bed and sides of the notch arc sufficiently remote from the edges of the V-notch to allow for a sufficiently great approach velocity component parallel to the weir face so that the contraction is fully developed is a fully contracted weir. In case of a fully contracted weir C_d is fairly constant for a particular angle of notch.

At lower heads, frictional effects reduce coefficients. For the most common angle of notch 90 degree, the discharge coefficient, C_d is about 0.6.

Apparatus

1. A constant steady water supply with a means of varying the flow rate.
2. An approach channel
3. A V-notch weir plate
4. A flow rate measuring facility
5. A point gauge for measuring H.

Procedure

1. Position the weir plate at the end of approach channel, in a vertical plane, with the sharp edge on the upstream side.
2. Admit water to channel until the water discharges over the weir plate.
3. Close the flow control valve and allow water to stop flowing over weir.
4. Set the point gauge to a datum reading.
5. Position the gauge about half way between the notch plate and stilling baffle.
6. Admit water to the channel and adjust flow control valve to obtain heads, H, increasing in steps of 1 cm.
7. For each flow rate, stabilize conditions, measure and record H.
8. Take readings of volume and time using the volumetric tank to determine the flow rate.

Objective

1. To find C_d for the V-notch.
2. To plot Q_t vs. Q_a in a plain graph paper.
3. To plot Q_a vs. H in a log-log paper and to find (a) the exponent of H and (b) C_d

EXPERIMENT NO.: 8
FLOW OVER A V-NOTCH

DATA AND CALCULATION SHEET

Course no.:

Group no.:

Student ID no.:

Date:

Angle of the notch, θ = ______________

K= __________

Cross-sectional area of the measuring tank= ______________

Initial point gauge reading = ______________

Final point gauge reading= ______________

Difference in reading = ______________

Datum water level reading = ______________

Water level above vertex= ______________

Final water level reading= ______________

No of obs.	Height of Water h	Volume of Water, V	Collection time T	Actual discharge Q_a	Effective head H	Theoretical discharge Q_t	Co-eff. of discharge

No of observation					
Actual discharge Q_a					
Effective head H					
Theoretical discharge					

Signature of the Teacher

Head losses in pipes and fittings

Objective

- To find the head losses in pipe, elbow, expansion and contraction in pipe, globe valve and overall system.
- To plot the Head losses vs. Velocity graph and to analyze the losses characteristics in flow.
- To calculate the friction factor of pipe.
- To calculate the minor loss coefficients of elbow, expansion and contraction in pipe, and globe valve.

Theory

Friction loss is the loss of energy or "head" that occurs in pipe flow due to viscous effects generated by the surface of the pipe. Friction Loss is considered as a "major loss" and it is not to be confused with "minor loss", which includes energy lost due to obstructions.

This energy drop is dependent on the wall shear stress between the fluid and pipe surface. The shear stress of a flow is also dependent on whether the flow is turbulent or laminar. For turbulent flow, the pressure drop is dependent on the roughness of the surface. In laminar flow, the roughness effects of the wall are negligible because, in turbulent flow, a thin viscous layer is formed near the pipe surface that causes a loss in energy, while in laminar flow, this viscous layer is non-existent.

One of the accepted methods to calculate friction losses resulting from fluid motion in pipes is by using the Darcy–Weisbach equation. For a circular pipe:

$$h_f = \frac{f\,Lv^2}{2gd}$$

Where:

h_f = Head loss due to friction, given in units of length

f = Darcy friction factor

L = Pipe length

d = Pipe diameter

v = Flow velocity

g = Gravitational acceleration

The minor losses of energy are those which are caused on account of the change in velocity of flowing fluid. In case of long pipes these losses are usually quite small as compared with the loss of energy due to friction and hence these are termed 'minor losses' which may even be neglected without serious error. However, in short pipes, these losses may sometimes outweigh the friction loss. Some of the losses of energy which may be caused due to the change of velocity are indicated below:

(a) Loss of energy in bends and various pipe fittings

(b) Loss of energy due to sudden expansion and contraction

(c) Loss of energy due to gradual expansion and contraction

(d) Loss of energy at the entrance and exit of pipe

With pipe bends, valves etc., it is usually to account for head losses through these devices, in addition to the losses sustained by the pipes. This must almost always be done by resorting to experimental results. Such minor loss is given in the form

$$h_l = K\frac{v^2}{2g}$$

Where,

h_l = Minor loss

K = Minor loss coefficient

v = Flow velocity

g = Gravitational acceleration

As there are two different velocities in expansion and contraction, the largest velocity of the smaller diameter pipe is considered to calculate minor losses.

Setup components

Piping arrangement with the wall-

i. GI pipes
ii. Pressure gauges
iii. Water meter
iv. Ball valve
v. Globe valve
vi. Pipe fittings
vii. Couplers
viii. Flexible pipes

Manometer-

i. Coupler
ii. Acrylic tube
iii. Mercury
iv. Flexible rubber tube
v. Ring clips
vi. Measuring scale
vii. Hardboard

Working procedures

1. Water meter is connected in the path of flow to evaluate the volumetric flow-rate.
2. Calculating the time period of certain flow by stopwatch the volumetric flow-rate can be measured.
3. Thus from the known diameter of the pipes, the velocity of the flow can be computed.
4. Female ports of the couplers are connected with the male ports at certain points covering 1.94m of the pipe, elbow, globe valve, and expansion and contraction sockets; in order to find the pressure difference of those points in mercury column in manometer.
5. Pressure losses are converted to SI unit by essential calculations and are further assigned to calculate the friction factor of pipe and minor loss coefficients of the fittings, valves, and expansion and contraction in pipe.

Experimental Data

Specifications:

Pipe length, L = 1.94m

Thin pipe dia. = ¾ inch = 0.01905m; Thick pipe dia. = 1½ inch

Cross-sectional area of smaller pipe, $A = \frac{1}{4}\pi d^2 = \frac{1}{4} \times 3.1416 \times (0.01905)^2 = 2.85 \times 10^{-4}$ m²

Density of Mercury, ρ_{hg} = 13550 kg/m³; Specific weight of Water, γ_w = 9810

Table: Flow Rate, Velocity and Losses in Pipes and Fittings

No. of Observations	Flow rate, Q (m^3/s)	Velocity, v = Q/A (m/s)	Head loss, h_{hg} (mm mercury column)					
			Loss in pipe	Loss in elbow	Loss for expansion	Loss for contraction	Loss in globe valve	Overall loss
1								
2								
3								
4								
5								

Calculation Data

Table: Friction Factor of Pipe and Minor Loss Coefficients of Fittings

No. of obs.	Pipe friction factor *F*	Elbow loss coefficient, K	Expansion loss coefficient, K	Contraction loss coefficient, K	Globe valve loss coefficient, K	Overall loss from manometer (m of water)
1						
2						
3						
4						
5						
Avg.						

Sample calculation

- Pressure drop due to pipe friction, $p = \gamma_{hg} h_{hg}$

$$= \rho_{hg} g h_{hg}$$

$$=$$

Head loss of water due to friction, $h_f = \dfrac{p}{\gamma_w}$

$$=$$

$\therefore$ Friction factor, $f = \dfrac{2gdh_f}{Lv^2}$

$$=$$

- Pressure drop in elbow, $p = \gamma_{hg} h_{hg}$

$$=$$

Head loss of water, $h_l = \dfrac{p}{\gamma_w}$

$$=$$

$\therefore$ Elbow loss coefficient, $K = \dfrac{2gh_l}{v^2}$

$$=$$

- Pressure drop for expansion, $p = \gamma_{hg} h_{hg}$

$$=$$

Head loss of water, $h_l = \dfrac{p}{\gamma_w}$

$$=$$

$\therefore$ Expansion loss coefficient, $K = \dfrac{2gh_l}{v^2}$

$$=$$

- Pressure drop for contraction, $p = \gamma_{hg} h_{hg}$

$$=$$

Head loss of water, $h_l = \dfrac{p}{\gamma_w}$

$$=$$

$\therefore$ Contraction loss coefficient, $K = \dfrac{2gh_l}{v^2}$

$$=$$

- Pressure drop in globe valve, $p = \gamma_{hg} h_{hg}$

$$=$$

Head loss of water, $h_l = \dfrac{p}{\gamma_w}$

$$=$$

$\therefore$ Globe valve loss coefficient, $K = \dfrac{2gh_l}{v^2}$

$$=$$

- Overall Pressure drop, $p = \gamma_{hg} h_{hg}$

$$=$$

$\therefore$ Overall head loss of water, $h_l = \dfrac{p}{\gamma_w}$

$$=$$