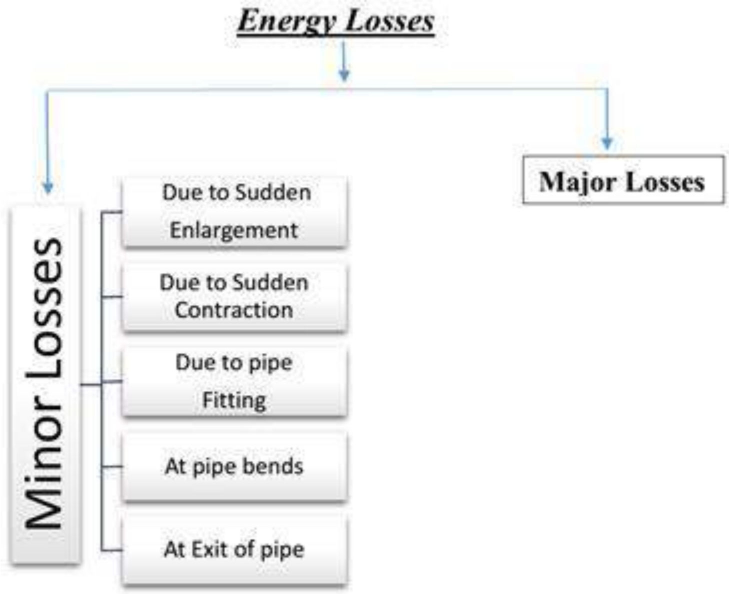
Flow Through Pipes

Flow through pipes is an important topic in fluid mechanics. It is important to understand the different types of losses occurred during the flow through pipes. Based on different losses, the total energy at the exit point of the pipe is calculated.



Major Losses in Flow Through Pipes

In flow through pipes, losses that occur in the pipe flow are a very important parameter for the design. These losses include the major loss due to friction and some minor losses. Darcy Weisbach's equations can calculate major losses in flow through pipes. These are explained as follows.

Loss of head due to friction

$$h_f = 4fLv^2/2gd$$

where,

- L = Length of pipe,
- v = Mean velocity of flow
- d = Diameter of pipe,
- f = Coefficient of friction

$$\text{or } h_f = f'Lv^2/2gd$$

$$f' = 4f$$

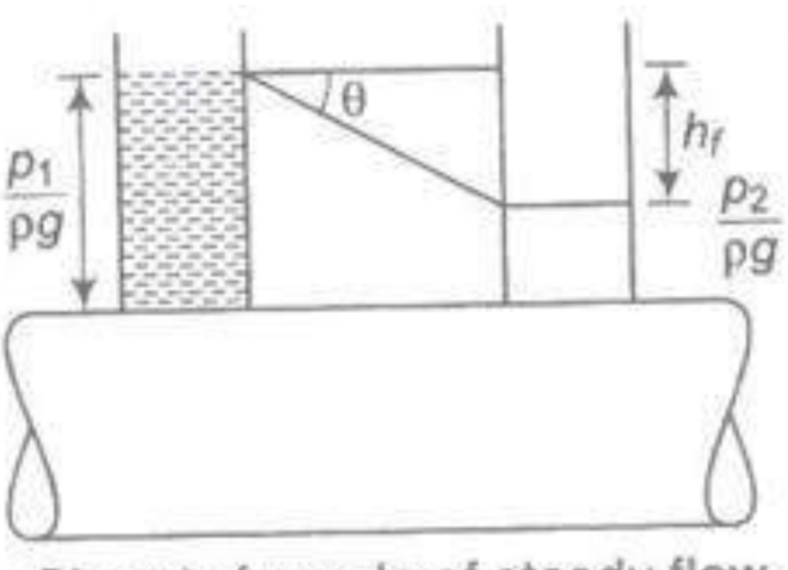
friction factor for laminar flow, $f = 64/R_e$

Coefficient of friction, $f = 16/R_e$

For turbulent flow, the coefficient of friction

$f = 0.079/(R_e)^{0.25}$

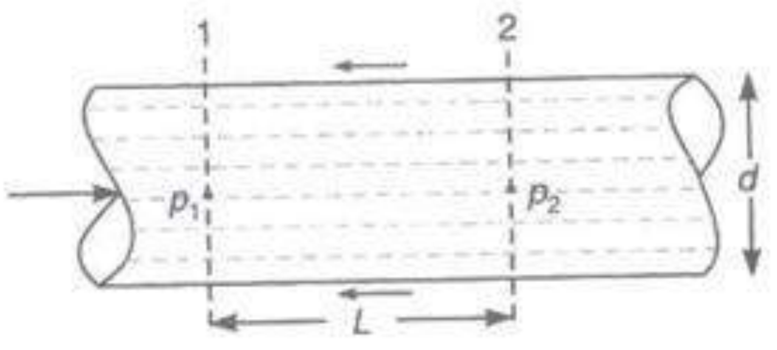
Chezy's Formula: In fluid dynamics, Chezy's formula describes the mean flow velocity of steady, turbulent open channel flow.



Chezy's formula of steady flow

$v = c\sqrt{mi}$, **c= Chezy's Constant =** $\sqrt{8g/f}$

Relation between Coefficient of Friction and Shear Stress



Coefficient of friction and shear stress

We get

$$f = 2\tau_0/\rho v^2$$

where,

- f = Coefficient of friction
- τ_0 = Shear stress

Minor Losses in Flow Through Pipes

Another type of head loss, minor loss, is induced for the following reasons.

Loss due to Sudden Enlargement

Head loss, $h_L = (v_1 - v_2)^2/ 2g$

Loss due to Sudden Contraction

Head loss, $h_L = 0.5\ v_2^2/ 2g$

Remember, v_2 is the velocity at a point in the contracted section.

Loss of Head at Entrance to Pipe

Head loss,

$h_L = 0.5V^2{}_1/2g$

Loss at Exit from Pipe

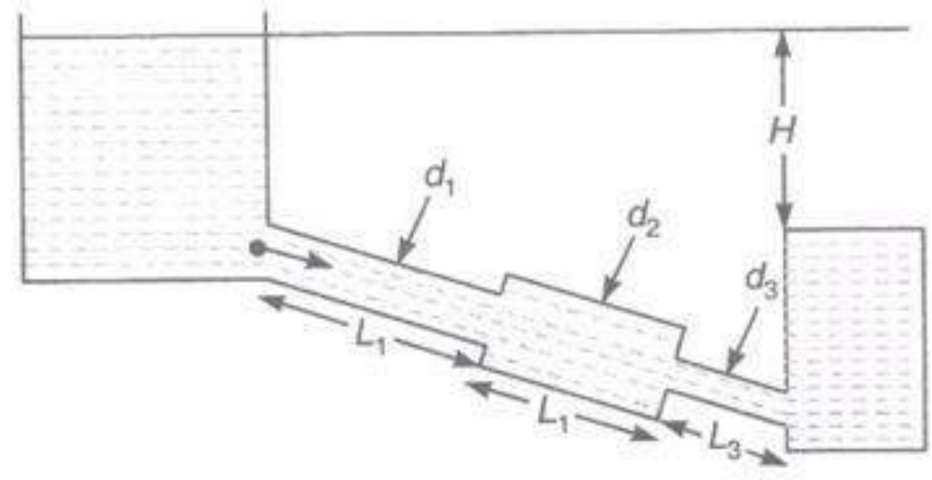
Head loss,

$h_L = V^2{}_1/2g$

Combination of Pipe Connections

Pipes may be connected in series, parallel or in both. Let's see their combinations.

Pipe in Series: As pipes are in series, the discharge through each pipe will be the same.



Pipe in series

$Q = A_1v_1 = A_2v_2 = A_3v_3$

Total loss of head = Major loss + Minor loss

$H = h_{L1} + h_{L2}$

Major loss = Head loss

due to friction in each pipe

$h_{L1} = h_{f1} + h_{f2} + h_{f3}$

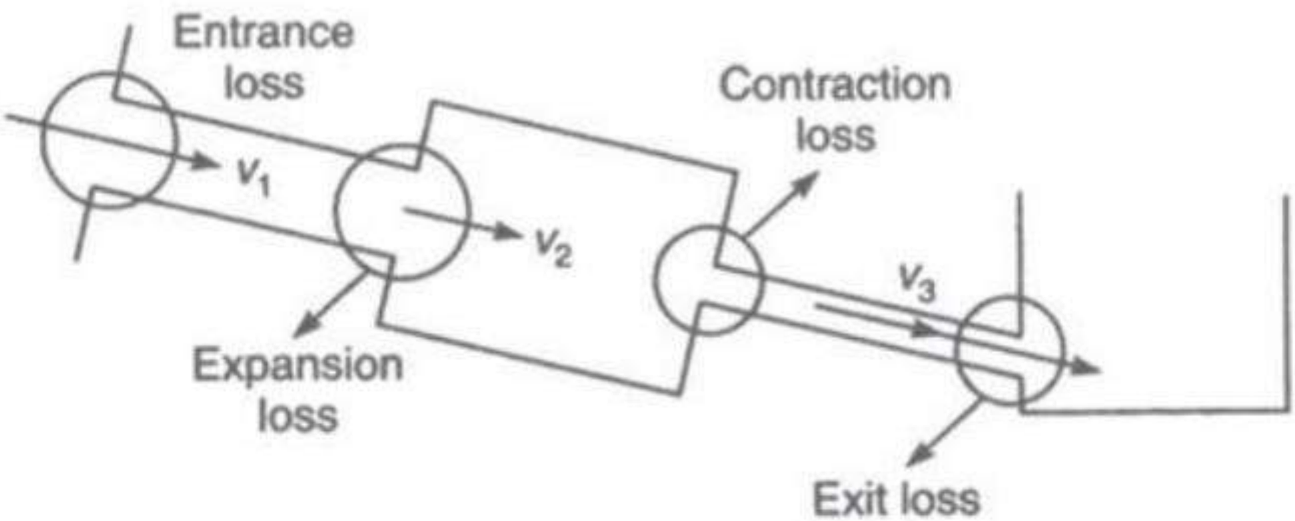
While, minor loss = Entrance loss + Expansion loss + Contraction loss + Exit loss

$$h_{L_2} = \frac{0.5v_1^2}{2g} + \frac{(v_2 + v_1)^2}{2g} + \frac{0.5v_3^2}{2g} + \frac{v_3^2}{2g}$$

If minor losses are neglected, then,

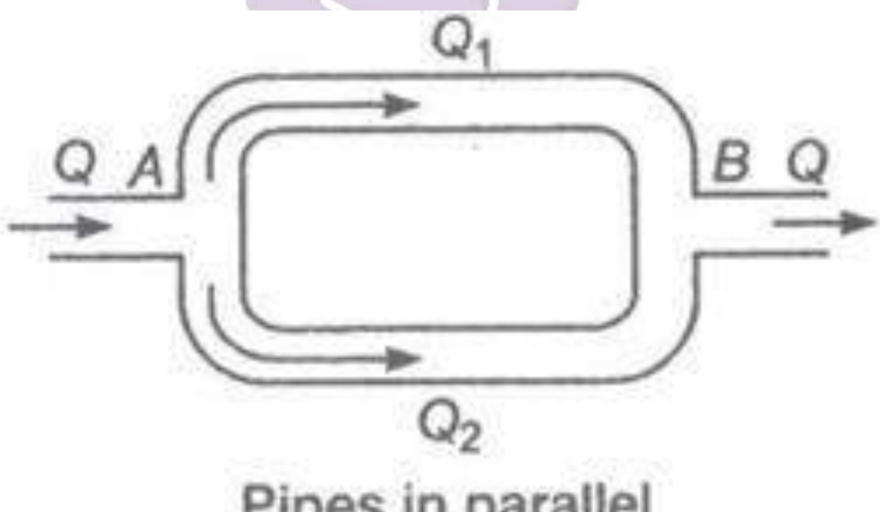
$$H = \frac{f_1 L_1 v_1^2}{d_1 .2g} + \frac{f_2 L_2 v_2^2}{d_2 .2g} + \frac{f_3 L_3 v_3^2}{d_3 .2g}$$

$$H = \frac{f_1 L_1 Q^2}{12 \cdot 1 d_1^5} + \frac{f_2 L_2 Q^2}{12 \cdot 1 d_2^5} + \frac{f_3 L_3 Q^2}{12 \cdot 1 d_3^5}$$



Head loss when minor loss are neglected

Pipes in Parallel: In this, discharge in the main pipe is equal to the sum of discharge in each parallel pipe.



Pipes in parallel

Hence, $Q = Q_1 + Q_2$

The head loss in each parallel pipe is the same,

$$h_{f1} = h_{f2}$$

where h_{f1} and h_{f2} are head loss at 1 and 2, respectively.

Equivalent Pipe: A compound pipe with several pipes of different lengths and diameters to be replaced by a pipe with a uniform diameter and the same length as a compound pipe is called an equivalent pipe.

$$h_{L_e} = h_{f_1} + h_{f_2} + h_{f3}$$

$$\frac{fLQ^2}{12.1d^5} = \frac{f_1 L_1 Q^2}{12.1d_1^5} + \frac{f_2 L_2 Q^2}{12.1d_2^5} + \frac{f_3 L_3 Q^2}{12.1d_3^5}$$

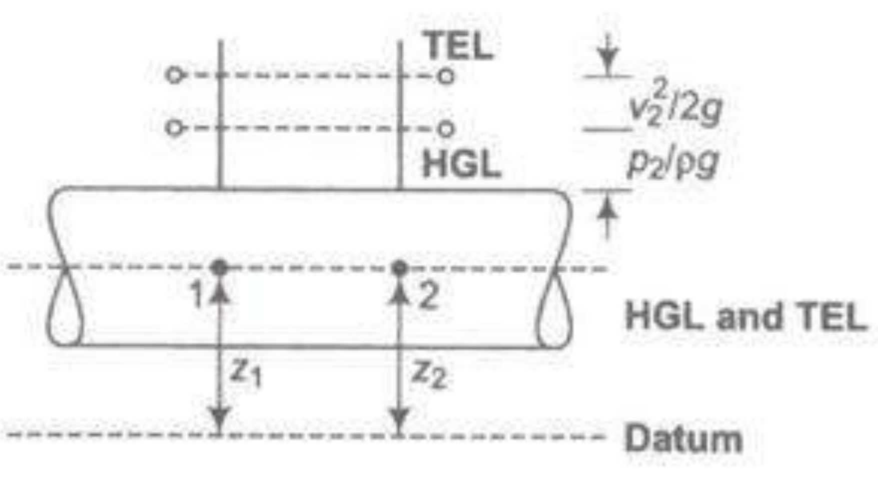
(where, $L = L_1 + L_2 + L_3$)

If $f = f_1 = f_2 = f_3$

Then,

$$\frac{L}{d^5} = \frac{L_1}{d_1^5} + \frac{L_2}{d_2^5} + \frac{L_3}{d_3^5} \Rightarrow \frac{L}{d^5} = \frac{L_1}{d_1^5} + \frac{L_2}{d_2^5} + \frac{L_3}{d_3^5}$$

Hydraulic Gradient Line (HGL) and Total Energy Line (TEL)



Equivalent pipe diagram

HGL → It joins the piezometric head ((p/ρg) + z) at various points.

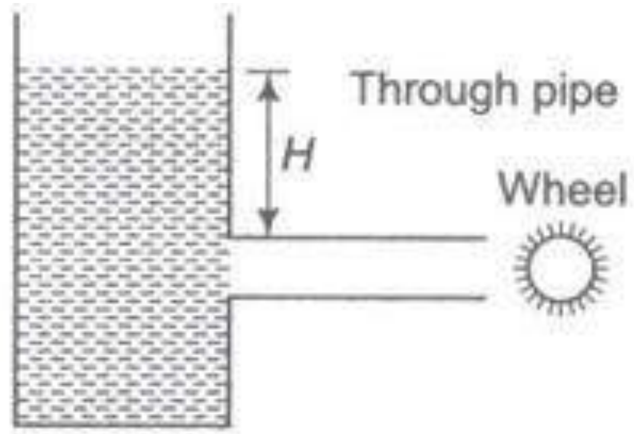
TEL → It joins the total energy head at various points:

{((p/ρg) + z) + (v²/2g)}

Note: HGL is always parallel but lower than TEL.

Power Transmission Through Pipe (P)

When a pipe is connected to a water tank, Power applied by a pipe flow at the outlet end depends upon the flow characteristics, pipe characteristics, etc. It will be explained below in detail for different cases.



Power transmission through pipe

P_{ideal} = ρgQH

P_{actual} = ρgQ(H - h_f); h_f = head loss

Efficiency, η = (H - h_f)/H

Power delivered by a given pipeline is maximum when the flow is such that one-third of the static head is consumed in pipe friction. Thus, efficiency is limited to only 66.66%

Maximum efficiency, η_{max} = H/3.

Water Hammer: When a liquid is flowing through a long pipe fitted with a vale at the end of the pipe, and the valve is closed, suddenly, a pressure wave of high intensity is produced behind the valve. This high-intensity pressure wave has the effect of hammering action on the walls of the pipe. This phenomenon is known as a **water hammer**.

The intensity of pressure rise due to the water hammer

$$P = -\rho Lv/t$$

When the valve is closed gradually, when valve closes suddenly with a rigid pipe.

$$P = v \times (K\rho)^{0.5}$$

When the valve closed suddenly with a plastic pipe

$$\rho = v \times [\rho/\{(1/K) + (D/Et)\}]^{0.5}$$

If the time required to close the valve

$t > 2L/C \Rightarrow$ Valve closure is said to be gradual.

$t < 2L/C \Rightarrow$ The valve closure is said to be sudden.

Where,

- L = Length of pipe
- D = Diameter of pipe
- C = Velocity of pressure wave produced due to water hammer = $\sqrt{(K/P)}$
- v = Velocity of flow
- K = Bulk modulus of water
- E = Modulus of elasticity for pipe material.
- t = Time required to choose the valve.