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1. **Introduction**

A fluid is conveyed through close passage when it is required to maintain a certain pressure with respect to atmospheric pressure. Circular pipes, in most of the cases are widely used to carry fluids over a certain distances. Pipe is a close conduit through which fluid flows. The flow in the pipe is termed as pipe flow when the fluid completely fills the cross section of the pipe and there is no free surface of the fluid.

Since the fluid in a pipe is in motion, it has to overcome the frictional resistance between the adjacent fluid layers and that between the fluid layer and pipe walls. As fluid flows from one point to another, there is a loss of head due to friction. Thus there is a drop in energy gradient line. In a fully developed pipe flow, the pressure drops linearly along the length of the pipe. Therefore the pressure gradient along the flow remains constant.

2. **Laws of fluid friction for Laminar and turbulent flow**

**Laws of fluid friction for Laminar flow**-

1. Frictional resistance is proportional to velocity of flow.
2. Frictional resistance is independent of pressure.
3. Frictional resistance is proportional to surface area in contact of fluid.
4. Frictional resistance varies with change in temperature.
5. Frictional resistance is independent on nature of surface of contact (smooth or rough).

**Laws of fluid friction for turbulent flow**-

1. Frictional resistance is proportional to square of velocity of flow.
2. Frictional resistance is independent of pressure.
3. Frictional resistance is proportional to density of fluid.
4. Frictional resistance slightly varies with temperature.
5. Frictional resistance is dependent on nature of surface of contact (smooth or rough).
3. Major Losses

The major losses of energy are due to friction. Which are considerable hence it is called as major losses. It is determined by Darcy-Weisbach formula and Chezy’s formula. Head loss due to friction is denoted by \( h_f \).

**Darcy-Weisbach formula**

\[
 h_f = \frac{4 f L V^2}{2 g d}
\]

Where, \( h_f \) – loss of head due to friction in meter of fluid

\( f \) - Coefficient of friction

Coefficient of friction is function of Reynolds’s Number (Re).

If Re is less than 2000 (i.e. laminar flow) \( f = \frac{16}{Re} \)

If Re is greater than 4000 (i.e. turbulent flow) \( f = \frac{0.0719}{Re^{1/4}} \)

\( L \) - Length of pipe in m.

\( V \) - Velocity of flow in m/s.

\( d \) - Diameter of pipe in m.

Let, \( V = \frac{Q}{A} \), Hence Darcy-Weisbach formula in the term of discharge Q,

\[
 h_f = \frac{f L Q^2}{12 d^5}
\]

**Chezy’s formula**

\[
 V = C \sqrt{mi}
\]

Where \( V \) – velocity of flow in m/s

\( C \) – Chezy’s constant

\( i \) – Loss of head per unit length of pipe = \( \frac{h_f}{L} \)

\( m \) – Hydraulic mean depth = (Area of flow/ Perimeter) = A / P

\( m = \frac{d}{4} \) for pipe flow

4. Minor losses

The losses due to disturbances in flow pattern or due to change in velocity are called as minor losses. These losses may occur due to sudden change in the area of flow and the direction of flow. These losses are less as compare to major losses. The minor loss of the head (energy) includes the following cases:
1. Loss of head due to sudden enlargement
2. Loss of head due to sudden contraction
3. Loss of head at the entrance of a pipe
4. Loss of head at the exit of a pipe
5. Loss of head due to bends
6. Loss of head in various pipe fittings
7. Loss of head due to obstruction

1. Loss of head due to sudden enlargement

Fig. represents a pipe in which fluid experiences sudden enlargement. Here the head loss occurs due to the separation of the flow at the periphery of the smaller pipe, which leads to eddying motion in the corner region.

The Equation gives head loss due to sudden expansion.

\[ h_e = \frac{(V_1 - V_2)^2}{2g} \]

Where, \( V_1 \) = Velocity of fluid at section 1-1
\( V_2 \) = Velocity of fluid at section 2-2

2. Loss of Head Due to Sudden Contraction

Fig. represents a pipe in which fluid experiences sudden contraction. The stream lines are converging from section 1-1 to section C-C. The head loss occurs only after the vena contracta CC. This is because the flow up to this section is accelerating and the boundary layer separation does not occur. Let the area at section C-C be \( A_C \) and velocity of fluid be \( V_C \).

Using Bernoulli’s equation, continuity and momentum equation at section 1-1 and 2-2, it can be proved that head loss due to sudden contraction is,
\[ hc = \left(\frac{1}{c_c} - 1\right)^2 \frac{v^2}{2g} \]

Where, \( V_2 = \) Velocity of fluid at section 2-2

\( C_c = \) Coefficient of contraction = \( A_c/A_2 \)

If \( C_c \) not given,

\[ hc = 0.5 \frac{v^2}{2g} \]

3. Loss of Head at the entrance of a pipe

The loss of head at the entrance of pipe is a similar case to loss of head due to sudden contraction as there is an abrupt reduction in area from an area of reservoir to area of a pipe. The loss of head is caused mainly by the turbulence created by the sudden enlargement of the jet after it has passed through the vena contracta.

\[ h = 0.5 \frac{v^2}{2g} \]

4. Loss of head at the exit of a pipe

When the fluid from the pipe enters into a relatively larger reservoir the entire velocity is dissipated. If \( V \) is the velocity of fluid in a pipe, the head loss at exit is given by

\[ h = \frac{V^2}{2g} \]

5. Loss of head due to bends

The loss of head in bends provided in pipes may be expressed as,

\[ h = k \frac{V^2}{2g} \]

\( V \) is the mean velocity of flow of liquid and \( K = \) coefficient of bend and is depends on the angle of bend, radius of the curvature and diameter of pipe.

6. Loss of Head in Various Pipe Fittings

Pipe fittings in a piping system cause obstruction to flow and the loss of head occurs. The loss of head may be expressed as,

\[ h = k \frac{V^2}{2g} \]

Where, \( K = \) Coefficient of pipe fitting

Various pipe fitting shown in following figure,
7. Loss of head due to obstruction

The loss of head due to obstruction in a pipe takes place due to reduction in the cross sectional area of the pipe by the presence of obstruction which is followed by an abrupt enlargement of the stream lines beyond the obstruction. (Shown in figure)

Let, \( V = \) Velocity of fluid in pipe
\( A_0 = \) Maximum area of obstruction
\( A = \) Area of pipe
\( h_o = \) head loss due to obstruction

\[
h_o = \frac{1}{2C_C (A - A_0)} - 1 \left( \frac{V^2}{2g} \right)
\]

5. HGL & TEL

Hydraulic gradient line (HGL): It is defined as the line which gives the sum of pressure head (\( p/w \)) and datum head (\( z \)) of flowing fluid in a pipe with reference to some reference line. HGL may rise or fall depending upon the pressure changes.

\[
\text{HGL} = \frac{p}{\rho g} + z
\]
**Total Energy Line (TGL/TEL):** Total energy line is the line which gives sum of pressure head, datum head and kinetic head of flowing fluid in a pipe with respect to some reference line. When fluid flows along the pipe, there is loss of head and total energy decreases in the direction of flow.

\[
TEL = \frac{p}{\rho g} + z + \frac{v^2}{2g}
\]

6. Pipes in Series and Parallel

If piping system is formed by joining pipes of different diameter and lengths in continuation as shown in Fig., these are said to be pipes in series.

In this case, \( Q = Q_1 = Q_2 = Q_3 \)

And the total head loss between two ends of the pipe is given by,

\[
h_f = h_{f1} + h_{f2} + h_{f3}
\]

If two or more pipes are joined to form a single pipe, there are said to be in parallels. In Figure, pipe 1 and 2 are in parallels between points A and B. In this case, by continuity equation,

\[
Q = Q_1 + Q_2
\]
And neglecting minor losses, total head loss in this system is given as,

\[ h_{f1} = h_{f2} \]

7. Hydraulic power transmission through pipe

Power is transmitted through pipes by flowing water or other liquids power flowing through then transmitted depends upon (i) the weight of liquid flowing through the pipe and (ii) the total head available at the end of the pipe.

Consider a pipe AB connected to a tank conveying discharge Q from point A to B as shown in fig.

Let,
- \( L \) = length of the pipe,
- \( d \) = diameter of the pipe,
- \( H \) = total head available at the inlet of pipe,
- \( V \) = velocity of flow in pipe,
- \( h_f \) = loss of head due to friction
- \( f \) = co-efficient of friction

The head available at the outlet of the pipe, if minor losses are neglected,

\[ = \text{Total head at inlet} - \text{loss of head due to friction} \]
\[ = H - h_f \]
\[ = H - \frac{4 f L V^2}{2 g d} \]

The power transmitted at the outlet of the pipe,

\[ P = \text{weight of water per sec} \times \text{head at outlet} \]
\[ = \rho g Q (H - h_f) \text{ kw} \]

The power transmitted at the inlet of the pipe,

\[ P = \text{weight of water per sec} \times \text{head at inlet} \]
\[ = \rho g Q H \text{ kw} \]
Efficiency of power transmitted through the pipe,

\[
\eta = \frac{\text{Power available at the outlet of the pipe}}{\text{Power supplied at the inlet of the pipe}}
\]

\[
\eta = \frac{\rho g Q (H - hf)}{\rho g Q H}
\]

\[
\eta = \frac{H - hf}{H}
\]

**Condition of power transmission:**

The condition of maximum power transmission is obtained by differentiating power transmission at outlet with respect to \( V \) and equation the same to zero. Thus,

\[
\frac{d}{dV} (P) = 0
\]

\[
\frac{d}{dV} \left[ \frac{\rho g}{1000} \times \frac{\pi}{4} d^2 \left( HV - \frac{4 flV^3}{2gd} \right) \right] = 0
\]

\[
\frac{\rho g}{1000} \times \frac{\pi}{4} d^2 \left( H - \frac{4 \times 3 \times flV^2}{2gd} \right) = 0
\]

\[
H - \frac{3 \times 4 flV^3}{2gd} = 0
\]

\[
H - 3 \times h_f = 0
\]

\[
h_f = \frac{H}{3}
\]

Above equation shows that the head lost in friction should be one-third of head available at entry for maximum power transmission.

The maximum efficiency is,

\[
\eta_{\text{max}} = \frac{H - h_f}{H} = \frac{H - \frac{H}{3}}{H} = 66.7\%
\]

8. **Water Hammer in Pipes**

Consider a long pipe \( AB \) as shown in Figure connected at one end to a tank containing water at a height of \( H \) from the center of the pipe. At the other end of the pipe, a valve to regulate the flow of water is provided. When the valve is completely open, the water is flowing with a velocity, \( V \) in the pipe.
If the valve is suddenly closed, the momentum of the flowing water will be destroyed and consequently a wave of high pressure will be set up. This wave of high pressure will be transmitted along the pipe with a velocity equal to the velocity of sound wave and may create noise called knocking. Also this wave of high pressure has the effect of hammering action on the walls of the pipe and hence it is known as water hammer.

The pressure rise due to water hammer depends upon:

1. The velocity of flow of water in pipe,
2. Length of pipe,
3. Time taken to close the valve,
4. Elastic properties of the material of the pipe

Remedy to avoid water hammer:

In order to avoid water hammer in pipes, the valve must close gradually. The time (t) required to close valve should be greater than \( \frac{2L}{C} \), Which is considered as valve has been closed gradually.

\[
t > \frac{2L}{c}
\]

Where, \( L = \) length of pipe and \( C = \) Velocity of pressure wave

Causes:

If a fluid flowing in a pipe suddenly brought to rest by closing valve, there will be sudden rise in pressure due to momentum of the moving fluid being destroyed.

1. This causes series of pressure vibration
2. These vibration setups noise in the pipe

Effect:

1. This increase in pressure in the pipe line causes the pipe to be expanded if it is elastic or burst if it is non-elastic.
2. The water hammer also sets vibrations in the pipeline a using joints to be open