DEPARTMENT OF MECHANICAL ENGINEERING

19MEB201 - Fluid Mechanics and Machinery
UNIT -2 FLOW OVER FLAT PLATE AND FLOW THROUGH CIRCULAR CONDUITS
NOTES

Therefore, the head loss of the latter case is four times of the former comes due to doubled mean velocity.

ii) Various Minor Losses:-

The loss of energy due to friction in a pipe is known as major losses while the loss of energy caused on account of the change in velocity of flowing fluid is called minor loss of energy. In case of long pipes, these losses are usually quite small as compared to the loss of energy due to friction and hence, they are called 'minor losses'.

Some times, it may be neglected without serious error. But in case of short pipes these losses are comparable with the loss of energy due to friction. Some of the losses of energy, which may cause due to the change of velocity, are as follows.

1. Loss of energy due to Sudden enlargement
2. Loss of head due to Sudden Contraction
3. Loss of energy at the entrance to the pipe
4. Loss of energy at the exit from the pipe
5. Loss of energy due to gradual Contraction or enlargement

6. Loss of energy due to an obstruction in a pipe

7. Loss of energy in bends

8. Loss of energy in various pipes fittings.

(2) Two tanks of fluid ($\rho = 998\ kg/m^3$ and $\mu = 0.001\ kg$ at 20°C are connected by a capillary tube 4 mm in diameter and 3.5 m long. The surface of tank 1 30 cm higher than the surface of tank 2. Estimate the flow rate in m^3/h. Is the flow laminar? For what tube diameter will Reynolds number be 500? (NOV 2013)

Given data:

$\rho = 998\ kg/m^3 \quad \mu = 0.001\ kg/ms = 0.001\ \frac{N}{m}$

$D = 4mm = 0.004\ m, \quad L = 3.5m$

$Z_1 - Z_2 = H = 30\ cm = 0.3\ m$

Solution:

Exit velocity of flow in the capillary tube

$$V = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 0.3} = 2.4\ \frac{m}{s}$$

From Continuity equation

$$\text{flow rate } Q = AV = \frac{\pi}{4} D^2 V.$$

$$= \frac{\pi}{4}(0.004)^2 \times 2.426$$

$$= 3.05\ m^3/s$$

Reynolds number $\quad Re = \frac{\rho V D}{\mu}$

$$= \frac{998 \times 2.426 \times 0.004}{0.001}$$

$$= 9684.59 > 5000$$

Therefore, the flow is turbulent since the flow through tube is considered as flow through pipes and Reynolds number of the flow is more than 5000.

For the Reynolds number 500, the diameter of the tube is given by

$$D = \frac{Re\,\mu}{\rho V} = \frac{500 \times 0.001}{998 \times 2.426} = 0.206\,mm$$

(3) A 150mm diameter pipe reduces in diameter abruptly to 100mm diameter. If the pipe carries water at 30 litres per second, calculate the pressure loss across the contraction. Take coefficient of contraction as 0.6 (Nov 2012)

Given data:

$d_1 = 150mm = 0.15m$, $d_2 = 100mm = 0.1m$.

$Q = 30\ lit/s = 0.03\ m^3/s$

Co-efficient of contraction $C_c = 0.6$

Solution:

Area $A_1 = \frac{\pi}{4} d_1^2 = \frac{\pi}{4}(0.15)^2 = 0.01767\ m^2$

$A_2 = \frac{\pi}{4} d_2^2 = \frac{\pi}{4}(0.1)^2 = 7.85 \times 10^{-3}\ m^2$

From Continuity equation (1)

$$A_1 V_1 = A_2 V_2$$

$$V_1 = \frac{Q}{A_1} = \frac{0.03}{0.01767} = 1.697 \text{ m/s}$$

$$V_2 = \frac{Q}{A_2} = \frac{0.3}{7.85 \times 10^{-3}} = 3.82 \text{ m/s}$$

Head loss due to Sudden Contraction.

$$h_c = \frac{V_2^2}{2g}\left[\frac{1}{C_c} - 1\right]^2$$

$$= \frac{3.82^2}{2 \times 9.81}\left[\frac{1}{0.6} - 1\right]^2$$

$$\boxed{h_c = 0.444 \text{ m}}$$

(4) A plate of 600mm length and 400mm wide is immersed in a fluid of specific gravity 0.9 and kinematic viscosity of (ν) $= 10^{-4}$ m²/s The fluid is moving with the velocity of m/s Determine

(1) Boundary Layer thickness.

(2) Shear stress at the end of the plate

(3) Drag force on one side of the plate

Given data:

$L = 600\,mm = 0.6\,m$, $S = 0.9$ $U = 6\,m/s$

$b = 400\,mm = 0.4\,m$ $\nu = 10^{-4}\,m^2/s$

solution:

(i) Boundary Layer thickness

Reynolds number $R_e = \frac{UL}{\nu} = \frac{6 \times 0.6}{10^{-4}} = 36000$

Since $R_e < 5 \times 10^5$ the flow is Laminar, therefore, the thickness of boundary layer and shear stress for laminar flow are obtained as follows.

The empirical relation for thickness of boundary Layer for Laminar flow is given by

Prandtl - Blassius as

$$\delta_{lam} = \frac{5x}{\sqrt{R_e}} = \frac{5 \times 0.6}{\sqrt{3600}} = 0.0158$$

(ii) Shear Stress at the end of the Plate

$$\text{Shear Stress } \tau_0 = \frac{\mu U \pi}{2\delta} = \frac{0.9 \times (1 \times 10^{-4}) \times 6 \times \pi}{2 \times 0.0158}$$

$$= 0.0536\ N/m^2$$

(iii) Drag force on the Side of the plate

Force = Stress × area

$$F_D = \tau_0 \times b \times L = \frac{\mu U \pi}{2\delta} \times b \times L$$

$$F_D = \frac{0.9 \times (1\times10^{-4}) \times 6 \times \pi}{2 \times 0.0158} \times 0.4 \times 0.6$$

$$\boxed{F_D = 0.01288\ N.}$$

(5) A pipe of 12cm diameter is carrying an oil ($\mu = 2.2$ Pa.S and $\rho = 1250\ kg/m^3$) with a velocity of 4.5 m/s. Determine the shear stress at the wall surface of the pipe, head loss, if the length of the pipe is 25m and the power lost. (NOV 2011)

Given Data:

$D = 12cm = 0.12m$

$L = 25m$, $\mu = 2.2\ Pa.s = 2.2\ N.s/m^2$

$\rho = 1250\ kg/m^3$, $U = 4.5\ m/s$.

Solution:

$$Q = AU = \frac{\pi}{4} D^2 U = \frac{\pi}{4} \times 0.12^2 \times 4.5$$

$$Q = 0.051\ m^3/s.$$

From Hagen-poiseuille's equation

$$P_1 - P_2 = \frac{128 \mu QL}{\pi D^4}$$

$$P_1 - P_2 = \frac{128 \times 2.2 \times 0.051 \times 25}{\pi \times 0.12^4}$$

$$\boxed{P_1 - P_2 = 551,147.67\ Pa}$$

Shear stress at the pipe wall

$$\tau_{max} = \left(-\frac{dp}{dx}\right)\frac{R}{2}$$

$$= \frac{P_1 - P_2}{L} \times \frac{R}{2}$$

$$= \frac{551147}{25} \times \frac{0.12}{2\times 2}$$

$$= 661.38\ N/m^2$$

Head loss due to friction $h_L = \frac{32 \mu U L}{w D^2}$

$$= \frac{32 \mu U L}{\rho g D^2}$$

$$= \frac{32 \times 2.2 \times 4.5 \times 25}{(1250 \times 9.81) \times (0.12)^2}$$

$$= 44.85\ m$$

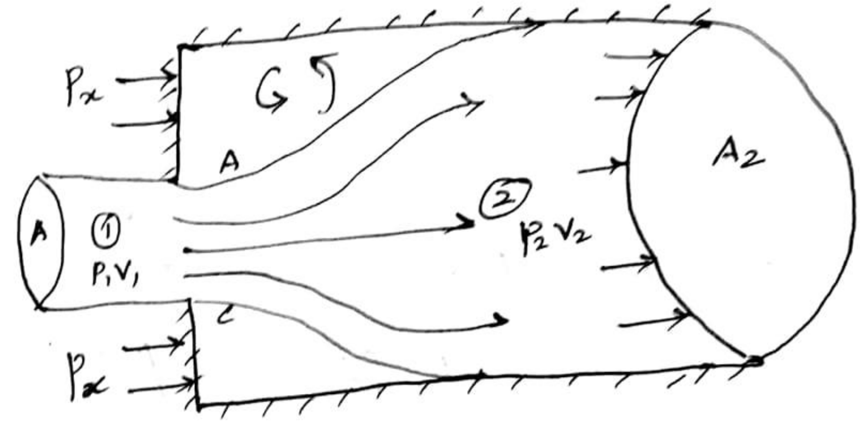
Power Lost $P = wQ h_L$

$$P = (1250 \times 9.81) \times 0.051 \times 44.85$$

$$\boxed{P = 28.05\ kW}$$

Minor Head Losses

The local or minor head losses are caused by certain local features or disturbances. The disturbances may be caused by changes in the size or shape of a pipe; this would affect the velocity distribution and may result in eddy formation.



The above sketch explains two pipes of cross-sectional area A_1 and A_2 flanged together with a constant density fluid from the smaller-diameter pipe to the larger-diameter pipe.

The fluid fails to make an adjustment with the change in direction needed for complete filling of the larger diameter pipe.

• If a
diff
lin

TI

f

• I

Tot

G

The flow brakes away from the edge of narrow section; eddies form and the resulting turbulence causes dissipation of energy.

The initiation and onset of turbulance is due to fluid momentum and its inertia

Consider 2 sections 1-1 through the plane of expansion
2-2 End of the region of extensive turbulence caused by fluid separation

From Momentum Considerations:

$$P_1 A_1 + P_x (A_2 - A_1) - P_2 A_2 = \frac{WQ}{g}(V_2 - V_1) \quad \text{---} (1)$$

neglecting any radial acceleration of fluid in the plane of change in section, the velocity at the annular AB and CD is very small and so the pressure there can be assumed to be equal to the pressure of incoming fluid

i.e. $P_x = P_1$ and then the momentum equation transforms to

$$P_1 - P_2 \cancel{A_2} = \frac{WQ}{g}(V_2 - V_1)$$

or. $$\frac{P_1 - P_2}{w} = \frac{Q}{A_2 g}(V_2 - V_1)$$

$$= \frac{V_2 (V_2 - V_1)}{g}$$

Invoking the Bernoullis equation.

$$\frac{P_1}{w} + \frac{V_1^2}{2g} = \frac{P_2}{w} + \frac{V_2^2}{2g} + h_{exp}$$

where h_{exp} represents the head loss due to an abrupt expansion.

$$h_{exp} = \left(\frac{P_1 - P_2}{w}\right) + \frac{V_1^2 - V_2^2}{2g} \quad \text{——} \; (2)$$

Combining expression (i) and (ii)

$$h_{exp} = \frac{V_2 (V_2 - V_1)}{g} + \left(\frac{V_1^2 - V_2^2}{2g}\right)$$

$$h_{exp} = \frac{(V_1 - V_2)^2}{2g} \quad \text{——————} \; (3)$$

Evidently the loss of head due to abrupt expansion equals the velocity head computed for the velocity difference, Since by Continuity

$$A_1 V_1 = A_2 V_2$$

$$V_2 = \frac{A_1 V_1}{A_2}$$

and therefore, equation (3) may be alternatively written as $h_{exp} = \left[1 - \left(\frac{A_1}{A_2}\right)\right]^2 \frac{V_1^2}{2g} = K_{exp} \frac{V_1^2}{2g}$ — (4)

The head loss is a function of incoming velocity head. When area A_2 is very Large as Compared with A_1, Velocity V_2 Can be assumed to be zero.

Loss of velocity head and kinetic energy is then Complete. The flow situation Corresponds to a pipe discharging into a Large reservoir of sufficient size.

Hence, Head loss is called as pipe exit loss h_{exit}.

$$h_{exit} = K_{exit} \frac{V^2}{2g}$$

$$\boxed{h_{exit} = 1 \frac{V^2}{2g}} \quad \text{——— (5)}$$

V represents the average velocity in the pipe

other Terms Synonyms with the loss of head due to an abrupt enlargement are

- Eddy loss because the expansion loss of head is expended exclusively on eddy formation, and Continuous Sustenance of rotational motion of the fluid masses.
- Shock loss because an abrupt expansion Causes Sudden slowing of the fluid Stream.

Important formulas:

(1.) Loss of energy due to Sudden enlargement (h_e)

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

(2.) Loss of energy due to Sudden Contraction (h_c)

$$h_c = \frac{K V_2^2}{2g}$$

$K = \left(\frac{1}{C_c} - 1\right)^2$

where $K = 0.375$ to 0.5

If C_c Value or K is not given, then the head loss due to friction is taken as $h_c = \frac{0.5 V_2^2}{2g}$

(3) Loss of energy at the entrance to a pipe (h_i)

$$h_i = \frac{0.5 V^2}{2g}$$

(4) Loss of energy at the exit from a pipe (h_o)

$$h_o = \frac{V^2}{2g}$$

(5) Loss of energy due to an obstrution in a pipe (h_{obs})

$$h_o = \frac{V^2}{2g} \cdot \left(\frac{A}{C_c\,(A-a)} - 1\right)^2$$

V_c - Velocity of liquid at Vena - Contracta

A_c - Area of Cross Section at Vena - Contracta

(6) Loss of energy due to gradual Contraction or Enlargement (h_L)

$$h_L = k \frac{(V_1 - V_2)^2}{2g}$$

(7) Loss of energy due to Bend in pipe (h_b)

$$h_b = \frac{KV^2}{2g}$$

K - Co-efficient which depends on the total angle of bend or radius of curvature of bend.

(8) Loss of energy in various pipe fittings.

$$h_v = \frac{KV^2}{2g}$$

K → coefficient, which depends on the type of pipefitting.