LECTURE 6- ENERGY LOSSES IN HYDRAULIC SYSTEMS

SELF EVALUATION QUESTIONS AND ANSWERS

1. What is the head loss (in units of bars) across a 30mm wide open gate valve when oil (SG=0.9) flow through at a rate of 0.004 m^3/s

2.A directional control valve with an effective area of 0.00032258 m^2 provides a pressure drop of 275.8 kPa at 0.00379 m^3/sec. if the fluid has a specific gravity of 0.9, find flow coefficient K factor for the valve. Find also the capacity coefficient of this valve.

3. Oil (SG=0.9 and kinematic viscosity = 0.0001 m^2/s) flows at a rate of 0.002 m3/s through a 20 mm diameter commercial steel pipe . What is the equivalent length of a 20mm wide open gate valve placed in the line.

4.Oil with a kinematic viscosity of $0.32 \times 10^{-4} m^2/s$ is flowing through a 25 mm pipe at the rate of 375 l/min. Is the flow laminar or turbulent?

5. Oil with a specific gravity of 0.85 and an absolute viscosity of 0.44Ns/m^2 is flowing in a 25mm diameter pipe 120m long at the rate of 55.1 l/min. Determine the type of flow and calculate the pressure drop.

6. Oil with a specific gravity of 0.85 and a kinematic viscosity of $1.932 \times 10^{-4} m^2/s$ is flowing through a 50 mm diameter commercial steel pipe at the rate of 3500 l/min. What is the pressure drop in 150m.

7. A hydraulic pump delivers oil at 60 bar, 120 l/min into a circuit laid on a horizontal plane. There are four elbows (K = 0.75), one globe valve fully open (K=10) and a direction control valve (pressure drop = 3 bar) with the inside diameter of the pipe as 30 mm. The total length of the straight run pipe is 20m and the specific gravity of the oil is 0.9. The kinematic viscosity of the oil is 0.0001 m^2/s. Determine the pressure at the exit point of the pipe.

8. The system as shown in Figure 1 contains a pump delivering high pressure oil of specific gravity 0.9 and kinematic viscosity $1.25 \times 10^{-4} m^2/s$, to a hydraulic motor. A pipe connects the pump and motor has an inner diameter of 25 mm and length 15 m. The pipe has two elbow fittings (K=0.75) and one check in valve (K=4.0). The motor is placed 6m above the pump. The inlet pressure to the motor is 34 bar. Determine the pump discharge pressure, if the discharge from the pump is 150 l/min.

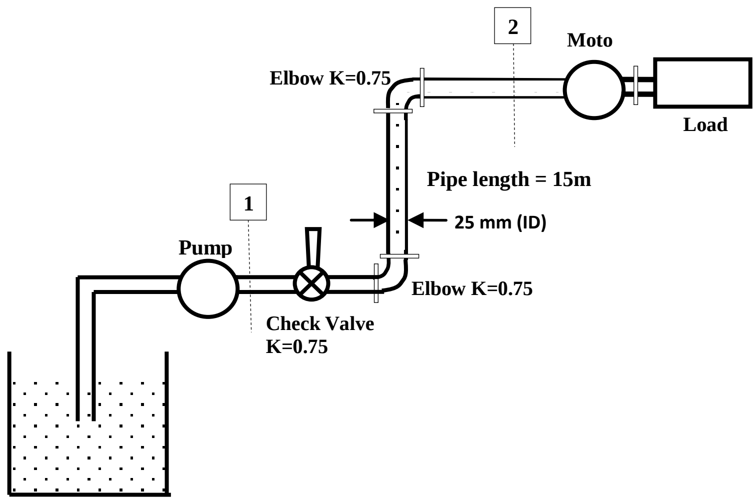

Figure 1 for the Problem No 8

Q1 Solution

K = 0.19 for the wide open gate valve (from the table)

$$Velocity\ of\ fluid = \frac{Flow\ rate}{area} = \frac{0.004}{\frac{\pi(0.03^2)}{4}} = 5.66\ m/s$$

$$H_L = K\left(\frac{V^2}{2g}\right) = 0.19x\left(\frac{5.66^2}{2x9.81}\right) = 0.31\ m$$

The pressure loss is

$$\Delta p = \gamma H_L = 1000\frac{kg}{m^3}x0.90x9.81\frac{m}{s^2}0.31 = 2740\frac{N}{m^2} = 0.0274\ bar$$

Q2 Solution

We know that

$H_L = K\left(\frac{V^2}{2g}\right)$------ 1

$\Delta p = \gamma H_L$ ---------2

Using 2 in 1, we get

$$\frac{\Delta p}{\gamma} = K\left(\frac{V^2}{2g}\right)$$

Also

$$Velocity\ of\ fluid = \frac{Flow\ rate}{area} = \frac{0.00379}{0.00032258} = 11.75\ m/s$$

$$K = \frac{2\ g\Delta p}{\gamma V^2} = \frac{2\ xg\left(\frac{m}{s^2}\right)x\Delta p\frac{N}{m^2}}{\gamma\left(\frac{N}{m^3}\right)V^2\left(\frac{m^2}{s^2}\right)} = \frac{2\ x9.81x275.8x1000}{1000x0.9x9.81x11.75^2} \cong 4.43$$

For a give opening position, a valve behaves as an orifice Flow through the orifice is given by (for details see chapter on flow through valves).

$$Q = 0.0851\, A\, C_V \sqrt{\frac{\Delta p}{SG}} =$$

Where Q= volume flow rate in LPM= 0.00379 m^3/sec =227.13 LPM

C_V= capacity coefficient = 0.80 for sharp edges orifice, c= 0.6 for square edged orifice.

A = area of orifice opening in mm^2=0.00032258 m^2=322.58 mm^2

Δp = pressure drop across the orifice (kPa)= 2.758 bar =275.8 kPa.

SG= specific gravity of flowing fluid = 0.9

$$Q = 0.0851\, A\, C_V \sqrt{\frac{\Delta p}{SG}} = 0.0851x\ 322.58\ C_V \sqrt{\frac{275.8}{0.9}} = 227.13$$

Substituting all the values we get C_V =0.473

Note that C_V and K are dimensionless. Values are independent of system of units.

Q3 Solution

We know that

$$Velocity\ of\ fluid = \frac{Flow\ rate}{area} = \frac{0.002}{\frac{\pi(0.02^2)}{4}} = 6.37\ m/s$$

$$R_e = \frac{VD\rho}{\mu} = \frac{VD}{\frac{\mu}{\rho}} = \frac{VD}{\nu} = \frac{6.37x0.02}{0.0001} = 1274, \qquad flow\ is\ laminar$$

$$f = \frac{64}{R_e} = \frac{64}{1274} = 0.0502$$

$$L_e = \left(\frac{KD}{f}\right)$$

$$L_e = \left(\frac{KD}{f}\right) = \left(\frac{0.19x0.020}{0.0502}\right) = 0.0706m$$

Q4 Solution

Velocity of flow, V = $\frac{Q}{A}$

$$= \frac{(375 \times 10^{-3}/60)}{\frac{\pi}{4}\times (0.025)^2}$$

= **12.73 m/s**

Reynolds number, $Re = \frac{VD}{\upsilon}$

$$= \frac{12.73 \times 0.025}{0.32 \times 10^{-4}}$$

= **9945.3**

The Reynolds number is greater than 2000. So the flow is turbulent.

Q5 Solution

Velocity of flow V = $\frac{Q}{A} = \frac{(55 \times 10^{-3} / 60)}{\frac{\pi}{4}\times(0.025)^2}$ = 1.87 m/s

Reynolds number, $Re = \frac{\rho VD}{\mu} = \frac{(0.85 \times 1000) \times 1.87 \times 0.025}{0.044} = 903$

The Reynolds number is less than 2000. So the flow is laminar.

For laminar flow,Friction factor $f = \frac{64}{Re} = \frac{64}{903}$ = **0.0709**

Head loss, $H_L = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) = 0.0709\left(\frac{120}{0.025}\right)\left(\frac{1.87^2}{2 \times 9.81}\right) = 60.66\text{m}$

Pressure drop = γH_L = (0.85 × 1000 × 9.81) × 60.66

= 5.06 × 10^5 Ns/m^2

= 5.06 bar

Q6 Solution

Velocity of flow V = $\frac{Q}{A} = \frac{(3500\times10^{-3}/6)}{\frac{\pi}{4}\times(0.05)^2}$ = **29.71 m/s**

Reynolds number $Re = \frac{VD}{\nu} = \frac{29.71 \times 0.05}{1.932 \times10^{-4}} = 7689$

The Reynolds number is greater than 2000. So the flow is turbulent.

The pipe used is a commercial steel pipe. So absolute roughness (ε) = 0.046 mm

Relative roughness $\frac{\varepsilon}{D} = \frac{0.046}{50}$

Now locate R_e and $\frac{\varepsilon}{D}$ values in Moody diagram. Draw the projections and find the meeting point.

Draw the projections and find the meeting. Draw a projection from the meeting point to '*f*' axis. The '*f*' value obtained is 0.02

Head loss $H_L = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) = 0.02\times\left(\frac{150}{0.05}\right)\left(\frac{29.71^2}{29.71}\right)$ = **2699**

Pressure loss $= \gamma H_L$

= (0.85 × 1000 × 9.81) × 2699

= 225 × 10^5 N/m^2

= **225 bar**

Q7 Solution

Velocity of flow $V = \frac{Q}{A} = \frac{(120\times10^{-3}/60)}{\frac{\pi}{4}\times0.03^2}$ = 2.83m/s

Reynolds number $Re = \frac{VD}{\nu} = \frac{2.83 \times 0.03}{0.0001}$ = **849**

The Reynolds number is less than 2000, so the flow is laminar.

Since the flow is laminar,Friction factor $f = \frac{64}{Re} = \frac{64}{849}$ = **0.075**

K factors for the valves and fittings

4 elbows (K=0.75) = 3

1 Globe valve(K=10) = 10/13

$\therefore$ Equivalent length for fittings $= \frac{KD}{f} = \frac{(13 \times 0.03)}{0.075} = 5.2\, m$

Total equivalent length, L_e = Pipe length + Equivalent length for fittings

= 20 + 5.2 = 25.2 m

Head Loss $H_L = f\left(\frac{Le}{D}\right)\left(\frac{V^2}{2g}\right) = 0.075 \times \left(\frac{25.2}{0.03}\right) \times \left(\frac{2.83^2}{2\times9.81}\right)$ = 25.72 m

Pressure drop in pipe and fittings = γH_L = (0.9 × 1000 × 9.81) × 25.72

= 2.27 × 10^5 N/m^2= 2.27 bar

Pressure drop in direction control valve = 3 bar

$\therefore$Pressure at the exit of the pipe = 60 – (2.27 + 3) = **54.73 bar**

Q8 Solution

Velocity of flow in the pipe $V = \left(\frac{Q}{A}\right) = \left\{\frac{(150\times 10^{-3}/60)}{\frac{\pi}{4}\times (0.025)^2}\right\}$ = 5.09 m/s

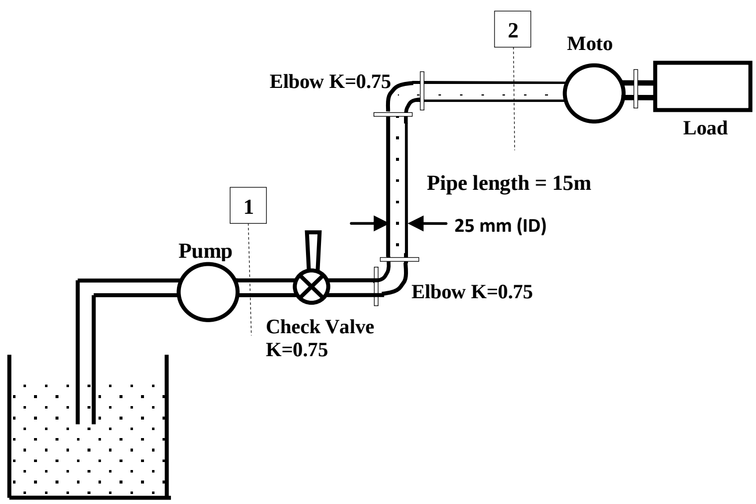

Figure 1 for the Problem No 8

Reynolds number $= \frac{VD}{\nu} = \frac{(5.09\times 0.025)}{(1.25\times 10^{-4})}$ = **1018**

The Reynolds number is less than 2000. So the flow is laminar.

Since the flow is laminar $f = \frac{64}{Re} = \frac{64}{1018}$ = **0.0629**

K value for the fittings and valves = (2 × 0.75) + 4

Total equivalent length = length of pipe + equivalent length of fittings

$= 15 + \left(\frac{KD}{f}\right) = 15 + \left\{\frac{(5.5\times 0.025)}{0.0629}\right\}$ = **17.19 m**

Head Loss = $f\left(\frac{Le}{D}\right)\left(\frac{V^2}{2g}\right) = 0.0629 \times \left(\frac{17.19}{0.025}\right)\left(\frac{5.09^2}{2\times 9.81}\right)$**= 57.11 m**

Applying Bernoulli's equation between station 1 and 2

$$\frac{P_1}{\gamma} + \frac{V_2^2}{2g} + Z_1 - H_L = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2$$

Here, $V_1 = V_2$;

$$\frac{(P_1 - P_2)}{\gamma} = (Z_2 - Z_1) + H_L$$

= 6 + 57.11, [where, change in datum head $Z_2 - Z_1 = 6$m]

= 63.11 m

$P_1 - P_2$= (0.9 × 1000 × 9.81) × 63.11

= 5.6×10^5 N/m^2

= 5.6 bar

∴ Pump discharge pressure P_1= 5.6 + 34= **39.6 bar.**