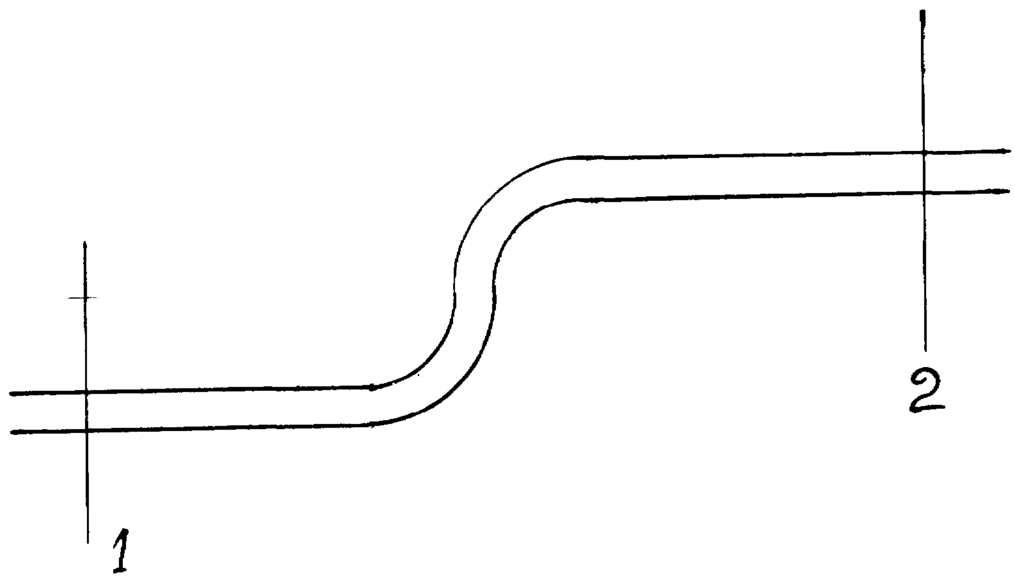
Fluid Mechanics - Course 223

PIPE FLOW PROBLEMS

So far we have looked at separate aspects of fluid flow in circular pipes. We now have to consider the combined effect of these aspects on a complete system. This involves the use of

(a) the continuity equation $A_1V_1 = A_2V_2$.

(b) Bernoulli's Equation.



Considering the two points, (1), (2), on the diagram, Bernoulli's Equation may be written as follows:

$$E_{PR(1)} + E_{PE(1)} + E_{KE(1)} + E_{ADD} = E_{PR(2)} + E_{PE2} + E_{KE2} + E_{LOSS}$$

where E_{PR} = Pressure Energy

E_{PE} = Potential Energy

E_{KE} = Kinetic Energy

E_{ADD} = Pump Energy

E_{LOSS} = Energy loss due to surface and fluid friction

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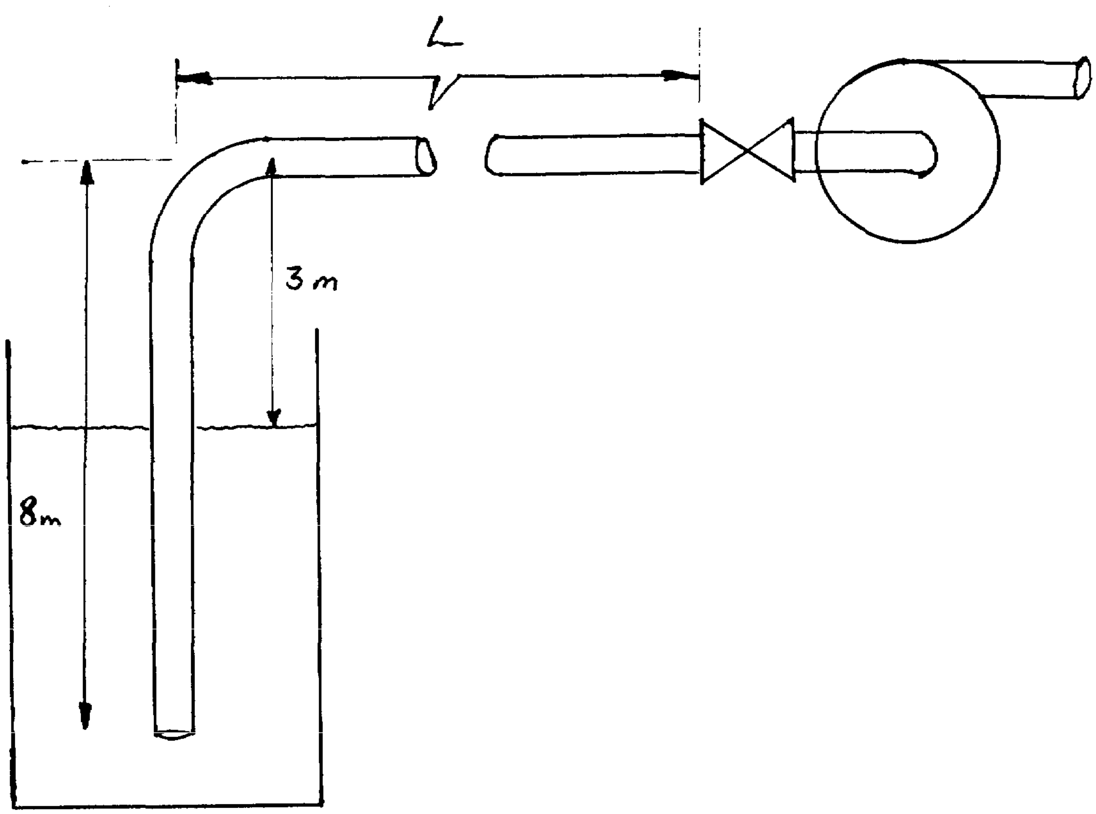
This equation may be written as follows:

$$\frac{P_1}{\ell} + gh_1 + \frac{V_1^2}{2} + E_{ADD} = \frac{P_2}{\ell} + gh_2 + \frac{V_2^2}{2} + E_{LOSS} \quad \text{Joules/kg}$$

The previous lessons have basically shown us how to calculate E_{LOSS}. We must now apply this to a real system, where there may be a change in height and thus a change in potential energy and a change in section and thus a change in kinetic energy. It should be clearly understood that changes in KE, PE and the losses due to friction ONLY affect pressure energy. It is the pressure energy which is replaced, using a pump, in a fluid flow system.

Example 1

Water is being pumped at 0.3 m^3/s. The suction line is 10" SCH 40 and the minimum suction pressure at the pump is 15 kPa(a). Calculate the maximum length of suction line 'L' when the suction line is fitted with a standard 90° elbow and an open gate valve. $\mu = 1.005 \times 10^{-3}$ Ns/m^2.



From Bernoulli's equation

$$\frac{P_1}{\ell} + gh_1 + \frac{V_1^2}{2} + E_{ADD} = \frac{P_2}{\ell} + gh_2 + \frac{V_2^2}{2} + E_{LOSS}$$

$P_1 = 101$ kPa(a) + $\ell gh = 101000 + 998 \times 9.8 \times 4$ Pa

$h_1 = V_1 = E_{ADD} = 0$

$P_2 = 15$ kPa(a), $h_2 = 8$ m, $V_2 = \dfrac{0.3}{508.7 \times 10^{-4}} = 5.9$ m/s

$E_{LOSS} = ?$

Thus $\dfrac{P_1}{\ell} = \dfrac{P_2}{\ell} + gh_2 + \dfrac{V_2^2}{2} + E_{LOSS}$

$\therefore E_{LOSS} = \dfrac{P_1}{\ell} - \dfrac{P_2}{\ell} - gh_2 - \dfrac{V_2^2}{2}$

$$= \frac{1}{998}(101000 + 998 \times 9.8 \times 5 - 15000) - 9.8 \times 8 - \frac{5.9^2}{2}$$

$= 135.2 - 78.4 - 17.4$

$= \underline{39.4}$ J/kg

E_{LOSS} = loss due to pipe + loss due to fittings + loss due to exit/entrance.

		K/D
loss due to fittings	– standard 90° elbow	30
	open gate valve	13
		43

Thus equivalent length = 43 diameters

$= 43 \times 10 \times 2.54 \times 10^{-2}$

$= \underline{10.9}$ m

Entrance loss – k for projecting pipe = 0.78

Thus $L = \dfrac{KD}{f} = \dfrac{0.78 \times 10 \times 2.54 \times 10^{-2}}{f}$

$R_E = \dfrac{VD\ell}{\mu}$ $\qquad V = \dfrac{0.3}{508.7 \times 10^{-4}} = \underline{5.9}$ m/s

$R_E = \dfrac{5.9 \times 10 \times 2.54 \times 10^{-2} \times 1000}{1.005 \times 10^{-3}}$

$= 1.49 \times 10^6$

Using Chart 1 $\varepsilon/D = 0.00018$

Using Chart 2 $f = 0.014$

$$\text{Thus entrance loss} = \frac{0.78 \times 10 \times 2.54 \times 10^{-2}}{0.014}$$

$$= \underline{14.2} \text{ m}$$

$$\text{Thus } E_{LOSS} = f \frac{(x + 10.9 + 14.2)}{2D} V^2$$

$$\therefore \frac{E_{LOSS} \times 2D}{V^2 \times f} = (x + 10.9 + 14.2)$$

$$\therefore \frac{39.4 \times 2 \times 10 \times 2.54 \times 10^{-2}}{5.9^2 \times 0.014} = 41.1 = (x + 10.9 + 14.2)$$

Thus the maximum length $x = 41.1 - 10.9 - 14.2$

$= \underline{16.0}$ m

$\therefore L = 16.0 - 8\text{m} = 8$ m

Example 2

The condensate extraction pumps take the condensate from the hot well and pump it to the deaerator, via the drain cooler and 6 lp heaters.

Flowrate is 2 x 3855 gpm

Power input to pumps is 2 x 679 bhp

Pump efficiency = 0.83%

Hot well level = 255.25 ft

Hot well pressure = 5 kPa(a)

Deaerator height = 352 ft

Deaerator pressure = 288 kPa(a)

Calculate:

(a) The energy loss due to friction through the pipe, heaters, fittings, etc.

(b) What percentage of the pump energy available does the energy loss represent?

Flowrate = 2 x 3855 gpm

$$= 2 \times 3855 \times 4.546 \times 10^{-3}\ \text{m}^3/\text{min}$$

$$= \frac{2 \times 3855 \times 4.546 \times 10^{-3} \times 1000}{60}\ \text{kg/s}$$

$$= \underline{584.2}\ \text{kg/s}$$

$$\text{Pressure energy added by pumps} = \frac{2 \times 679 \times 0.83 \times 746}{584.2}$$

$$= \underline{1439}\ \text{J/kg}$$

Bernoulli's Equation

$$\frac{P_1}{\rho} + gh_1 + \frac{V_1^2}{2} + E_{ADD} = \frac{P_2}{\rho} + gh_2 + \frac{V_2^2}{2} + E_{LOSS}$$

The velocity at the pump is the same as that just before entering the deaerator.

$$\frac{5000}{1000} + (9.81 \times 255.25 \times 12 \times 2.45 \times 10^{-2}) + 1439 =$$

$$\frac{288000}{1000} + (9.81 \times 352 \times 12 \times 2.45 \times 10^{-2}) + E_{LOSS}$$

Thus $5 + 736 + 1439 = 288 + 1015 + E_{LOSS}$

Thus $E_{LOSS} = 877$ J/kg

$$\%\ \text{loss due to friction} = \frac{877}{1439} \times 100$$

$$= \underline{60.9\%}$$

ASSIGNMENT

1. In question #2, calculate the amount of heat energy added to the condensate, via the pump.

2. In question #2, calculate the energy loss due to the fittings, drain cooler and feed heaters if the pipework is 80 m of 24" SCH 40. $\mu = 0.406 \times 10^{-3}$ kg/ms.

3. Calculate the discharge pressure in question #2.

4. A pump takes heavy water from a header, which is 12 metres above the pump, and pumps it to a storage tank 20 metres above the pump. The suction pipework is 16" SCH 40 and has two fully open gate valves, three standard elbows and is 28 metres long.

The discharge pipework is 12" SCH 40 and has a swing check valve, two gate valves, 5 long sweep elbows and a standard tee with flow through a branch and is 46 metres long. The flowrate is 0.36 m^3/s $\mu = 0.55 \times 10^{-3}$ Ns/m^2. Calculate the current taken by the 3 ph, 4.16 kv, 0.75 pf motor which drives the pump. The motor is 85% efficient and the pump is 84% efficient.

How much heat energy does the pump add to the fluid?

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