LECTURE 4 – GOVERNING LAWS AND PRINCIPLES

SELF EVALUATION QUESTIONS AND ANSWERS

1 : In the hydraulic press shown in figure 1, a force of 100N is exerted on the small piston. Determine the upward force on the large piston. The area of the small piston is 50 x 102 mm2. Also find the distance moved by the large piston if the small piston moves by 100 mm.

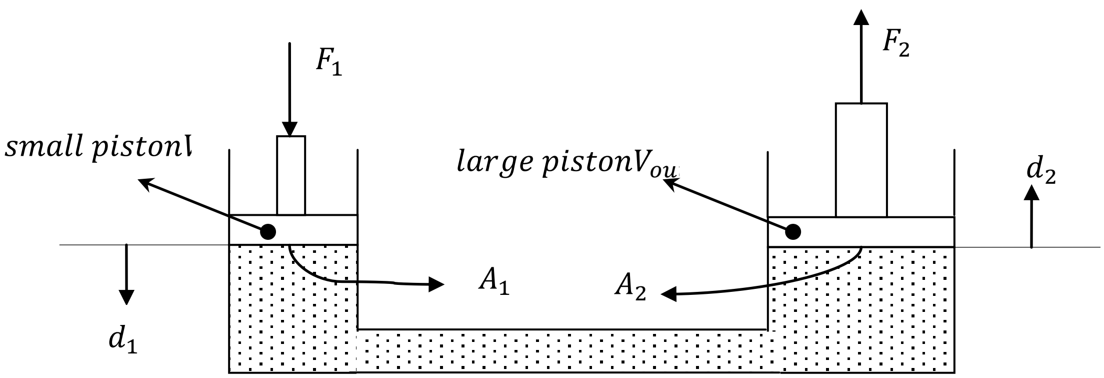


Figure 1 for the Problem No 1

2: Fluid is flowing horizontally at 0.006309 $\frac{m^3}{s}$ from a 50.8mm diameter pipe to a 25.4mm diameter pipe, as shown below (Figure 2). If the pressure at a point 1 is 68950 Pa, find the pressure at the point 2. The specific gravity of the oil is 0.9

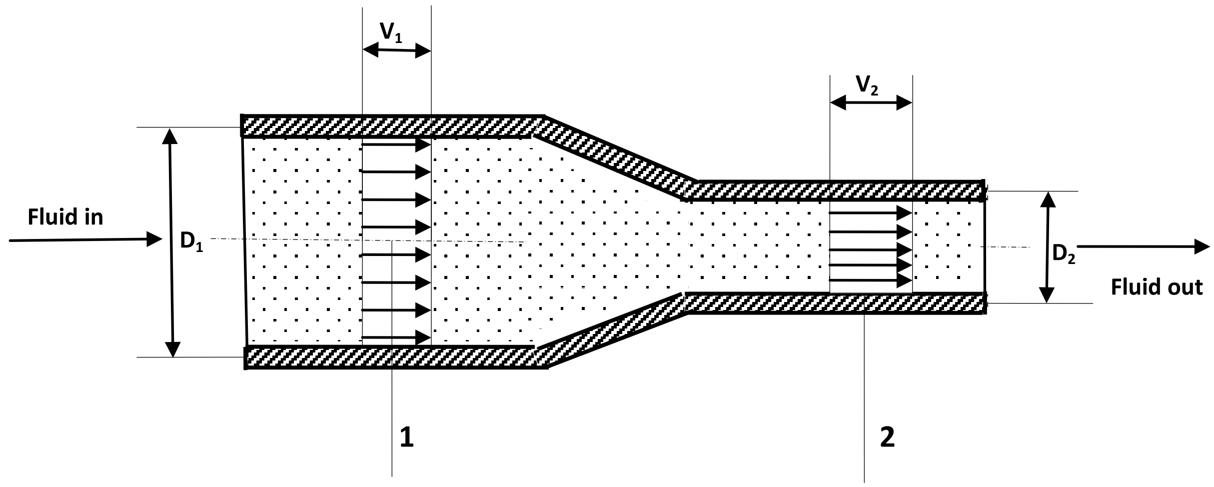


Figure 2

3 Determine the Torque delivered by a hydraulic motor if the speed is 1450 rpm and the mechanical output power is 10 kW.

4 A turbine in a hydroelectric plant has flow of 22.65 m^3/s at a pressure at inlet of 413.7 KPa. If the turbine discharges the water to the atmosphere, determine the work output of the turbine. Assume that the inlet and the outlet pipes have the same diameter and that losses in turbine equal 1.524 m.

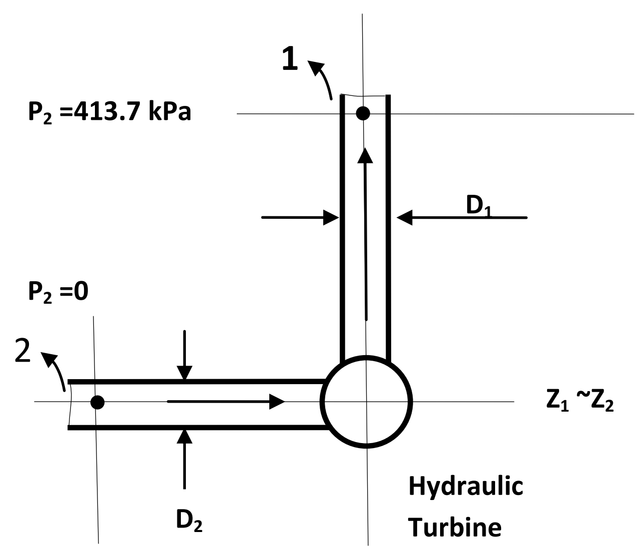


Figure 3 for the Problem No4

5 A pump is required to pump water from a large reservoir to a point located 20m above the reservoir. (Figure 4) If 0.05 m3/s of water having a density of 1000 kg/ m3 is pumped through a 50-m pipe, how much power is required to be delivered to the water by the pump? Neglect all the flow losses in the pipe.

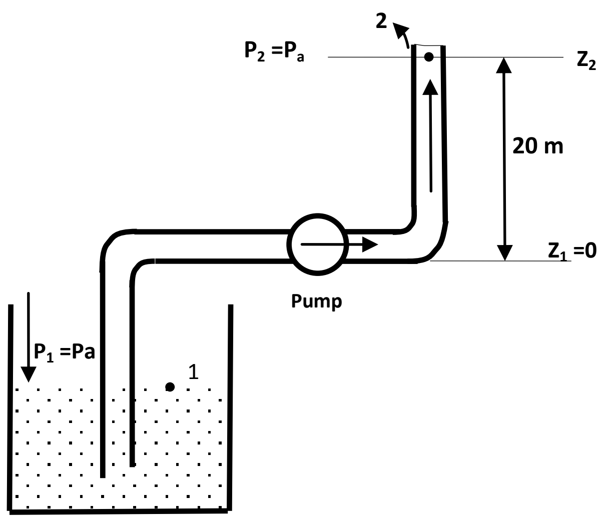


Figure 4 for the Problem No5

6 Water at $10^0\mathrm{C}$ is flowing at the rate of 115 LPM through the fluid motor shown in Fig 5. The pressure at A is 700 kPa and the pressure at B is 125 kPa. It is estimated that due to friction in the piping there is an energy loss of 4.0N.m/N of water flowing (a) calculate the power delivered to the fluid motor by the water.(b) if the mechanical efficiency of the fluid motor is 85%, calculate the power output.

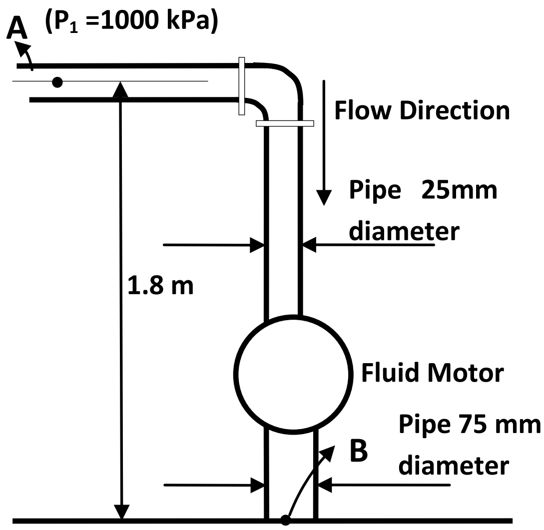


Figure 5 for the Problem No 6

7. Water flows through the double nozzle as shown in Fig. 6. determine the magnitude and direction of the resultant force the water exerts on the nozzle. The velocity of both the nozzle jets is 12 m/s. the axes of the pipe and both nozzles lie in a horizontal plane.

$\boldsymbol{\gamma = 9.81\,\frac{kN}{m^3}}$. **Neglect friction.**

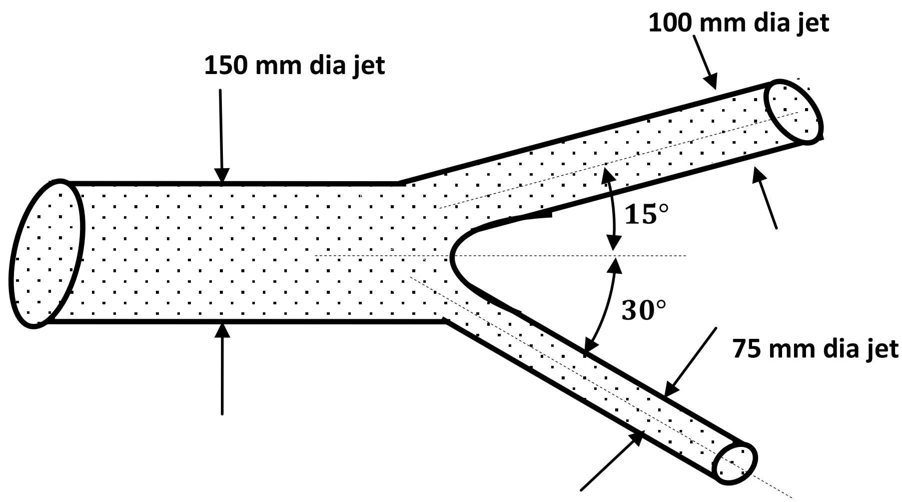


Figure 6 for the Problem No 7

8 Fluid flows from a large reservoir at the rate of 0.366 m3/s through a pipe system as shown in Figure 7 below. Calculate the total amount of energy lost from the system because of the valve, the elbows, the pipe entrance, and fluid section.

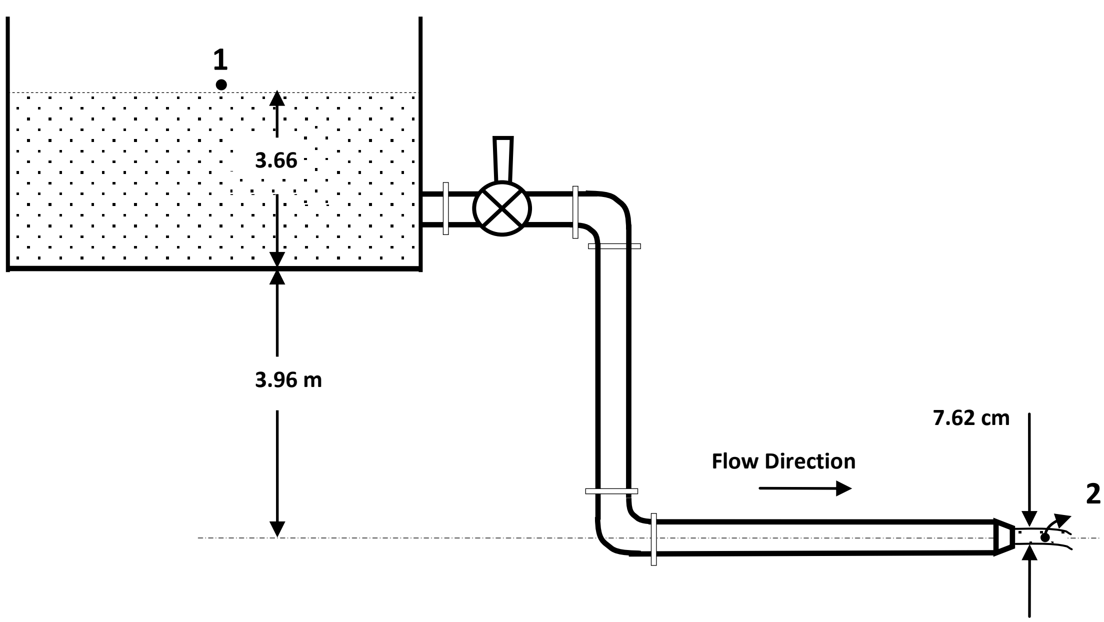


Figure 7 for the Problem No 8

9 For the fluid system shown in Figure 8 below ,point (1) is at a height of 10m above point (2). If the diameter of the outlet at (2) is 50 mm, determine :

The jet velocity (m/s) and flow rate (in LPM) for an ideal fluid.

The jet velocity (m/s) and flow rate (in LPM) for a head loss of 2m.

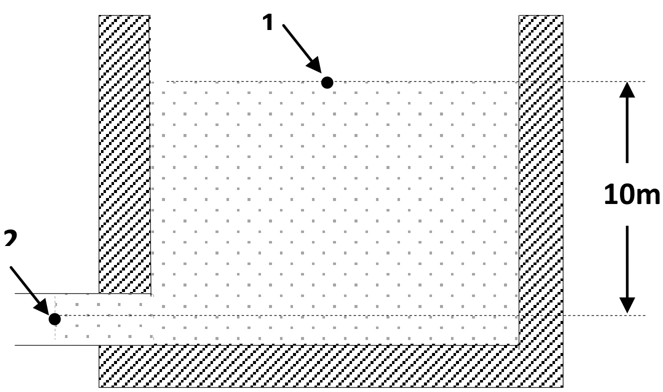


Figure 8 for the Problem No 9

Example 10 For the pump test arrangement shown in Figure 9. below, determine the mechanical efficiency of the pump if the input power is measured to be 2.2371kW when pumping 1.892 m3/min of oil ($\gamma = 249.18\ \mathrm{N/m^3}$).

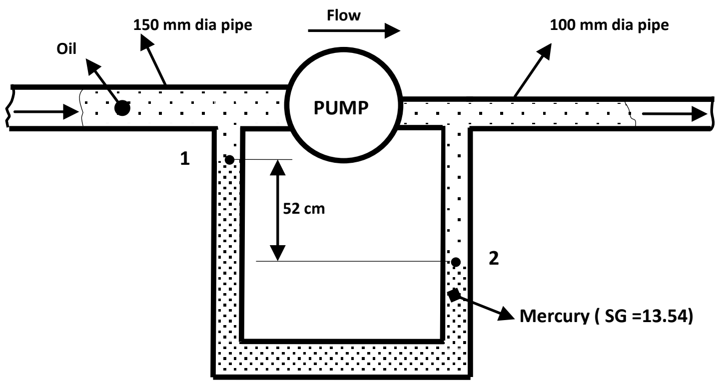


Figure 9 for the Problem No 10

11 The inlet pipe to a pump is 20 mm in diameter and 2.5 m long. If the tank, at atmospheric pressure, is positioned 1 m above the pump inlet and the pump flow rate is 90 L/min when losses are taken into account, calculate the pump inlet pressure. Assume a high-water-content fluid having $\mu = 0.001\ \mathrm{Ns/m^2}$, $\rho = 10^3 \mathrm{kg/m^3}$. At what temperature would the pump cavitate?

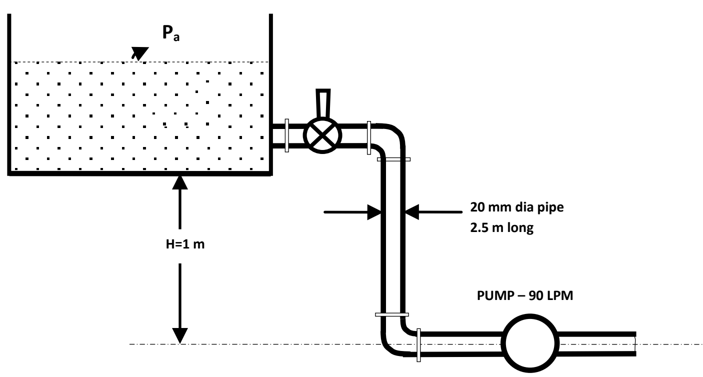


Figure 10 for the Problem No 11

Q1-Solution:

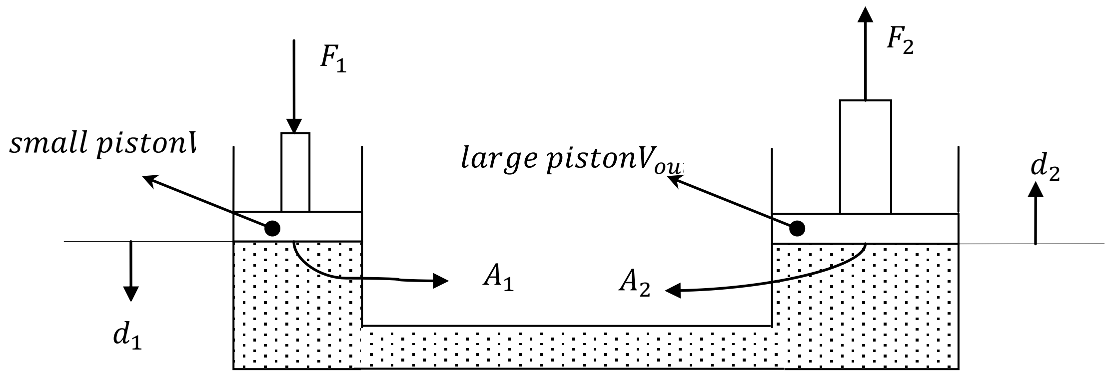


Figure E4.2 for the Problem No 2

F_1= 100N
A_1= 50×10^2 mm^2
A_2= 500×10^2 mm^2
d_1= 100 mm
d_2= ?
F_2=?

Force on the large piston, F_2.
By Pascal's law, we have

$$\frac{F_1}{F_2} = \frac{A_1}{A_2}$$
$$F_2 = \frac{A_2 \times F_1}{A_1}$$
$$= \frac{100N}{50 \times 10^2 \text{mm}^2} \times 500 \times 10^2 \text{mm}^2$$

$$F_2 = 1000N$$

Distance moved by the large piston, d_2
We also know that by conversation of energy,

$$\frac{F_1}{F_2} = \frac{d_1}{d_2}$$

$$d_2 = \frac{d_1 \times F_1}{F_2} = \frac{100 \times 100}{1000}$$

$$d_2 = 10\ mm$$

Q2-Solution:

$D_1 = 50.8mm = 0.0508\ m$

$D_2 = 25.4mm = 0.0254\ m$

$$V_1 = \frac{\text{flow rate}}{\text{annulus area at point 1}} = \frac{0.0006309}{\frac{\pi}{4}(0.0508^2)} = 3.113\ \text{m/s}$$

$$V_2 = \frac{\text{flow rate}}{\text{annulus area at point 2}} = \frac{0.0006309}{\frac{\pi}{4}(0.0254^2)} = 12.45\ \text{m/s}$$

Applying Bernoulli's theorem

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + \cancel{z_1} + \cancel{H_p} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + \cancel{z_2} + \cancel{H_L}$$

$$\frac{P_1}{\gamma} - \frac{P_2}{\gamma} = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} = \frac{12.45^2}{2x9.81} - \frac{3.1135^2}{2x9.81} = 7.41m$$

$$\frac{P_1 - P_2}{9800x0.9} = 7.41m$$

$$P_1 - P_2 = 65{,}360\ Pa$$

$$P_1 - P_2 = P_1 - 65{,}360\ Pa = 68950 - 65360 = 3590\ Pa\ (\ gauge)$$

Q3-Solution:

$$P = \frac{2\pi\ NT}{60}$$

Where,

P= Power (kW)

N= Speed (rpm)

T= Torque (Nm)

$$T = \frac{60P}{2\pi N} = \frac{60 \times 10 \times 10^3}{2\pi \times 1450} = 65.857\ Nm$$

Q4-Solution:

Given : $\boldsymbol{z_1 \approx z_2, P_1 = 413.7\ \text{KPa}\ , P_2 = 0, h_L = 1.524\ \text{m}, D_1 = D_2}$

Find: $\boldsymbol{H_T}$

Assumptions: Steady incompressible flow, no losses

Basic Equations: Continuity: $\boldsymbol{A_1V_1 = A_2V_2}$

Energy :

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + H_L + H_T$$

Solution:

Write the energy equation

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + H_L + H_T$$

As before $V_1 = V_2, z_1 = z_2$ but $H_L = 1.524$ m, $P_2 = 0$, therefore

$$H_T = \frac{P_1}{\gamma} - H_L$$

Substituting and solving we get

$$H_T = 40.7\ m$$

Notice that the losses subtract from the ideally possible output of the turbine.

Q5-Solution:

Given: Pump, $\boldsymbol{z_1 = 0,\ z_2 = 20\ m,\ P_1 = 0,\ P_2 = 0,\ h_L = 0, D = 50\ \text{mm}, Q = 0.05\ \text{m}^3/}$ **s,**

$\boldsymbol{\rho = 1000\ kg/m^3,\ V_1 = 0.}$

Find: Required pump horsepower

Assumptions: Steady incompressible flow, no losses

Basic Equations: Continuity: $\boldsymbol{Q = A_1 V_1 = A_2 V_2}$

Energy :

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + H_P = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2$$

Power (P)

$$P = H_p\ x\ Q\ x\ \gamma$$

<u>**Solution:**</u>

Let us first write the energy equation between sections 1 and 2

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}+z_1+\ H_P\ =\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+z_2$$

since there are no losses in the pipe.

As $V_1\ =0, P_1\ =\ \ P_2 = P_a$, $z_1\ =0$, H_P is given by

$$H_P\ =\frac{V_2^2}{2g}+z_2$$

Since $= AV$, we have

$$V\ =\ \frac{0.05}{\pi[(0.05)^2/4]}=25.5\ m/s$$

Using this value of V gives us

$$H_P\ =\frac{25.5^2}{2\ x\ 9.81}+20=53.1\ m$$

We can now obtain the horsepower required as follows:

$$power\ \ =H_p\ x\ Q\ x\ \ \gamma\ \ =53.1\ x\ 0.05\ x\ 1000\ x\ \ 9.81$$

$$power\ \ =\ \ 26045\ watts=26.1kW$$

Q6-Solution:

Writing the energy equation.

Choosing points A and B as our reference points, we get

$$\frac{P_A}{\gamma}+Z_A+\frac{v_A^2}{2g}-h_R-h_L=\frac{P_B}{\gamma}+Z_B+\frac{v_B^2}{2g}$$

$$h_R=energy\ removed\ by\ fluid\ motor, h_L=energy\ losed$$

Compare this equation with your results:

$$h_R = \frac{P_A - P_B}{\gamma} + (Z_A - Z_B) + \frac{v_A^2 - v_B^2}{2g} - h_L$$

The correct results are:

$$\frac{P_A - P_B}{\gamma} = \frac{(700 - 125)(10^3)N}{m^2} \times \frac{m^3}{9.81 \times 10^3 N} = 58.6m$$

$Z_A - Z_B = 1.8$

Solving for $\frac{v_A^2 - v_B^2}{2g}$

$$Q = \frac{115L}{min} \times \frac{\frac{1m^3}{s}}{\frac{60000L}{min}} = 1.92 \times 10^{-3} m^3/s$$

$$v_A = \frac{Q}{A_A} = \left(1.92 \times \frac{10^{-3} m^3}{s}\right) \times \frac{1}{4.909 \times 10^{-4} m^2} = 3.91 m/s$$

$$v_B = \frac{Q}{A_B} = \left(1.92 \times \frac{10^{-3} m^3}{s}\right) \times \frac{1}{4.418 \times 10^{-3} m^2} = 0.43 m/s$$

$$\frac{v_A^2 - v_B^2}{2g} = ((3.91)^2 - (0.43)^2)/(2)(9.81) m^2/s.s\text{^}2/m = 0.77m$$

$h_L = 4.0\ m$ (given)

Substituting the known values we get

$$P_R = h_R W = h_R \gamma Q$$

Where $P_R = is\ the\ power\ delivered\ by\ the\ fluid\ to\ fluid\ motor$

$$P_R = 57.2\ m \times 9.81 \times \frac{10^3 N}{m^3} \times 1.92 \times \frac{10^{-3} m^3}{s} = 1080 N.\frac{m}{s}$$

$$P_R = 1.08\ kW$$

This is the power delivered to the fluid motor by the water. How much useful power can be expected to be put out by the motor?Because the efficiency of the motor is 85%, we get 0.92 kW of power out.

$$\eta_M = \frac{P_O}{P_R}$$

We get $P_0, power\ output\ from\ motor,$

$$P_0 = \eta_M P_R = (0.85)(1.08\ kW) = 0.2kW$$

Q7-Solution:

$$A_2V_2 + A_3V_3 = A_1V_1$$

$$15^2 V_1 = 10^2(12) + 7.5^2(12)$$

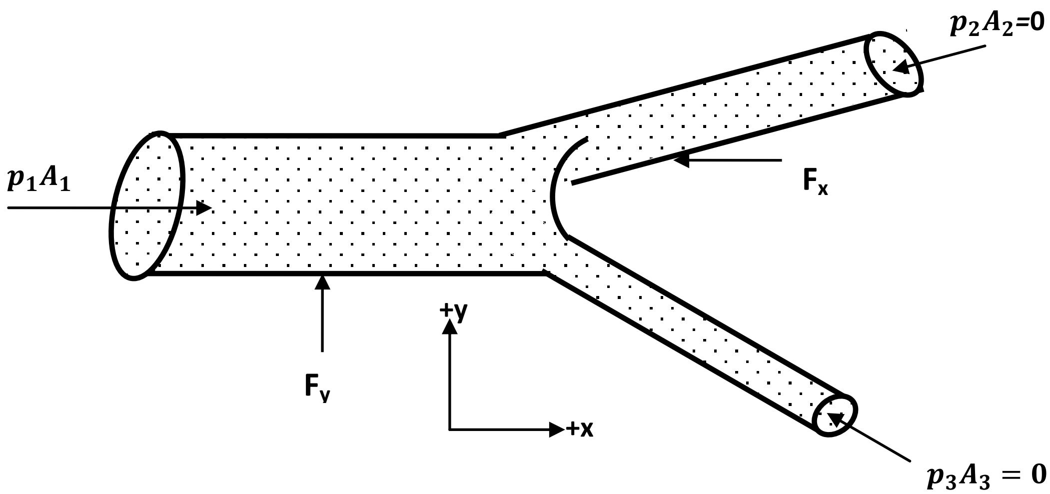
$$V_1 = 8.33 m/s$$

$$Q_1 = \frac{\pi}{4(0.15)^2(8.33)} = (0.1473 m^3)/s$$

$$Q_2 = (0.0942 m^3)/s$$

$$Q_3 = 0.0530 m^3/s$$

Jets 2 and 3 are free, i.e., in the atmosphere, so $P_2 = P_3 = 0$.



Writing the energy equation along a streamline:

$$\frac{P_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + z_2$$

$$\frac{P_1}{\gamma} + \frac{(8.33)^2}{2(9.81)} + z_1 = \frac{P_2}{\gamma} + \frac{12^2}{2(9.81)} + z_2$$

$$\frac{P_1}{\gamma} = 3.80\ m$$

$$P_1 = 37.3\frac{kN}{m^2}$$

$$P_1A_1 = 0.659\ kN$$

Eq. (6.7 a): $\sum F_x = P_1A_1 - 0 - F_x = (\rho Q_2 V_{2x} + \rho Q_3 V_{3x}) - \rho Q_1 V_{1x}$

$$\rho = \frac{\gamma}{g} = \frac{\frac{9.81kN}{m^3}}{9.81\frac{m}{s^2}} = 1.0kN.\frac{s^2}{m^4} = \frac{10^3 kg}{m^3}$$

$$V_{2x} = V_2\ \cos 15 = 12(0.966) = 11.59\frac{m}{s}$$

$$V_{3x} = V_3 \cos 30 = 12(0.866) = \frac{10.39m}{s}$$

$$V_{1x} = V_1 = 8.33\frac{m}{s}$$

$$0.659 - F_x = 10^3(0.0942)(11.59) + 10^3(0.0530)(10.39) - 10^3(0.1473)(8.33)$$

$$= 0.417\ kN$$

$$F_x = 0.659 - 0.417 = 0.242\ kN\ \leftarrow$$

Eq.(6.7b):

$$\sum F_y = 0 - 0 + F_y = (\rho Q_2 V_{2y} + \rho Q_3 V_{3y}) - \rho Q_1 V_{1y}$$

$$V_{2y} = V_2 \sin 15 = 12(0.259) = 3.11 m/s$$

$$V_{3y} = -V_3 \sin 30 = -12(0.5) = -6.00 m/s$$

$$V_{1y} = 0$$

So $F_y = 10^3(0.0942)(3.11) + 10^3(0.0530)(-6.00) - 10^3(0.1473)(0)$

$$= 0.291 - 0.318 - 0 = -0.027 kN \uparrow = 0.027 kN \downarrow$$

The minus sign indicates that the direction we assumed for F_y was wrong. Therefore it acts in negative y direction.$F_{L/N}$is equal and opposite to F.

$$(F_{L/N})_x = 0.242\ kN \rightarrow (in\ the\ positive\ x\ direction)$$

$$(F_{L/N})_y = 0.027 \uparrow \quad (in\ the\ positive\ y\ direction)$$

$$(F_{L/N}) = 0.243\ at\ 5.90^o$$

Q8-Solution:

Using an approach similar to that used with Bernoulli's equation, select two sections of interest and write the general equation before looking at the next panel.

The sections at which we know the most information about the system are selected.
The complete general equation is:

$$\frac{\mathrm{p}_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_A - h_R - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

The value of some of these terms is zero. Determine which are zero and simplify the energy equation accordingly.

The value of the following terms is zero

$\mathrm{p}_1 = 0$ Surface of reservoir exposed to atmosphere

$\mathrm{p}_2 = 0$ Free stream of fluid exposed to the atmosphere

$\mathrm{v}_1 = 0$ (Approximately) surface area of reservoir is large

$\mathrm{h_A} = \mathrm{h_R} = 0$ No mechanical device in the system (i.e., head addition or removal is zero)

Then, the general energy equation becomes

$$\mathrm{z}_1 - \mathrm{h_L} = \mathrm{z}_2 + \frac{\mathrm{v}_2^2}{2\mathrm{g}}$$

Since we are looking for the total energy lost from the system, solve this equation for $\mathrm{h_L}$, which gives

$$\mathrm{h_L} = (\mathrm{z}_1 - \mathrm{z}_2) - \frac{\mathrm{v}_2^2}{2\mathrm{g}}$$

Now evaluate the terms on the right side of the equation to determine $\mathrm{h_L}$ in the units of m.

The answer is $\mathrm{h_L} = 4.8\mathrm{m}$. Here is how it is done:

$$\mathrm{z}_1 - \mathrm{z}_2 = +7.62\mathrm{m}$$

$$\mathrm{v}_2 = \frac{\mathrm{Q}}{\mathrm{A}_2}$$

Since Q was given as 0.034 m^3/s and the area of a 0.0762m diameter jet is 0.00456m^2, we have

$$\mathrm{v}_2 = \frac{\mathrm{Q}}{\mathrm{A}_2} = \frac{0.034\ \mathrm{m}^3}{\mathrm{s}} \times \frac{1}{0.00456\ \mathrm{m}^2} = 7.34\mathrm{m/s}$$

$$\frac{v_2^2}{2g} = \frac{(7.34)^2\,\mathrm{m}^2}{\mathrm{s}^2} \times \frac{\mathrm{s}^2}{(2)(9.81)\mathrm{m}} = 2.819\mathrm{m}$$

Then the total amount of energy lost from the system is

$$h_L = (z_1 - z_2) - \frac{v_2^2}{2g} = 7.62 - 2.8194\mathrm{m}$$

$$h_L = 4.8\mathrm{m}$$

Q9-Solution:

h_1=10 m

D_2= 50mm =50×10^{-3}

v_2 and Q_2? At H_L=0

v_2 and Q_2? At H_L=2m

Let us apply the energy equation to the system, i.e.,

$$Z_1 + \frac{P_1}{\gamma} + \frac{v_1^2}{2g} + H_p - H_m - H_L = Z_2 + \frac{P_2}{\gamma} + \frac{v_2^2}{2g}$$

Where Z_1= h

P_1=P_2= atmospheric pressure =0, Pa (g)

v_1=0, as the tank is quite large, hence negligible velocity.

H_p= 0(no pump)

H_m=0 (no motor)

Z_2= base reference=0

By substituting these values in equation (1), we get,

$$h + 0 + 0 + 0 - 0 - H_L = 0 + 0 + \frac{v_2^2}{2g}$$

or

$$v_2^2 = 2\mathrm{g}(\mathrm{h} - H_L)$$

Or

$$v_2 = \sqrt{}(2g((\mathrm{h} - H_L))$$

a. *When H_L=0 (ideal fluid)*

$$v_2 = \sqrt{2 \times 9.81(10 - 0)}$$
$$= \sqrt{196.2}$$
$$v_2 = 14m/s$$

The flow rate is given by,

$$Q_2 = A_2 v_2$$
$$= \pi \times (50 \times 10^{-3})^2 \times 14/4$$
$$= \frac{0.027m^3}{s}$$
$$Q_2 = 0.027 \times 10^{-3}(litre) \times 60\left(\frac{sec}{\mathrm{min}}\right)$$
$$Q_2 = 1620lpm$$

b. When H_L= 2m

Velocity,

$$v_2 = \sqrt{(2 \times 9.81(10 - 2))}$$
$$v_2 = 12.53 m/s$$

Flow rate,

$$Q_2 = \frac{\pi}{4}(50 \times 10^{-3})^2 \times 12.53$$
$$= 0.0246 m^3/s$$
$$Q_2 = 1476 lpm$$

Q10-Solution:

Using the points identified as 1 and 2 in above figure, we have

$$\frac{P_1}{\gamma} + \frac{v_1^2}{2\mathrm{g}} + z_1 = \frac{P_2}{\gamma} + \frac{v_2^2}{2\mathrm{g}} + z_2$$

Because we must find the power delivered by the pump to the fluid, we should now solve for h_A.

This equation is used:

$$h_A = \frac{p_2 - p_1}{\gamma} + (Z_2 - Z_1) + (\frac{v_2^2 - v_1^2}{2g})$$

It is convenient to solve for each term individually and then combine the results. The manometer enables us to calculate $(p_2 - p_1)/\gamma$ because it measures the pressure difference. Write the manometer equation between points 1 and 2.

Starting at point1, we have

$$p_1 + \gamma_0 y + \gamma_m (20.4\ in) - \gamma_0 (20.4\ in) - \gamma_0 y = p_2$$

Where y is the unknown distance from point 1 to the top of the mercury column in the left leg of the manometer. The terms involving y cancel out. Also in this equation containing $\gamma_0$is the specific weight of the oil and $\gamma_m$is the specific weight of the mercury gage fluid.

$$\gamma_m = (13.54)(\gamma_w) = (13.54)\left(157.11\frac{N}{m^3}\right) = 844.9(157.11)\ \frac{N}{m^3}$$

$$p_2 = p_1 + \gamma_m(.518m) - \gamma_0(.518m)$$

$$p_2 - p_1 = \gamma_m(.518m) - \gamma_0(.518)$$

$$\frac{p_2 - p_1}{\gamma_0} = \frac{\gamma_m(.518)}{\gamma_0} - .518m = \left(\frac{\gamma_m}{\gamma_0} - 1\right)(20.4)$$

$$= \left(\frac{844.9(157.11)\frac{N}{m^3}}{56.0(157.11)\frac{N}{m^3}} - 1\right)(.518m) = (15.1 - 1)(.518m)$$

$$\frac{p_2 - p_1}{\gamma_0} = (14.1)(.518m)\left(\frac{1\,ft}{12\,in}\right) = 24.0\ (0.3048m) = 7.31m$$

The next term in the Equation is $Z_2 - Z_1$. What is its value?

It is zero because both the points are on the same elevation. These terms could have been cancelled from the original equation. Now find $(\frac{v_2^2 - v_1^2}{2g})$

Now you should have $\frac{v_2^2 - v_1^2}{2g} = 1.99\ ft$

$$Q = \frac{500gal}{\min\left(\frac{\frac{1(0.3048)^3m^3}{s}}{2041.19\ l/min}\right)} = \frac{1.11(.3048)^3m^3}{s} = 0.031\ m^3/s$$

Using $A_1 = 0.2006(.3048m)^2 = 0.0186m^2$ and $A_2 = 0.0844ft^2$ from appendix F, we get

$$v_1 = \frac{Q_1}{A_1} = \frac{0.0314m^3}{s} \times \frac{1}{0.0186\ m^2} = 1.69\ m/s$$

$$v_2 = \frac{Q_2}{A_2} = \frac{0.0314\ m^3}{s} \times \frac{1}{0.0082\ m^2} = 3.84\ m/s$$

$$\left(\frac{v_2^2 - v_1^2}{2g}\right) = \frac{3.84^2 - 1.69^2}{2(9.81)} \frac{m^2 s^2}{m\ s^2} = 0.606\ m$$

Now place these results into energy equation and solve for h_A.

Solving for h_A, we get

$$h_A = 7.315\ m + 0 + 0.6065\ m = 7.921\ m$$

We can now calculate the power delivered to the oil, P_A

The result $P_A = 2.95\ hp$

$$P_A = h_A \gamma Q = 25.99 \left(\frac{25.4\ kgf}{m^3}\right)\left(\frac{1.11m^3}{s}\right)$$

$$P_A = 1620\ (0.453)kgf - \frac{(0.3048)m}{s\left(\frac{745.7\ W}{550(0.453)kgf - \frac{(0.3048\ m)}{s}}\right)} = 2.199\ kW$$

The final step is to calculate η_M, the mechanical efficiency of the pump.

$$\eta_M = \frac{P_A}{P_I} = \frac{2.95}{3.85} = 0.77$$

Expressed as a percentage, the pump is 77 percent efficient at the stated conditions.

Q11-Solution:

The solution to this problem is to consider both the energy equation and the pressure-drop equation. First, the $R_e$number is calculated:

Pump inlet conditions $U_{mean} = \frac{90 \times \frac{10^{-3}}{60}}{\frac{\pi \times 0.02^2}{0.001}} = 4.77\ m/s$

$$R_e = \frac{1000\ \times 4.77\ \times 0.02}{0.001} = 95{,}400$$

Hence the flow is turbulent. From the earlier work, it is deduced that

Turbulent flow $4f = \frac{0.316}{R_e^{1/4}} = \frac{0.316}{95400^{1/4}} = 0.018$

$$\Delta P = 4f\left(\frac{1}{2}\rho U_{mean}^2\right)\left(\frac{l}{d}\right) = 0.018\left(\frac{1}{2} \times 1000 \times 4.77^2\right)\left(\frac{2.5}{0.02}\right)$$

$$\Delta P = 0.26 \times 10^5 N/m^2 (0.26\ bar)$$

The absolute inlet pressure at the pump is, therefore:

$$P_i = P_o + \rho g H - \Delta p = 10^5 + 0.1 \times 10^5 - 0.26 \times \frac{10^5 N}{m^2}$$

$$P_i = 0.84 \times 10^5 N/m^2 (0.94\ bar)$$

It can be seen that the temperature can increase to a value of around 90℃ - that is, almost to the boiling point of water before cavitation occurs. The pressure drop that is due to pipe friction exceeds the pressure-head advantage of the raised tank.