Civil Engineering Hydraulics

Piping System Problems

Calvin: I think night time is dark so you can imagine your fears with less distraction.

Homework Notes

- The first slide is not a homework problem.
- There are two homework problems and the second homework problem is on the last two slides.

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Pump Requirements

- When we first considered the Bernoulli expression with a pump in the system we wrote the expression as

$$gz_1 + \frac{v_1^2}{2} + \frac{p_1}{\rho} + e_{pump} = gz_2 + \frac{v_2^2}{2} + \frac{p_2}{\rho}$$

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Pump Requirements

- When we look at the expression in terms of pressure

$$\rho g z_1 + \frac{\rho v_1^2}{2} + p_1 + \rho e_{pump} = \rho g z_2 + \frac{\rho v_2^2}{2} + p_2$$

Pump Requirements

- And add in the loss terms

$$\rho g z_1 + \frac{\rho v_1^2}{2} + p_1 + \rho e_{pump} + Friction + Minor = \rho g z_2 + \frac{\rho v_2^2}{2} + p_2$$

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Pump Requirements

- Substituting the forms we developed

$$\rho g z_1 + \frac{\rho v_1^2}{2} + p_1 + \rho e_{pump} - \sum \frac{fL}{d}\frac{\rho v^2}{2} - \sum K \frac{\rho v^2}{2} = \rho g z_2 + \frac{\rho v_2^2}{2} + p_2$$

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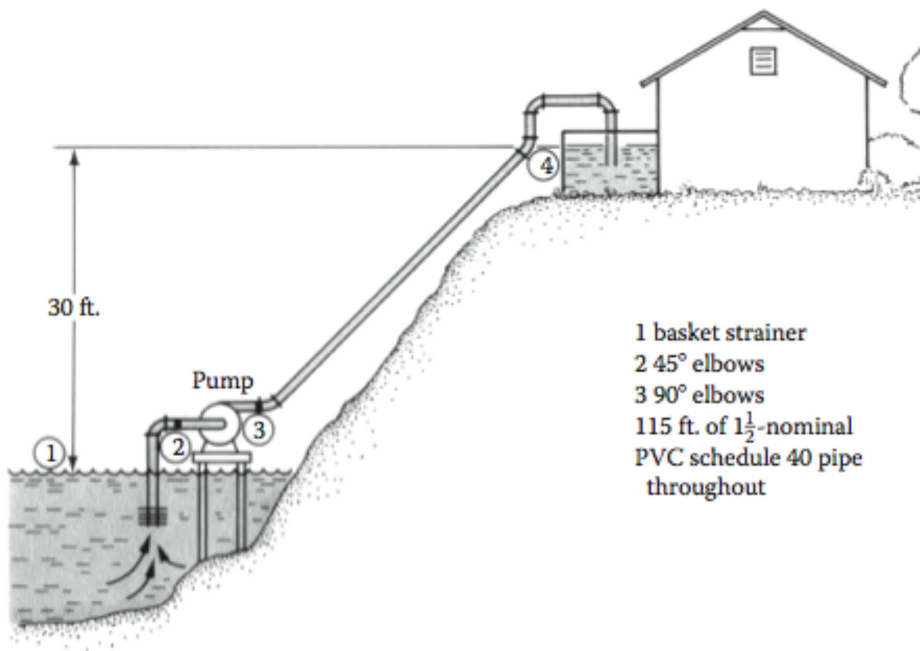
Pump Requirements

- To get the form in terms of energy we divide by the density and multiply by the mass flow rate
- I am also collecting terms on the right side.

$$-\frac{dW}{dt}_{pump} = \dot{m}\left(gz_2 + \frac{v_2^2}{2} + \frac{p_2}{\rho} - gz_1 - \frac{v_1^2}{2} - \frac{p_1}{\rho} + \sum \frac{fL}{d}\frac{v^2}{2} + \sum K \frac{v^2}{2} \right)$$

Example 5.31

- A house is located near a freshwater lake. The homeowner decides to install a pump near the lake to deliver 25 gpm of water to a tank adjacent to the house. The water can then be used for lavatory facilities or sprinkling the lawn. For the system sketched in Figure 5.31, determine the pump power required.



Example 5.31

- Dr. Janna chooses to look at the problem in three parts. This is really not necessary. We can look at the points labeled 1 and 4 and work through the problem.

At point 1

$$v_1 := 0\,\frac{ft}{s} \qquad z_1 := 0ft \qquad p_1 := 0\,\frac{lbf}{ft^2}$$

At point 2

$$v_4 := 0\,\frac{ft}{s} \qquad z_4 := 30ft \qquad p_4 := 0\,\frac{lbf}{ft^2}$$

Example 5.31

- Considering the fluid

For the entire system

$$Q := 25 \frac{gal}{min} = 0.056 \frac{ft^3}{s}$$

$$\rho := 1.94 \frac{slug}{ft^3} \qquad \mu := 1.9 \cdot 10^{-5} \frac{lbf \cdot s}{ft^2}$$

Example 5.31

- And the pipe characteristics

And the characteristics of the pipe

$d := 0.125\text{ft}$

$A := \pi \cdot \frac{d^2}{4} = 0.012\,\text{ft}^2$

$L := 115\text{ft}$

$\varepsilon := 0\text{ft}$

Calculating the velocity in the pipe and the friction factor.

$$v := \frac{Q}{A} = 4.539\,\frac{ft}{s}$$

$$Re := \frac{\rho \cdot v \cdot d}{\mu} = 5.793 \times 10^{4}$$

Flow is Turbulent

$$f := \frac{0.25}{\log\left(\frac{\varepsilon}{3.7 \cdot d} + \frac{5.74}{Re^{0.9}}\right)^{2}} = 0.02$$

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Example 5.31

So the friction loss is

$$Loss_{friction} := \frac{f \cdot L}{d} \cdot \frac{v^2}{2} = 17.686 \frac{m^2}{s^2}$$

$$Loss_{friction} \cdot \rho \cdot Q = 0.037\,hp$$

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Example 5.31

And the minor losses

$K_{strainer} := 1.3$ $K_{45} := 0.35$ $K_{90} := 0.31$ $K_{exit} := 1$

$$Loss_{minor} := \left(K_{strainer} + 2 \cdot K_{45} + 3 \cdot K_{90} + K_{exit}\right) \cdot \frac{v^2}{2} = 40.482 \frac{ft^2}{s^2}$$

$$Loss_{minor} \cdot \rho \cdot Q = 7.953 \times 10^{-3} hp$$

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Example 5.31

For the system

$$Pump_{power} := -\rho \cdot Q \cdot \left(g \cdot z_4 + \frac{v_4^{\,2}}{2} + \frac{p_4}{\rho} - g \cdot z_1 - \frac{v_1^{\,2}}{2} - \frac{p_1}{\rho} + Loss_{friction} + Loss_{minor} \right) = -0.235 \text{ hp}$$

$$Pump_{power} = -129.246 \, \frac{ft \cdot lbf}{s}$$

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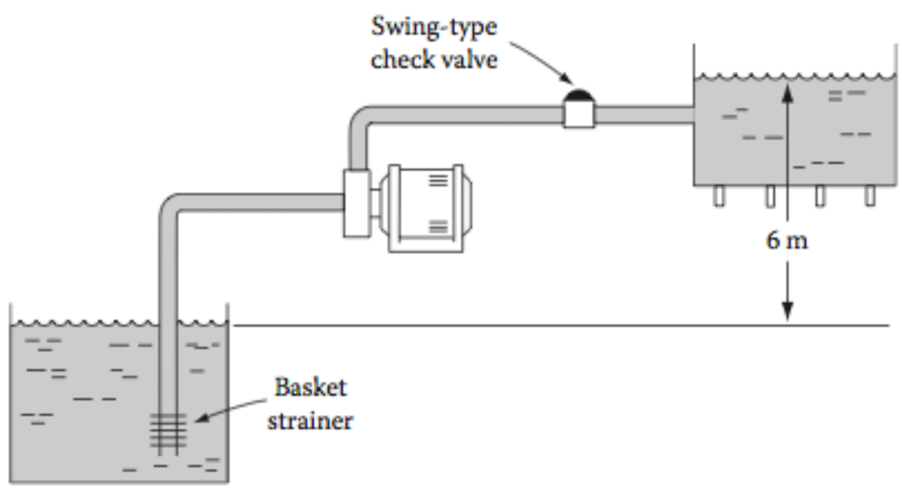
Problem 5.71

In a dairy products processing plant, milk (ρ= 030 kg/m^3, μ=2.12×10^{-3} N s/m^2) is pumped through a piping system from a tank to a container packaging machine. The pump and piping are all stainless steel (smooth walled), arranged as shown in Figure P5.71. The pump inlet line (4-nominal, schedule 40 pipe) is 2 m long. The pump outlet line (3 1/2-nominal, schedule 40 pipe) is 15 m long. All fittings are flanged, and the flow rate through the system is 0.015 m^3/s. Determine the electrical power input to the pump if the pump-motor efficiency is 88%.



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Problem 5.71

At point 1 which is the top of the tank.

$$v_1 := 0\,\frac{\text{ft}}{\text{s}} \qquad z_1 := 0\text{ft} \qquad p_1 := 0\,\frac{\text{lbf}}{\text{ft}^2}$$

At point 2 which is the top of the container.

$$v_2 := 0\,\frac{\text{ft}}{\text{s}} \qquad z_2 := 6\text{m} \qquad p_2 := 0\,\frac{\text{lbf}}{\text{ft}^2}$$

Problem 5.71

For the entire system

$$Q := 0.015 \frac{m^3}{s}$$

$$\rho := 1030 \frac{kg}{m^3} \qquad \mu := 2.12 \cdot 10^{-3} \frac{N \cdot s}{m^2}$$

Problem 5.71

And the characteristics of the pipes. Point 3 is the pump.

$$d_{1to3} := 4.026in = 0.102\,m \qquad A_{1to3} := \pi \cdot \frac{d_{1to3}^{\;2}}{4} = 8.213 \times 10^{-3}\,m^2$$

$$d_{3to2} := 3.548in = 0.09\,m \qquad A_{3to2} := \pi \cdot \frac{d_{3to2}^{\;2}}{4} = 6.379 \times 10^{-3}\,m^2$$

$$L_{1to3} := 2m \qquad L_{3to2} := 15m$$

I looked both the diameters and the relative roughness on the internet.

$$\varepsilon := 0.015 \cdot 10^{-3}m = 1.5 \times 10^{-5}\,m$$

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Problem 5.71

Calculating the velocity in the pipes and the friction factors.

$$v_{1to3} := \frac{Q}{A_{1to3}} = 1.826\ \frac{m}{s} \qquad v_{3to2} := \frac{Q}{A_{3to2}} = 2.352\ \frac{m}{s}$$

$$Re_{1to3} := \frac{\rho \cdot v_{1to3} \cdot d_{1to3}}{\mu} = 9.074 \times 10^{4}$$

Flow is Turbulent

$$Re_{3to2} := \frac{\rho \cdot v_{3to2} \cdot d_{3to2}}{\mu} = 1.03 \times 10^{5}$$

Flow is Turbulent

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Problem 5.71

So the friction loss is

$$Loss_{friction} := \frac{f_{1to3} \cdot L_{1to3}}{d_{1to3}} \cdot \frac{v_{1to3}^2}{2} + \frac{f_{3to2} \cdot L_{3to2}}{d_{3to2}} \cdot \frac{v_{3to2}^2}{2} = 9.238 \frac{m^2}{s^2}$$

$$Loss_{friction} \cdot \rho \cdot Q = 142.73\ W$$

Problem 5.71

So the friction loss is

$$Loss_{friction} := \frac{f_{1to3} \cdot L_{1to3}}{d_{1to3}} \cdot \frac{v_{1to3}^{2}}{2} + \frac{f_{3to2} \cdot L_{3to2}}{d_{3to2}} \cdot \frac{v_{3to2}^{2}}{2} = 9.238 \frac{m^2}{s^2}$$

$$Loss_{friction} \cdot \rho \cdot Q = 142.73 \text{ W}$$

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Problem 5.71

And the minor losses

On the left side there is a strainer and a 90 degree bend. On the right side (3 to 2), there is a 90 degree bend, a check valve, and an exit.

$K_{strainer} := 1.3 \qquad K_{90} := 0.31 \qquad K_{valve} := 2.5 \qquad K_{exit} := 1$

$$Loss_{minor} := \left(K_{strainer} + K_{90}\right) \cdot \frac{{v_{1to3}}^2}{2} + \left(K_{valve} + K_{90} + K_{exit}\right) \cdot \frac{{v_{3to2}}^2}{2} = 13.22 \, \frac{m^2}{s^2}$$

$$Loss_{minor} \cdot \rho \cdot Q = 204.249 \, W$$

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Problem 5.71

For the system

$$Pump_{power} := \left[-\rho \cdot Q \cdot \left(g \cdot z_2 + \frac{{v_2}^2}{2} + \frac{p_2}{\rho} - g \cdot z_1 - \frac{{v_1}^2}{2} - \frac{p_1}{\rho} + Loss_{friction} + Loss_{minor}\right)\right]$$

$$Pump_{power} = -1256.1\ W$$

Problem 5.71

At 88% effeciency

$$\text{Pump}_{\text{power}} := \frac{\text{Pump}_{\text{power}}}{0.88} = -1.427\,\text{kW}$$

Homework 20-1

In the first example problem shown in class if the pump in the system is replaced by a pump delivering 0.5 hp, what would the flow rate in the system be?

Homework 20-2

In the first example problem, if the homeowner wanted to increase the flow in the system by a factor of 4 (4 times the flow of the original problem) and decided to by a pump with 4x the power of the original system, what percentage of their desired flow rate would they achieve?

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Homework 20-3

Octane is to be pumped overland in a piping system. The octane is routed from storage tanks to the main pump by smaller pumps. One such arrangement is sketched in Figure shown. This pump must supply 0.4 m3/s of octane to the main pump. All fittings are flanged; the pipe is cast iron, schedule 160, 24-nominal, with L=65 m. The absolute pressure at section 2 is 282.5 kPa. Determine the power required to be transferred to the liquid. Assuming an overall pump-motor efficiency of 75%, determine the input power required by the motor.