Homework #2 Hydraulics and Flow in Pipes

5 points total for entire homework

1. Water Pressure

a) What is the hydraulic head in ft equivalent to a pressure of 30 lbs per square inch (psi)?

$$H = \frac{P}{\gamma} + Z$$
$$= \frac{30 \frac{lb}{in^2}\left(12 \frac{in}{ft}\right)^2}{62.4 \frac{lb}{ft^3}} + 0$$
$$\boxed{= 69.2\, ft}$$

1 point for #1

b) What is the pressure in psi equivalent to 80 ft of head?

$$P = \lambda(H - Z)$$
$$= 62.4 \frac{lb}{ft^3}(80\, ft - 0)\left(\frac{ft}{12 in}\right)^2$$
$$\boxed{= 34.7 \frac{lb}{in^2}}$$

2. Use the Darcy Weisbach equation to choose a pipe size (diameter in inches) given the following information: ductile iron pipe with roughness (ε) of 2x10^{-4} ft, flow of 600 gpm, pipe length of 3000 ft, and frictional head loss as close to 12 ft as feasible but do not exceed. Choose a pipe diameter that is a common nominal pipe diameter.

This is an iterative process:

1.5 points for #2

a. first guess a pipe diameter

D = 6 in = 0.5 ft

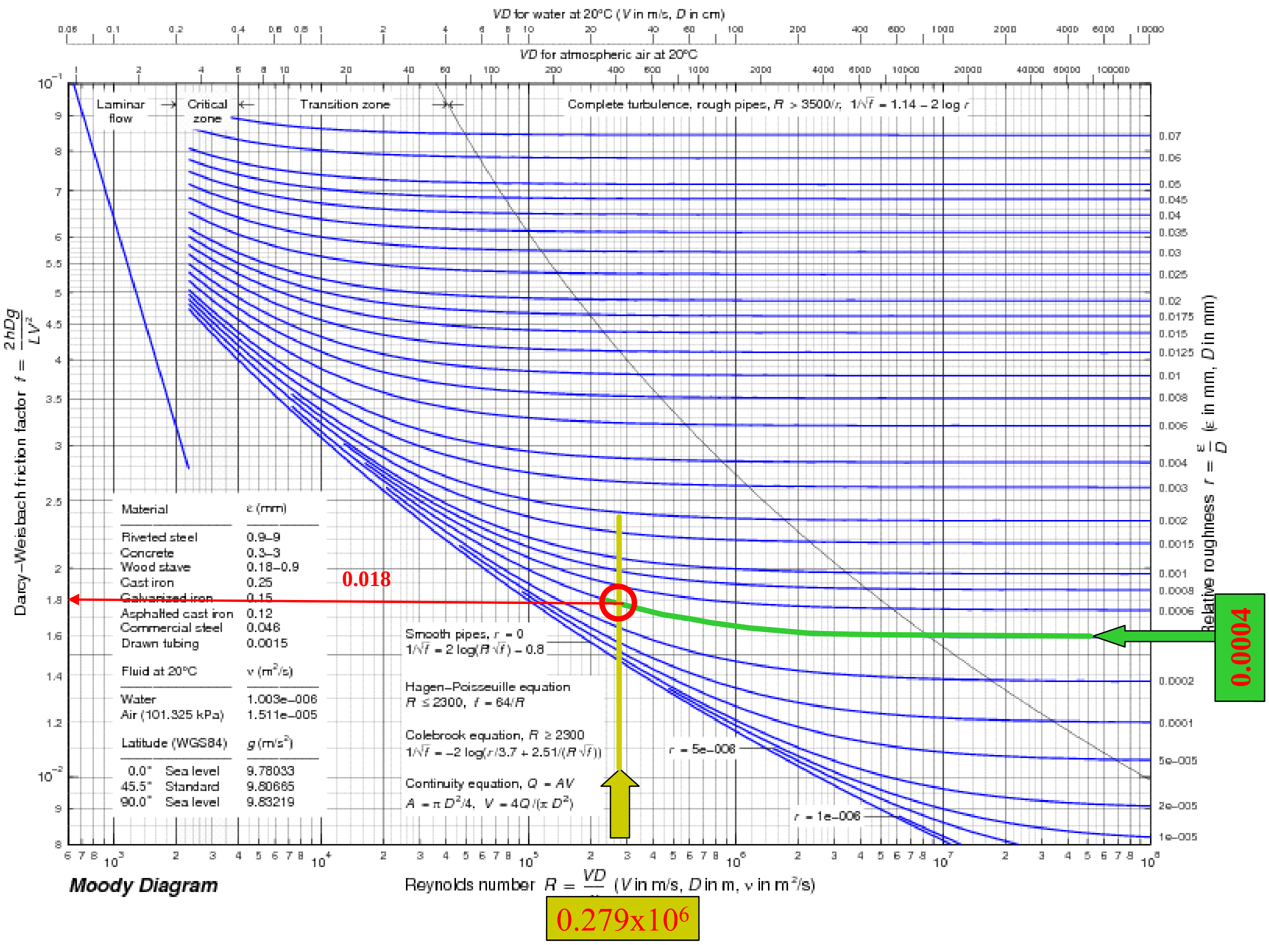
b. Next calculate the Reynolds number (using 60 F value for ν) and the relative roughness:

$$\mathrm{Re} = \frac{VD\rho}{\mu} = \frac{VD}{\nu}$$
$$= \frac{6.81 \frac{ft}{s}(0.5\, ft)}{1.22x10^{-5} \frac{ft^2}{s}}$$
$$= 279{,}000$$

$$r = \frac{\varepsilon}{D}$$

$$= \frac{2x10^{-4}\ ft}{0.5\ ft} = 4x10^{-4}$$

c. Find the Darcy Friction Factor from a Moody diagram



$$f = 0.018$$

Alternatively you can use the simplified diagram from their text (fig 4-6), however, this is for fully turbulent flow. Since the flow in this particular problem is in the transition zone (as determined from the Moody diagram above), there will be a small amount of error in using figure 4-6.

d. Now calculate headloss with the Darcy Weisbach equation

$$h_f = f\frac{L}{D}\left(\frac{V^2}{2g}\right) = f\frac{L8Q^2}{\pi^2 gD^5}$$

$$= 0.0182\frac{(3000\,ft)8\left(1.337\,\frac{ft^3}{s}\right)^2}{\pi^2\left(32.2\,{ft}/{s^2}\right)(0.5\,ft)^5}$$

$$= 77.7\,ft$$

Now repeat this for larger diameters:

Diameter (in)	Re	f	h_f (ft)
6	279,000	0.0180	77.7
8	209,000	0.0178	18.24
9	186,000	0.0177	10.07
10	**167,000**	**0.0180**	**6.04**
12	139,500	0.0185	2.50

Note: the preferred diameter is 10 inches. The smaller, 9 inch pipe would produce a headloss closer to the allowable 12 ft, but this is not a common pipe size.

3. Do Problem #2 but now use the Hazen Williams equation with a C of 140. Compare your answer to that obtained in Problem #2.

$$Q = 0.281CD^{2.63}\left(\frac{h_f}{L}\right)^{0.54}$$

1 point for #3

$$h_f = L\left[Q/\left(0.281CD^{2.63}\right)\right]^{1.85}$$

$$= 3000\,ft\left[600\,gpm/\left(0.281(140)(9)^{2.63}\right)\right]^{1.85}$$

$$= 10.55\,ft$$

Comparison between methods:

Diameter (in)	Headloss (ft) as determined by:	
	Darcy Weisbach	Hazen Williams
6	77.7	75.89
8	18.24	18.72
9	10.07	10.55
10	**6.04**	**6.32**

Using Hazen Williams, one can also solve directly for the diameter that gives exactly 12 ft of headloss. When this is done, the value obtained is 8.76 inches. Thus the nominal pipe size is possibly 9 inches if available, but more likely 10 inches.

4. Water is pumped 8 miles from a reservoir at an elevation of 120 ft to a second reservoir at an elevation of 280 ft. The pipeline connecting the reservoirs is 54 inches in diameter. It is concrete with a C of 100, the flow is 25 MGD, and the pump efficiency is 82%. What is the monthly power bill if electricity costs 8.5 cents per kilowatt-hour? (ignore minor losses)

First use Hazen Williams to get the headloss (C=100):

$$Q = 0.279CD^{2.63}\left(\frac{h_f}{L}\right)^{0.54}$$

1.5 points for #4

$$\begin{aligned} h_f &= L\left[Q/\left(0.279CD^{2.63}\right)\right]^{1.85} \\ &= 42{,}160\,ft\left[25MGD/\left(0.279(100)(4.5)^{2.63}\right)\right]^{1.85} \\ &= 22.83\,ft \end{aligned}$$

Now, the Bernoulli equation:

$$Z_A + \frac{P_A}{\gamma} + \frac{V_A^2}{2g} + H_p = Z_B + \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + H_L$$

can be simplified based on the pressure terms cancelling (both are at atmospheric pressure) as well as the velocity terms. So now we have:

$$\begin{aligned} H_p &= Z_B - Z_A + H_L \\ H_p &= 182.83\,ft \end{aligned}$$

And the power for the pump is:

$$\begin{aligned} P &= \frac{Q\gamma h_T}{\eta} = \frac{25MGD\left(1.55cfs/_{MGD}\right)62.4\,\tfrac{lb}{ft^3}(182.83\,ft)}{0.82} \\ &= 5.39x10^5\ ft-lb/s \\ &= 0.203kwh/s \end{aligned}$$

The monthly power usage is:

$$= 0.203\ {}^{kwh}\!/_{s}\,(60\ {}^{s}\!/_{\min})60\ {}^{\min}\!/_{hr}\,(24\ {}^{hr}\!/_{d})30\ {}^{d}\!/_{mo}$$
$$= 5.26x10^{5}\ kwh/mo$$

And the monthly power bill is:

$$= 5.26x10^{5}\ {}^{kwh}\!/_{mo}\,(0.085\ {}^{\$}\!/_{kwh})$$
$$\boxed{= \$44,700}$$