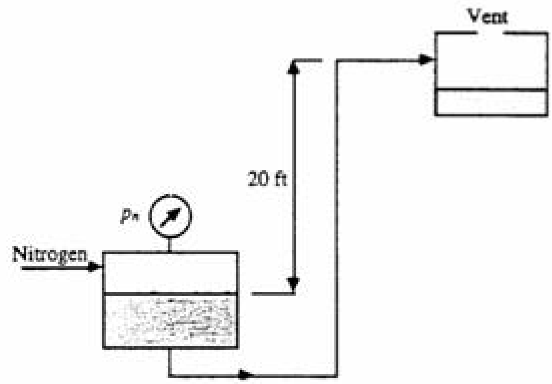
1. Do Problems 3.9, 3.10 and 3.13 of textbook.

3.9

Pumping Kerosene



Reynolds number

$$Re = \frac{\rho u_m D}{\mu}$$

$$= \frac{51 \times u_m \times \frac{2.067}{12}}{4.38/3600}$$

$$Re = 7,220\ u_m$$

Case 2-type problem

$$u_m = \sqrt{\frac{D}{2 f_F \rho L}\left[(p_1 - p_2) - \rho g \Delta z\right]}$$

$$= \sqrt{\frac{2.067/12}{2 f_F \times 51 \times 150}\left[\underbrace{15 \times 144 \times 32.2 - 51 \times 32.2 \times 20}_{36,708}\right]}$$

$$u_m = \frac{0.643}{\sqrt{f_F}}$$

Now roughness ratio is $\frac{\varepsilon}{D} = \frac{0.00015 \times 12}{2.067} = 8.71 \times 10^{-4}$

u_m (ft/s)	Re	f_F
–	–	0.005
9.09	65,654	0.0057
8.52	61,491	0.0058
8.44	60,958	0.0058

Flow rate

$$Q = \frac{\pi D^2}{4} u_m$$

$$= \frac{\pi}{4}\left(\frac{2.067}{12}\right)^2 \times 8.44$$

$$= 0.197 \times 60 \times 7.48$$

$$Q = 88.3\ \text{gpm}$$

3.10

Lodge Water Supply

①

$$Q = \frac{200}{60 \times 7.48} = 0.446 \ \frac{ft^3}{sec}$$

$L = 2{,}000 \ ft$ $\qquad p_2 = 40 \ psig$

②

Reynolds Number

$$Re = \frac{\rho u_m D}{\mu} = \frac{4 Q \rho}{\pi D \mu}$$

$$= \frac{62.4 \times 4 \times 0.446}{\pi D \times 1 \times 0.000672} = \frac{5.27 \times 10^4}{D} \quad (D - ft)$$

Pressure Drop $\qquad -\Delta p = 2 f_F \rho u_m^2 \frac{L}{D} + \rho g \Delta z$

$$\underbrace{-40 \times 144 \times 32.2}_{-1.85 \times 10^5} = \underbrace{\frac{32}{\pi^2} \frac{f_F \times 62.4 \times 0.446^2 \times 2000}{D^5}}_{10^4 \times 8.05 \frac{f_F}{D^5}} \underbrace{- 62.4 \times 32.2 \times 200}_{-4.02 \times 10^5}$$

Hence $D = 0.820 \times f_F^{0.2}$ $\qquad \epsilon = 0.00015 \ ft$

D (ft)	Re	ε/D	f_F	
0.25	2.11×10^5	0.00060	0.0049	agreement
0.283	1.86×10^5	0.00053	0.0049	

Hence $D = 0.283 \ ft = \underline{3.40 \ in}$

Next size up $= \underline{4.026 \ in}$ (nominal 4-in)

3.13

Pumping and Piping

Energy ② → ③ $\quad \frac{p_3 - p_2}{\rho} + g(z_3 - z_2) + 2f_F u_m^2 \frac{L}{D} = 0$

Flow rate $Q = \frac{\pi D^2}{4} u_m$ or $u_m^2 = \frac{16Q^2}{\pi^2 D^4}$

Hence $p_2 - p_3 = \rho g(z_3 - z_2) + \frac{32 f_F \rho Q^2 L}{\pi^2 D^5}$

$$= \frac{62.4 \times 32.2 \times 25}{32.2 \times 144} + \frac{32 f_F \times 62.4 \times Q^2 \times 1000}{\pi^2 \times \left(\frac{4.026}{12}\right)^5 \times 32.2 \times 144}$$

$$p_2 - p_3 = 10.83 + 10{,}265 f_F Q^2 = \Delta p_{pipe}$$

Cross-section $A = \frac{\pi}{4}\left(\frac{4.026}{12}\right)^2 = 0.0884 \text{ ft}^2$

Roughness (comm. steel) $k = \varepsilon = 0.0018$ in $\quad \frac{\varepsilon}{D} = \frac{0.0018}{4.026} = 0.00045$

For large Re, $f_F = 0.0045$

Pump Equation $\Delta p_{pump} = 19.2 - 133.4 Q^{4.5}$

Q ft³/sec	Δp_{pipe} psi	Δp_{pump} psi
0.3	14.99	18.61
0.38	**17.50**	**17.49**
0.4	18.22	17.04

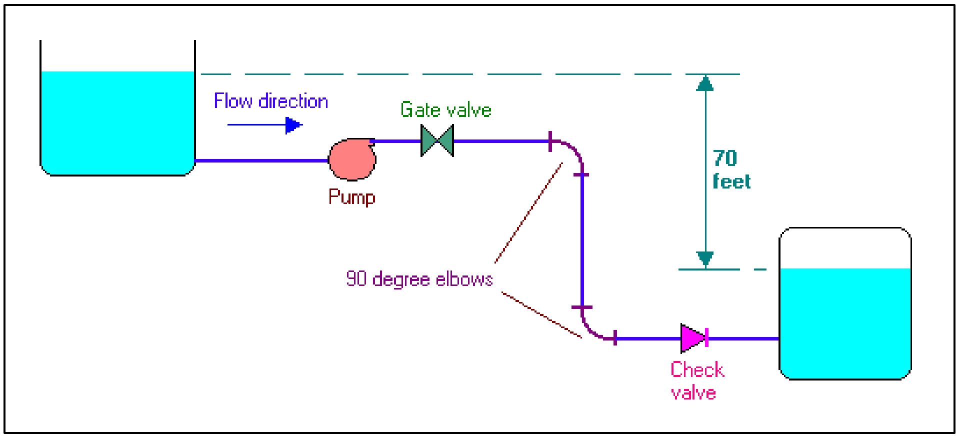
Check on f_F $\quad u_m = \frac{0.38}{0.0884} = 4.30$ ft/sec

$$Re = \frac{62.4 \times 4.30 \times \frac{4.026}{12}}{1 \times 0.00672} = 1.34 \times 10^5$$

$f_F = 0.0045$ – no change.

Further refinement not needed.

2. A 35^0 API distillate is being transferred from a storage tank at 1 atm absolute pressure to a pressure vessel at 50 psig by means of the piping arrangements shown in figure. The liquid flows at the rate of 23100 lb/hr through 3-inch Schedule 40 steel pipe; the length of the straight pipe is 450 feet. Calculate the minimum horsepower input to the pump having an efficiency of 60 percent. The properties of the distillate are: viscosity = 3.4 cP, density = 52 lb/ft3. The following are the data for the pipe and fittings:
   a. For 3 inch Schedule 40 Nominal pipe, OD = 3.5 inch; Thickness = 0.216 inch
   b. Flow coefficients for the fittings (K) are:
      i. Gate valve = 0.25; 90o elbow = 0.9; Check valve = 10
   c. Friction factor can be calculated from Blasius equation. Account for entry and exit losses also.



Conversion Factors			
1 feet		0.3048	m
1 lb		0.454	kg
1 inch		0.0254	m
1 centipoise		0.001	kg/m.sec
1 atm		14.7	psi
1 atm		1.01E+05	N/m^2
g		9.812	m/sec^2

Data given:					**Converted data:**	
Mass flow rate		23100	lb/hr	=	2.913167	kg/sec
Density	ρ	52	lb/ft^3	=	833.7087	kg/m ^{3}
Viscosity	μ	3.4	cP	=	0.0034	kg/m.sec
Pipe OD		3.5	inch			
Pipe thickness		0.216	inch			
Pipe length	L	450	feet	=	137.16	m
Vertical height	z_1- z_2	70	feet	=	21.336	m
Pump efficiency (in fraction)		0.6				
Loss coefficient of Gate Valve		0.25				
Loss coefficient of elbow		0.9				
Loss coefficient of check valve Valve		10				
Pipe ID	D	3.068	inch	=	0.077927	m

Pressure at 2	P_2	50	psig	=	344642.9	N/m^2

Calculations:			
Volumetric flow rate	Q	0.00349	m^3/sec
Velocity	v	0.7326	m/sec
Reynolds Number	NRe	13999	
Friction factor	f	0.00726	
h_f of pipe		1.3985	m
$v^2/2g$		0.02735	m
h_f of Gate valve		0.00684	m
h_f of 2 number of elbows		0.04923	m
h_f of Check valve		0.27351	m
h_f of sudden contraction at inlet		0.01094	m
h_f of sudden expansion at outlet		0.02735	m
Total frictional head		1.76642	m
Pump head		22.561	m
Minimum power for the pump		***1074.81***	***Watt***