3.7

Two Reynolds Numbers

$$-\Delta p = 2 f_F \rho u_m^2 \frac{L}{D}$$

Even though the friction factor decreases at the higher flow rate, it is overshadowed by the increase in u_m^2, and the pressure drop therefore increases, by a factor of

$$\frac{0.0045}{0.008} \times 10^2 = 56.25 \text{ times}$$

3.8

Erroneous Friction Factor

Reynolds number

$$Re = \frac{\rho u_m D}{\mu} = \frac{62.4 \times 10 \times \frac{1}{12}}{1 \times 0.000672} = 7.74 \times 10^4$$

Erroneous friction factor based on incorrect assumption of laminar flow

$$f_F^L = \frac{16}{Re} = 2.07 \times 10^{-4}$$

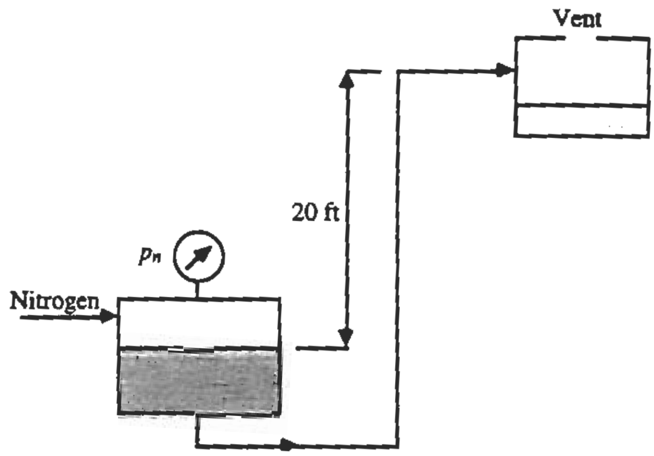
$$\frac{-\Delta p^L}{-\Delta p^T} = \frac{2 f_F^L \rho u_m^2 \frac{L}{D}}{2 f_F^T \rho u_m^2 \frac{L}{D}} = \frac{f_F^L}{f_F^T}$$

$$= \frac{2.07 \times 10^{-4}}{0.0060} = 0.0345$$

Hence the predicted pressure drop would be 3.45% of the correct value, or a deficiency of 96.55%.

3.9
Pumping Ketosene

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

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

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

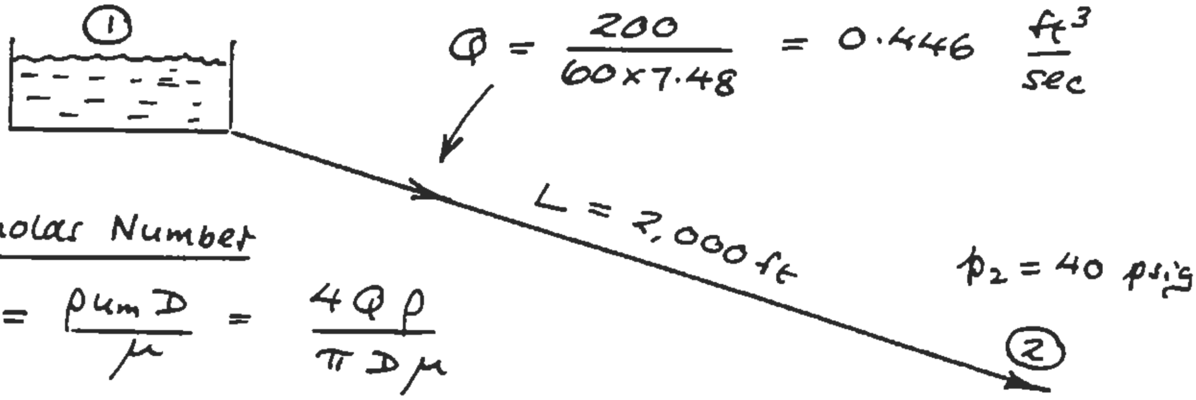
$$= 0.197 \times 60 \times 7.48$$

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

3.10

Lodge Water Supply

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



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

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

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

Hence $D = 0.820 \times f_F^{0.2}$

$\epsilon = 0.00015$ ft

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

Hence $D = 0.283$ ft $=$ **3.40 in**

Next size up $=$ **4.026 in** (nominal 4-in)

3.13

Pumping and Piping

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

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

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 $u_m = \frac{0.38}{0.0884} = 4.30$ 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.