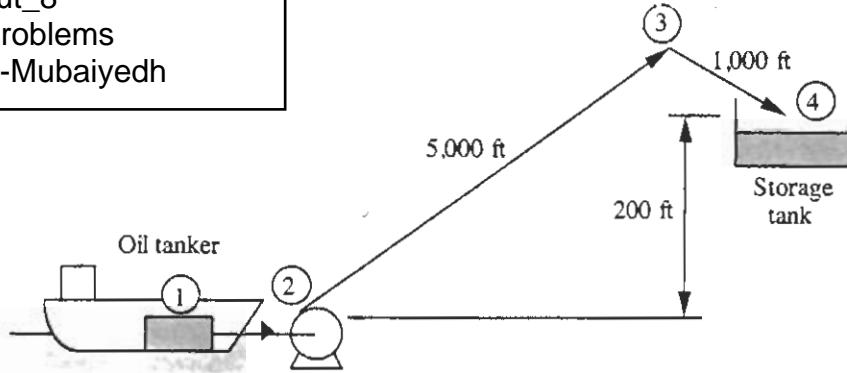


General. The following statements apply equally to Examples 3.2, 3.3, 3.4, and 3.5. Fig. E3.2 shows a pump that transfers a steady stream of 35° API crude

oil from an oil tanker to a refinery storage tank, both free surfaces being open to the atmosphere. The effective length—including fittings—of the commercial steel pipe is 6,000 ft. The discharge at point 4 is 200 ft above the pump exit, which is level with the free surface of oil in the tanker. However, because of an intervening hill, point 3 is at a higher altitude than point 4. Losses between points 1 and 2 may be ignored.

The crude oil has the following properties: $\rho = 53 \text{ lb}_m/\text{ft}^3$; $\mu = 13.2 \text{ cP}$; vapor pressure $p_v = 4.0 \text{ psia}$.

Handout_8
Pumping Problems
Dr. Usamah Al-Mubaiedyh



$$\rho = 53 \frac{\text{lb}_m}{\text{ft}^3}$$

$$\mu = 13.2 \text{ CP} = 8.87 \times 10^{-3} \frac{\text{lb}_m}{\text{ft} \cdot \text{s}}$$

Between points ② → ④ :

$$L = 6000 \text{ ft}$$

$$\Delta z = 200 \text{ ft}$$

The following equations are important:

$$-\Delta P = 2 f_F \rho u^2 \frac{L}{D} + \rho g \Delta z \quad (3.33)$$

$$f_F = \left\{ -1.737 \ln \left[0.269 \frac{E}{D} - \frac{2.185}{Re} \ln \left(0.269 \frac{E}{D} + \frac{14.5}{Re} \right) \right] \right\}_{-2}^{+2}$$

$$Re = \frac{\rho u D}{\mu} \quad \dots \quad (3.41)$$

Example 3.2—Unloading Oil from a Tanker

Specified Flow Rate and Diameter

Specific to Example 3.2. Implement the algorithm for a Case-1 type problem. If the pipeline is Schedule 40 with a nominal diameter of 6 in., and the required flow rate is 506 gpm, what pressure p_2 is needed at the pump exit? Solve the problem first by hand calculations, and then by a spreadsheet.

Q is known, D is known, but $-\Delta P$ is unknown

$$Q = 506 \text{ gpm} = \underline{1.127 \text{ ft}^3/\text{s}}$$

$$D = 6 \text{ in schedule -40 pipe} \Rightarrow D = 6.065 \text{ in}$$

$$\epsilon = 0.00015 \text{ ft (for commercial steel)}$$

$\nearrow = 0.5054 \text{ ft}$
see table 3-3

$$U_m = \frac{Q}{\frac{\pi}{4} D^2} = 5.62 \text{ ft/s}$$

$$Re = \frac{\rho U D}{\mu} = \frac{(53)(5.62)(0.5054)}{8.87 \times 10^{-3}} = 16972$$

$$\Rightarrow f_F = 0.00690$$

$$\Rightarrow -\Delta P = (2)(0.00690)(53) (5.62)^2 \frac{6000}{0.5054} + (53)(32.2)(200)$$

$$P_2 - P_4 = 615568 \frac{16m}{ft \cdot s^2} * \frac{1}{32.2 \frac{16m \text{ ft}}{lbf \cdot s^2}} * \frac{1}{144 \frac{in^2}{ft^2}}$$

$$= 132.76 \frac{lbf}{in^2} (\text{psi})$$

Example 3.3—Unloading Oil from a Tanker
Specified Diameter and Pressure Drop

Still consider the situation described at the beginning of Example 3.2, but now implement the algorithm for problems of type Case 2. If the pipeline is now specified to be of Schedule 40 with a nominal diameter of 6 in., and the available pressure at the pump exit is $p_2 = 132.7$ psig, what flow rate Q (gpm) can be expected?

$$-\Delta P = p_2 - p_4 = 132.7 \text{ psi} = 615303 \frac{\text{lbf}}{\text{ft}^2}$$

$$D = 0.5054 \text{ ft}$$

Q = unknown (Find u then find Q)

From equation (3.33) :

$$u = \sqrt{\frac{D [-\Delta P - g \Delta z]}{2 f_F S L}}$$

$$= \sqrt{\frac{(0.5054) [615303 - (53)(32.2)(200)]}{(2) f_F (53) (6000)}}$$

$$u = \sqrt{\frac{0.2177}{f_F}}$$

----- *

Solution procedure :

- ① guess Re
- ② calculate f_F from (3.41)
- ③ , , u from * above
- ④ calculate Re and check $Re_{calc} = Re_{reqd}$?
- ⑤ if not equal go back to step ②

$$\textcircled{1} \text{ guess } Re = 100000$$

$$\textcircled{2} \Rightarrow f_F = 0.00488$$

$$\textcircled{3} \Rightarrow U = \sqrt{(0.2177)/(0.00488)} = 6.679 \frac{\text{ft}}{\text{s}}$$

$$\textcircled{4} \text{ check } Re = \frac{(53)(6.679)(0.5054)}{(8.87 \times 10^{-3})}$$

$$= 20169.7 \neq \text{Re}_{\text{guess}}$$

\textcircled{5} go back to \textcircled{2} see summary below

Re_{guess}	$U (\text{ft/s})$	Recalculated
100000	6.679	20169.7
20169.7	5.728	17297.8
17297.8	5.629	16998.8
16998.8	5.618	16965.6
16965.6	5.616	16960.4

$Re_{\text{guess}} \approx Re_{\text{calculated}}$

$$\Rightarrow U = 5.616 \text{ ft/s}$$

$$\Rightarrow Q = 5.616 * \frac{\pi}{4} D^2 = 1.126 \frac{\text{ft}^3}{\text{s}}$$

Example 3.4—Unloading Oil from a Tanker
Specified Flow Rate and Pressure Drop

Consider again the situation described at the beginning of Example 3.2, but now implement the algorithm for problems of type Case 3. If the flow rate is specified as $Q = 506 \text{ gpm}$, and the available pressure at the pump exit is $p_2 = 132.7 \text{ psig}$, what pipe diameter D (in.) is needed?

$$Q = 506 \text{ gpm} = 1.127 \frac{\text{ft}^3}{\text{s}}$$

$$-\Delta P = p_2 - p_4 = 132.7 \text{ psi} = 615303 \frac{16m}{\text{ft} \cdot \text{s}^2}$$

$$D = \text{Unknown} ; U = \frac{Q}{\frac{\pi}{4} D^2}$$

From eq (3.33)

$$D = \left[\frac{32 f_F g Q^2 L}{\pi^2 (-\Delta P - 98 \Delta z)} \right]^{1/5}$$

$$= \left[\frac{(32) f_F (53) (1.127)^2 (6000)}{\pi^2 (615303 - (53)(32.2) 200)} \right]^{1/5}$$

$$= [4.78 f_F]^{1/5} \quad \dots \quad \text{--- } \textcircled{**}$$

① guess Re

② calculate f_F from (3.41)

③ " " D " $\textcircled{**}$

④ calculate Re and check $Re_{\text{guess}} = ? = Re_{\text{recalculated}}$

⑤ if not equal go to ②

(6)

Reguess	D (ft)	Recalculated
100 000	0.4716	18181.6
18181.6	0.5038	17017.1
17017.1	0.5054	16965.6
16965.6	0.5054	16963.2

$$\text{Reguess} = \text{Recalculated}$$

$$\Rightarrow D = 0.5054 \text{ ft}$$