Homework Assignment Number Five
Assigned: Wednesday, February 10, 1999
Due: Wednesday, February 17, 1999 BEFORE LECTURE STARTS.

Problem 1. Geankoplis, problem 2.10-3, page 111

$$\rho = 801\frac{kg}{m^3},\ \mu = 1.49\cdot 10^{-3}\frac{kg}{m\cdot s},\ \bar{v} = 4.57\frac{m}{s}$$

$$D = 1.5'' \text{ @ schd } 40 = 0.04089m,\ L = 61m$$

$$N_{Re} = \frac{D\bar{v}\rho}{\mu} = 100467$$ therefore flow is turbulent

(a) $$\frac{\varepsilon}{D} = \frac{4.6\cdot 10^{-5}}{0.04089} = 0.00112$$

from table on page 88 of Geankoplis $f = 0.006$

$$F_f = \frac{4fL\bar{v}^2}{D2} = 373.9\frac{J}{kg}$$

(b)

from table on page 88 of Geankoplis $f = 0.004$

$$F_f = \frac{4fL\bar{v}^2}{D2} = 249.3\frac{J}{kg}$$

percent reduction:

$$\frac{373.9 - 249.3}{373.9} = 0.333$$

Problem 2. Geankoplis, problem 2.10-5, page 112

$$q = 0.223\frac{ft^3}{s}\ \rho = 60.52\frac{lb_m}{ft^3},\ \mu = 2.33\cdot 10^{-4}\frac{lb_m}{ft\cdot s},$$

$$D_{1.5} = 1.5'' \text{ @ schd } 40 = 0.1342ft,\ A_{1.5} = 0.01414ft^2$$
$$D_{2.5} = 2.5'' \text{ @ schd } 40 = 0.2058ft,\ A_{2.5} = 0.03322ft^2$$

$\overline{v}_{1.5} = \frac{q}{A_{1.5}} = 15.77\frac{ft}{s}$ and $\overline{v}_{2.5} = \frac{q}{A_{2.5}} = 6.71\frac{ft}{s}$

$N_{Re,1.5} = \frac{D_{1.5}\overline{v}_{1.5}\rho}{\mu} = 549702$ therefore flow is turbulent in 1.5 inch pipe

$N_{Re,2.5} = \frac{D_{2.5}\overline{v}_{2.5}\rho}{\mu} = 358683$ therefore flow is turbulent in 2.5 inch pipe

$\frac{\varepsilon}{D_{1.5}} = \frac{0.00015}{0.1342} = 0.00112$ and $\frac{\varepsilon}{D_{2.5}} = \frac{0.00015}{0.2058} = 0.00073$

from table on page 88 of Geankoplis $f_{1.5} = 0.0048$, $f_{2.5} = 0.0045$

$L_{1.5} = 20ft$, $L_{2.5} = 125 + 10 + 50 = 185ft$

(a) Contraction loss at tank:

$$K_c = 0.55\left(1 - \frac{A_{1.5}}{A_1}\right) = 0.55,\ h_{f,c} = K_c\frac{\overline{v}_{1.5}^2}{2g_c} = 2.12\frac{ft \cdot lb_f}{lb_m}$$

(b) skin friction in 1.5 inch pipe:

$$F_{f,1.5} = \frac{4f_{1.5}L_{1.5}\overline{v}_{1.5}^{\ 2}}{D_{1.5}2} = 11.05\frac{ft \cdot lb_f}{lb_m}$$

(c) friction in 1.5 inch elbow:

$$h_{f,L,1.5} = K_L\frac{\overline{v}_{1.5}^2}{2g_c} = (0.75)\frac{\overline{v}_{1.5}^2}{2g_c} = 2.90\frac{ft \cdot lb_f}{lb_m}$$

(d) Expansion loss in pipe:

$$K_x = \left(1 - \frac{A_{1.5}}{A_{2.5}}\right)^2 = 0.33,\ h_{f,x} = K_x\frac{\overline{v}_{1.5}^2}{2g_c} = 1.27\frac{ft \cdot lb_f}{lb_m}$$

(e) skin friction in 2.5 inch pipe:

$$F_{f,2.5} = \frac{4f_{2.5}L_{2.5}\overline{v}_{2.5}^{\ 2}}{D_{2.5}2} = 11.31\frac{ft \cdot lb_f}{lb_m}$$

(f) friction in two 1.5 inch elbows:

$$h_{f,L,2.5} = K_L\frac{\overline{v}_{2.5}^2}{2g_c} = (0.75)\frac{\overline{v}_{2.5}^2}{2g_c} = 0.52\frac{ft \cdot lb_f}{lb_m}$$

$$2h_{f,L,2.5} = 1.05\frac{ft \cdot lb_f}{lb_m}$$

$$\sum F = h_{f,c} + F_{f,1.5} + h_{f,L,1.5} + h_{f,x} + F_{f,2.5} + 2h_{f,L,2.5} = 29.7\frac{ft \cdot lb_f}{lb_m}$$

$$0 = \frac{\Delta p}{\rho} + \frac{1}{g_c}\frac{\Delta v^2}{2\alpha} + \frac{g}{g_c}\Delta z + \hat{W}_s + \sum \hat{F}$$

$$0 = 0 + \frac{6.71^2}{2}\frac{1}{32.2} + \Delta z + 0 + 29.7$$

$$\Delta z = -30.4ft$$

Problem 3. Geankoplis, problem 2.10-8, page 112

(a) $$\rho = \frac{PMW}{RT} = \frac{101325 \cdot 0.0288}{8.314 \cdot 283} = 1.24\frac{kg}{m^3}$$

$$\mu = 0.0225 \cdot 10^{-3}\frac{kg}{m \cdot s}, \quad \bar{v} = 2\frac{m}{s}$$

$$D = 0.012m$$

$$N_{Re} = \frac{D\bar{v}\rho}{\mu} = 1323$$ therefore flow is laminar

$$L_e = 0.0575DN_{Re} = 0.91m$$

(b) $$\rho == 1000\frac{kg}{m^3}$$

$$\mu = 1.307 \cdot 10^{-3}\frac{kg}{m \cdot s}, \quad \bar{v} = 2\frac{m}{s}$$

$$D = 0.012m$$

$$N_{Re} = \frac{D\bar{v}\rho}{\mu} = 18363$$ therefore flow is turbulent

$$L_e = 50D = 0.6m$$

Problem 4. Geankoplis, problem 2.10-9, page 112

$$q = 3.494 \cdot 10^{-3}\frac{m^3}{s} \quad \rho = 833\frac{kg}{m^3}, \quad \mu = 3.3 \cdot 10^{-3}\frac{kg}{m \cdot s},$$

$$p_1 = 101325 + 345000 = 446325\text{Pa}$$

$$D_1 = 0.07792\text{m},\ A_1 = 0.00477\text{m}^2$$

$$\overline{v}_1 = \frac{q}{A_1} = 0.7325\,\frac{\text{m}}{\text{s}}$$

$$\dot{m} = \rho\overline{v}_1 A_1 = 2.91\frac{\text{kg}}{\text{s}}$$

$$N_{Re,1} = \frac{D_1\overline{v}_1\rho}{\mu} = 14407$$ therefore flow is turbulent

$$\frac{\varepsilon}{D_1} = \frac{4.6\cdot 10^{-5}}{0.07792} = 0.0006$$

from table on page 88 of Geankoplis $f_1 = 0.007$

$$L_1 = 120\text{m}$$

(a) Contraction loss at tank:

$$K_c = 0.55\left(1 - \frac{A_{1.5}}{A_1}\right) = 0.55,\ h_{f,c} = K_c\,\frac{\overline{v}_{1.5}^2}{2} = 0.148\,\frac{\text{J}}{\text{kg}}$$

(b) skin friction in pipe:

$$F_{f,1.5} = \frac{4f_1 L_1 \overline{v}_1^{\,2}}{D_1 2} = 11.78\,\frac{\text{J}}{\text{kg}}$$

(c) friction in elbows:

$$h_{f,L,1} = K_L\,\frac{\overline{v}_1^2}{2} = (0.75)\frac{\overline{v}_1^2}{2} = 0.201\frac{\text{J}}{\text{kg}}$$

$$2h_{f,L,1} = 0.403\,\frac{\text{J}}{\text{kg}}$$

(d) valve

$$h_{f,v} = K_v\,\frac{\overline{v}_1^2}{2} = (9.5)\frac{\overline{v}_1^2}{2} = 2.55\,\frac{\text{J}}{\text{kg}}$$

(e) Expansion loss:

$$K_x = \left(1 - \frac{A_1}{A_{tank}}\right)^2 = 1,\ h_{f,x} = K_x\,\frac{\overline{v}_1^2}{2} = 0.27\,\frac{\text{J}}{\text{kg}}$$

$$\sum F = h_{f,c} + F_{f,1} + 2h_{f,L,1} + h_{f,v} + h_{f,x} = 15.15\frac{J}{kg}$$

$$0 = \frac{\Delta p}{\rho} + \frac{1}{g_c}\frac{\Delta v^2}{2\alpha} + \frac{g}{g_c}\Delta z + \hat{W}_s + \sum \hat{F}$$

$$0 = \frac{\Delta p}{\rho} + \frac{\Delta v^2}{2\alpha} + g\Delta z + \hat{W}_s + \sum \hat{F}$$

$$0 = \frac{446325 - 101325}{833} + \frac{0.7325^2}{2} + 9.8(-20) + \hat{W}_s + 15.15$$

$$\hat{W}_s = -218.2\frac{J}{kg}$$

$$\dot{W}_s = \hat{W}_s\dot{m} = -218.2 \cdot 2.91 = -635.0\frac{J}{s}$$

$$\dot{W}_p = -\frac{\dot{W}_s}{\eta} = \frac{635}{0.65} = 977W = 1.0kW$$

Problem 5. Geankoplis, problem 2.10-10, page 112

$$q = 2.90 \cdot 10^{-3}\frac{m^3}{s}, L = 30m$$

$$D_1 = 1.0'' \text{ @ schd } 40 = 0.02664m, \; A_1 = 0.000557m^2$$

$$D_2 = 2.0'' \text{ @ schd } 40 = 0.05250m, \; A_2 = 0.002165m^2$$

cross-sectional area: $A = A_2 - A_1 = 0.001608m^2$

wetted perimeter = $wp = \pi D_1 + \pi D_2 = 0.24863m$

$$\bar{v} = \frac{q}{A} = 1.804\frac{m}{s}$$

density of water at T = 45 C from appendix $\rho = 990.16\frac{kg}{m^3}$

viscosity of water at T = 45 C from appendix $\mu_a = 0.599 \cdot 10^{-3}\frac{kg}{m \cdot s}$

viscosity of water at T = 49 C from appendix $\mu_w = 0.559 \cdot 10^{-3}\frac{kg}{m \cdot s}$

$$d = 4r_H = 4\frac{cross - sectional - area}{wetted - perimeter} = 0.02587m$$

$$N_{Re} = \frac{D\bar{v}\rho}{\mu} = 7.71 \cdot 10^4$$ therefore flow is turbulent

$$\frac{\varepsilon}{D_1} = \frac{4.6 \cdot 10^{-5}}{0.02587} = 1.77 \cdot 10^{-3}$$

from page 88 $f == 0.0057$

$$\psi = \left(\frac{0.599 \cdot 10^{-3}}{0.559 \cdot 10^{-3}}\right)^{0.17} = 1.0118$$

$$F_f = \frac{4fL\bar{v}^2}{\psi D2} = 42.52 \frac{J}{kg}$$

$$0 = \frac{\Delta p}{\rho} + \frac{1}{g_c}\frac{\Delta v^2}{2\alpha} + \frac{g}{g_c}\Delta z + \hat{W}_s + \sum \hat{F}$$

$$0 = \frac{\Delta p}{\rho} + 0 + 0 + 0 + 42.52$$

$$\Delta p = 42103 Pa$$

Problem 6. Frymier, Assignment 5, problem 4 (SP.6) located at http://flory.engr.utk.edu/~frymier/che240/hw_list.html

$$q = 810 \frac{gal}{min} = 0.0511 \frac{m^3}{s} \quad \rho = 1180 \frac{kg}{m^3}, \quad \mu = 1.2 \cdot 10^{-3} \frac{kg}{m \cdot s},$$

$$D_1 = 6.0'' \text{ @ schd } 40 = 0.1541 m, \; A_1 = 0.01865 m^2$$

$$\bar{v}_1 = \frac{q}{A_1} = 2.740 \frac{m}{s}$$

$$\dot{m} = \rho \bar{v}_1 A_1 = 60.30 \frac{kg}{s}$$

$$N_{Re,1} = \frac{D_1 \bar{v}_1 \rho}{\mu} = 415189$$ therefore flow is turbulent

$$\frac{\varepsilon}{D_1} = \frac{4.6 \cdot 10^{-5}}{0.1541} = 0.0003$$

from table on page 88 of Geankoplis $f_1 = 0.0035$

$$L_1 = 700 ft = 213.36 m$$

(a) Contraction loss at tank:

$$K_c = 0.55\left(1 - \frac{A_1}{A_{tank}}\right) = 0.55\text{, } h_{f,c} = K_c \frac{\overline{v}_1^2}{2} = 2.06 \frac{J}{kg}$$

(b) skin friction in pipe:

$$F_{f,1.5} = \frac{4 f_1 L_1 \overline{v}_1{}^2}{D_1 2} = 72.76 \frac{J}{kg}$$

(c) friction in elbows:

$$h_{f,L,1} = K_L \frac{\overline{v}_1^2}{2} = (0.75)\frac{\overline{v}_1^2}{2} = 2.82 \frac{J}{kg}$$

$$4h_{f,L,1} = 11.26 \frac{J}{kg}$$

(d) valves

$$h_{f,v} = K_v \frac{\overline{v}_1^2}{2} = (0.17)\frac{\overline{v}_1^2}{2} = 0.64 \frac{J}{kg}$$

$$2h_{f,v} = 1.28 \frac{J}{kg}$$

(d) tees

$$h_{f,T} = K_T \frac{\overline{v}_1^2}{2} = (1.0)\frac{\overline{v}_1^2}{2} = 3.75 \frac{J}{kg}$$

$$4h_{f,T,1} = 15.02 \frac{J}{kg}$$

(f) Expansion loss:

$$K_x = \left(1 - \frac{A_1}{A_{tank}}\right)^2 = 1\text{, } h_{f,x} = K_x \frac{\overline{v}_1^2}{2} = 3.75 \frac{J}{kg}$$

$$\sum F = h_{f,c} + F_{f,1} + 4h_{f,L,1} + 2h_{f,v} + 4h_{f,T,1} + h_{f,x} = 106.13 \frac{J}{kg}$$

$$0 = \frac{\Delta p}{\rho} + \frac{1}{g_c}\frac{\Delta v^2}{2\alpha} + \frac{g}{g_c}\Delta z + \hat{W}_s + \sum \hat{F}$$

$$\Delta p = \rho g H = 1180 \cdot 9.8 \cdot (200 \cdot 0.3048) = 704941 Pa$$

$$0 = \frac{704941 Pa}{1180} + 0 + 0 + \hat{W}_s + 106.13$$

$$\hat{W}_s = -703.5 \frac{J}{kg}$$

$$\dot{W}_s = \hat{W}_s \dot{m} = -703.5 \cdot 60.30 = -42423 \frac{J}{s}$$

$$\dot{W}_p = -\frac{\dot{W}_s}{\eta} = \frac{42423}{0.6} = 70705 W = 94.8 hp$$

(b)

$$\text{cost rate} = -\frac{0.56\$}{kW - hr}$$

time = 24 hours
cost = rate*power*time

$$\text{cost} = 0.056 \cdot 70.705 kW \cdot 24 hr = \$95.03$$