In the problems covered in the recent weeks' lectures, one topic that we discussed was Bernoulli's equation and the flow of fluids. We also discussed Newton's law and the limitations involved with it. A part of our discussion of hydrodynamics included us revisiting the laws of thermodynamics. Following that, we discussed friction losses in pipes and other systems and how to calculate them based on given information, as well as how to reference our textbooks to find the proper information. Finally, we learned about the Reynold's number and how to calculate flow patterns in different situations to determine whether flow is laminar or turbulent.

9/26/22
Devon Knight

MET 330 HW 1.4 Problems

2) 7.11

Q

h_L

745 gal/h | 1-in schedule 40 pipe | 10.5 lb-ft energy loss
(.00600 ft²)

a) power delivered (P_A)

$$z_1 + h_A - h_L = \frac{P_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

$$V = Q/A \qquad V = \frac{0.02769}{0.006} = 4.609$$

$$h_A = \frac{P_2}{\gamma} + (z_2 - z_1) + \frac{v_2^2}{2g} + h_L$$

$$h_A = \frac{5760.36}{62.4} + 120 + \frac{4.61^2}{2 * 32.19} + 10.5$$

$$92.3 + 120 + 0.33 + 10.5 = 223.13 \text{ ft}$$

$$P_A = 223.13 * 62.4 * \frac{745}{449 * 60} = 385.64 \text{ lb-ft/s} \left(\frac{1 \text{ hp}}{550 \text{ lb ft}}\right)$$

$$= .70$$

$e_m = .070 = \underline{70\%}$

Devon Kigler

7.16 840L/min (sg=0.85) DN 65 Sch 40 : 62.7mm

a) 4.2 N·m/N $P_1/\rho + V_1^2/2a_1 + z_1 g - W_p = P_4/\rho + V_4^2/2a_4 + z_4 g \ldots$

.85(1000) = 850 kg/m³ $\quad 0/850 + 0/2 (0 * 9.81) = \frac{825(10^3)}{850} + 0/2 + 14.5(9.81)$

$\dot{m}$ = 11.9 kg/sec

$+ W_p + 4.2(9.81) \quad W_p = -1154.03$ N·m/kg

P_A(Power delivered) = 11.9(1154.03) = $\underline{13,733 \text{ W}}$

b) $Q = A_3 V_3 \rightarrow Q = (\pi/4 d^2) V_3 \rightarrow V_3 = Q/(\pi/4 d^2)$

Area of pipe $\quad V_3 = 0.0139/(\pi/4 * 0.0627^2)$

$V_3 = 4.534$ m/sec

$0/850 + 0/2 + (0 * 9.81) = P_3/850 + 4.534^2/2 + (3*9.81) + (1.4*9.81)$

$P_3 = -45.42 \times 10^3$ N/m² → $\underline{-45.42 \text{ KPa}}$

7.22 Area of a cylinder $= \pi d^2/4 = \pi 5^2/4 = 19.635 in^2$
inside diameter = 5.0in   15 secs to travel 20 in exerting 11,000lb
11.5lb-ft/lb losses in suction   35.0lb-ft/lb in discharge
3/8in sch.80 pipes

a) $Q = $ (Area of cyl)(stroke length)/(time to complete stroke

$$\frac{(19.635 in^2)(20 in)\left|\frac{1 ft}{12 in}\right|\frac{1 ft^2}{144 in^2}}{15 s} = \underline{0.01515 ft^3/s}$$

b) $P_D = F/A_{cyl}$ $P_{cyl} = 11,000lb / 19.635 in^2 \left(144 in^2 / 1ft^2\right)$

$= \underline{80,672.27 lb/ft^2}$

$V_C = Q/A_C$ $V_C = 0.01515 ft^3/s / 0.000976 ft^2 = 15.52 ft/s$

Velocity at D $= V_D = h/t$ $\frac{20 in}{15 s}\left(\frac{1 ft}{12 in}\right) = 0.1111 ft/s$

$\gamma_o = sg(\gamma_w) = 0.90(62.4 lb/ft^3) = \underline{56.16 lb/ft^3}$

c) $P_C/\gamma_o = P_D/\gamma_o + V_D^2/2g + z_D - V_C^2/2g - z_C + h_{LD}$

80672.27 + 56.16

$$P_C = P_D + \gamma_o\left[\left(\frac{V_D^2 - V_C^2}{2g}\right) + (z_D - z_C) + h_{LD}\right] * (-3.741 + 45)$$

$$P_C = 80672.27 + 56.16\left[\frac{1.1111^2 - 15.52^2}{2(32.2)} + 10 + 35\right] \quad \underline{82990.506 lb/ft^2}$$

7.22 (cont'd)

d) $\frac{P_A}{\gamma_0} + \frac{V_A^2}{2g} + Z_A - h_{LS} = \frac{P_B}{\gamma_0} + \frac{V_B^2}{2g} + Z_B$

After substituting P_A and V_A with 0

$P_B = \gamma_0\left((Z_A - Z_B) - \frac{V_B^2}{2g} - h_{LS}\right)$

$P_B = 56.16\left((-5-0) - \frac{(15.52)^2}{2(32.2)} - 11.5\right)$

$56.16(-16.5 - 3.7402) = \underline{-1136.69 \text{ lb/ft}^2}$

to calculate power delivered, calculate net head =

$\frac{P_A}{\gamma_0} + \frac{V_A^2}{2g} + Z_A + h_A - h_{LS} - h_{LD} = \frac{P_D}{\gamma_0} + \frac{V_D^2}{2g} + Z_D$

$h_A = \frac{80672.27}{56.16} + \frac{(0.111)^2}{2(32.2)} + 10 + 5 + 11.5 + 35$

$1436.47 + (1.91 \times 10^{-4}) + 15 + 46.5 = 1497.97 \text{ ft}$

e) $P = h_A \gamma_0 Q / 550$ $\quad P = \frac{(1497.97 \text{ ft})(56.16 \text{ lb/ft}^3)(0.0155 \text{ ft}^3/\text{s})}{550}$

$P = \underline{2.32 \text{ hp}}$

7.35 $P_1/\gamma + z_1 + V_1^2/2g + h_A + h_R - h_L = P_2/\gamma + z_2 + V_2^2/2g$

P_1, P_2, V_1, and $h_A = 0$ in this case

$z_1 + hg - h_L = z_2 + V_2^2/2g \mid h_L = (z_1 - z_2) - V_2^2/2g - hg$

$P_A = h_A \gamma Q \rightarrow h_A = P_A/\gamma Q \rightarrow h_A = \frac{12{,}496}{58.032(0.39)}$

$= 552.18 \text{ lb}\cdot\text{ft/lb}$

$V_3 = 0.389/0.03326 = 11.73 \text{ ft/s}$

$V_2 \; 0.389/0.05132 = 7.6 \text{ ft/s}$

$P_3 = 58.032 - (7.69 - 1.24 + 552.18) \text{ lb/ft}^2 = 2.19 \text{ psi}$

$P_4 = 58.032(31525.88/58.032 - 28.5) \rightarrow (58.032)(514.75) = 207.44 \text{ psi}$

$P_5 = 58.032(-1 + 3.5) \rightarrow 1.01 \text{ psi}$

$h_R = -\left(\frac{145.08 - 29868.62}{58.032} + (-2)\right) = 514.19 \text{ ft}$

$P_R = 514.192 * 58.032 * 0.39 = \underline{21.16 \text{ hp}}$

7.42 $p_1 = 30\,psig = 4320\ lb/ft^2$ | $h_L = 15.5\ lb\cdot ft/lb$

$z_1 - z_2 = 220\,ft$ (3,5,212) $Q = 40\ gal/min$

$= 0.089\,ft^3/s$

$p_1, h_r, v_1, v_2 = 0$

$$z_1 + h_A + h_L = P_2/\gamma + z_2$$

$$h_A = P_2/\gamma + (z_2 - z_1) + h_L$$

$$h_A = 4320/62.4 + 220 + 15.5 = 69.23 + 220 + 15.5 = 304.73\,ft$$

$$P_A = 304.73 * 62.4 * 0.089 \rightarrow 1692.35\ lb\cdot ft/s * 1/550\ lb\cdot ft/s$$

3.08 hp

8.33 $P_1/\gamma + h + 0 - h_L = P_2/\gamma + 0 + V_2^2/2g$

$h + 0 - h_L = 0 + V_2^2/2g$

$Q = AV \rightarrow V = Q/A$

$D = 0.5054\,ft$ $\quad V = 250/0.2006 = 12.46\,ft/s$

$A = 0.2006\,ft^2$

$N_R = VD/\nu = 12.46 * 0.5054 / 9.15*10^{-6} = 688227.7 = 6.8x10^5$

$R_r = D/\epsilon \quad \epsilon = 1.5*10^{-4}\,ft \quad D/\epsilon = 0.5054/1.5*10^{-4}$

$= 3369.3$

Moody's diagram $= f = 0.0165$

$h_L = 0.0165 * 550/0.5054 * \frac{12.46^2}{64.4}$

$= 43.29\,ft$

$h = \frac{12.46^2}{64.4} + 43.29$

$= \underline{45.7\,ft}$

8.38

$h_A = (P_2/\gamma - p_{atm}/\gamma) + (z_2 - z_1) + v^2/2g + h_L$

$A = \pi D^2/4 \rightarrow A\ \pi(0.025\,m)^2/4 = 4.909\times10^{-4}\,m^2$

$Q = 95L/min \rightarrow 1.583\times10^{-3}\,m^3/s$

$V_2 = V_3 = V = Q/A \rightarrow V = 1.583\times10^{-3}/4.909\times10^{-4} = 3.22\,m/s$

$Re = \rho v D/\eta$ ρ = density η = dynamic viscosity

$\rho = (sg)(\rho w)$ $\rho = (1.10) * (1000\,kg/m^3) = 1100\,kg/m^3$

$Re = 1100 * 3.22 * 0.025/2\times10^{-3} = 44{,}275$

$f = 0.024$

head loss (h_L) $= f\,L/D * v^2/2g \rightarrow 0.024 * 85/0.025 * 3.22^2/2*9.81$

$= 43.122\,m$

$\gamma = 1.10 * (9.81\,kN/m^3) = 10.791\,kN/m^3$

$h_A = \left(\frac{140}{10.791} - \frac{101}{10.791}\right) + (10 - 2.7) + 3.22^2/64.4 + 43.122 = 54.197\,m$

$P = h_A(\gamma)(Q)$ $P = 54.197 * 10.791 \times 1.58\times10^{-3} = 0.924\,kW$

Substitute bernoulli's $P_1/\gamma + z_1 + h_A = P_3/\gamma + z_3 + v^2/2g$

$\frac{101}{10.791} + 1.2 + 54.197 = P_3/10.791 + 0 + 3.22^2/2 * 9.81 = 693.084\,kPa$

8.44 $V_A = Q/A_A$ $V_A = 0.50\ ft^3/s / 0.06868\ ft^2 = 7.28\ ft/s$

$V_B = Q/A_B$ $V_B = 0.50\ ft^3/s / 0.03326 = 15.03\ ft/s$

$\rho_f = sg * \rho_w$ $\rho_f = 1.026(1.94\ slugs/ft^3) = 1.9904\ slugs/ft^3$

$N_R = V_B D_B \rho_f/\mu = N_R = \frac{(15.03\ ft/s)(0.2058\ ft)(1.9904\ slugs/ft^3)}{4.0\times10^{-5}\ lb\cdot s/ft^2}$

$N_R = 6.156/4.0\times10^{-5} = 1.54\times10^5$

$Re > 2000$
turbulent flow

$D_B/\varepsilon = 0.2058\ ft / 1.5\times10^{-4}\ ft$
$= 1372$

friction factor: $f = \frac{0.25}{\left(\log\left(\frac{1}{3.7(1372)} + \frac{5.74}{(1.54\times10^5)^{0.9}}\right)\right)^2} \rightarrow \frac{0.25}{(\log(3.1427\times10^{-4}))^2}$

$\underline{0.020}$

$h_L = fLv_B^2/2gD_B \rightarrow h_L = (0.020)(80)(15.03)^2/64.4(0.2058)$
$= 27.27\ ft$

$\gamma_f = sg(\gamma_w) \rightarrow 1.026(62.4\ lb/ft^3) = 64.022\ lb/ft^3$

Substitute bernoulli's $\rightarrow h_A = \left(\frac{25-(-3.50)}{64.022}\left(\frac{144\ in^2}{ft^2}\right)\right) + 80 + \frac{15.03^2 - 7.28^2}{64.4} + 27.27$
$= 174.485\ ft$

power $\rightarrow P = h_A \gamma_f Q/550 \rightarrow P = (174.485)(64.022)(0.50)/550$
$5585.47/550 = 10.155 \rightarrow \underline{10.2\ hp}$

8.46 $p_1/\gamma + z_1 + v_1^2/2g + h_A - h_L = p_2/\gamma + z_2 + v_2^2/2g$

$\rightarrow p_1 = \gamma((z_2 - z_1) + h_L)$

$V = Q/A \rightarrow Q/\pi/_4 d^2 \quad V = 4/\pi/_4(8/12)^2 = 11.46 \text{ ft/s}$

Viscosity of water at 60°F via Table A.2 $= 1.21\times10^{-5} \text{ ft}^2/\text{s}$

$N_R = vD/\nu \rightarrow N_R = \dfrac{(11.46)(8/12)}{1.21\times10^{-5}} = 631{,}404.95$

relative roughness $= \varepsilon/d$ Steel pipe roughess via table 8.2 $= 1.5\times10^{-4}$ ft

$\varepsilon/d = 1.5\times10^{-4} \text{ ft} / 8/12 \text{ ft} = 0.000225$

Substitute energyloss equation $\rightarrow h_L = 0.0153 \times 2500/(8/12) \times 11.46^2/64.4$

$h_L = 117 \text{ ft}$

pressure $\rightarrow p_1 = 62.4 * 327 * 1/144 = \underline{141.7 \text{ psia}}$

8.49 Alter bernoulli's equation → $p1/\gamma + z_1 + V_1^2/2g - h_L + h_A = p2/\gamma + z_2 + V_2^2/2g$

$h_A = h_L + (z_2 - z_1) + V_2^2/2g$

Velocity (discharge) = $V_D = Q/A$ → $V_D = 0.668/0.05132 = 13.024$ ft/s

velocity (suction) = $V_S = Q/A$ → $V_S = 0.668/0.0884 = 7.56$ ft/s

Reynold's number → $N_R = vD/\nu$ → $N_{RD} = \frac{13.024 \times 0.2557}{2.15 \times 10^{-3}}$
$= 1548.98$

$f_D = 64/N_R$ → $64/1548.98 = 0.04132$

for suction pipe

$N_{RS} = 7.56 * 0.3355 / 2.15 \times 10^{-3} = 1179.711 = 0.054$

head due to friction → $h_D = f_D \frac{L_D}{D_D} \times V_D^2/2g$ (discharge)

$h_D = \frac{0.04132 * 75 * 13.024^2}{0.2557 * 64.4} = 31.92$ ft

head due to friction → $h_{LS} = f_S \, L_S/D_S \times V_S^2/2g$ (suction)

$h_S = \frac{0.054 * 25 * 7.56^2}{0.3355 * 64.4} = 3.57$ ft $\quad h_L = 31.92 + 3.57 = 35.49$ ft

$\gamma = 0.89 * 62.4 = 55.536$ lb/ft3 $\quad P = 55.536 * 0.6684 * 39.1 * 1/550$

$h_A = 35.49 + 1 + \frac{13.024^2}{64.4} = 39.1$ ft $\quad$ P = 2.64 hp

8.62 friction factor $77^{\circ F}$ 6-in schedule 40 pipe
12 ft/s

$$f = \frac{0.25}{\left(\log\left(\frac{1}{3.7(D/\varepsilon)} + \frac{5.74}{N_R^{0.9}}\right)\right)^2}$$

Reynold's number $N_R = vD/\nu$ $\nu = 1.27 * 10^{-3}\ ft^2/s$

$D = 0.5054\ ft$

$$N_R = \frac{(12)(0.5054)}{1.27\times10^{-3}} = 4775.43 \text{ — turbulent}$$

$$f = \frac{0.25}{\left(\log\left(\frac{1}{3.7\left(\frac{0.5054}{1.5\times10^{-4}}\right)} + \frac{5.74}{(4775)^{0.9}}\right)\right)^2} \rightarrow \frac{0.25}{(\log((3369.33) + (2.8\times10^{-3})))^2}$$

$$\rightarrow \frac{0.25}{(\log(3,369.33))^2} = 0.0388$$

10.20 energy loss $h_L = K(v_2^2/2g)$ | Small pipe $= Q = A_1 V_1$

$V_1 = Q/A_1$

Cross sections =

Small $= A_1 = \pi/4 \times D_1^2$

Large $= A_2 = \pi/4 \times D_2^2$

Large pipe $= Q = A_2 V_2$

$V_2\ Q/A_2$

$DN_{125} = 141.3mm$ | thickness $= 9.5mm$

$DN\ 50 = 60.3mm$ | thickness $= 5.54mm$

$D_1 = D_{OD} - 2t =$

$D_2 = 60.3 - 2(5.54) = 49.22mm \rightarrow 0.04922m$

$D_1/D_2 = 0.1223/0.04922 = 2.485$

$A_2 = \pi/4 \times D_2^2$

$= \pi/4 \times (0.04922m)^2$

$= 19.035 \times 10^{-4} m^2$

$K = .39$

$V_2 = Q/A_2 = \frac{500 L/min}{19.035 \times 10^{-4} m^2} \times \frac{1 m^3/s}{60{,}000 L/min}$

$V_2 = 4.378\ m/s$

$h_L = K(V_2^2/2g) = (0.39) \times \frac{(4.378 m/s)^2}{2(9.81 m/s^2)}$

$= 0.381\ N$

10.37 $Q = 12.5 gal/min$ $T = 77°f$ $h_L = K(v^2/2g)$

$D = 0.0518 ft$ $h_f = f \times L/D \times v^2/2g$

$A = 0.00211 ft^2$

$Q = Av$

$Q = 12.5 \times 0.1337 \times 1/60 = 0.0278 ft^3/s$ $V = Q/A$

$V = \frac{0.0278}{0.00211} = 13.175 ft/s$

$K = f_T(L_e/D)$ $L_e/D = 50$ $\epsilon = 1.5 \times 10^{-4} ft$

$D/\epsilon = \frac{0.0518}{1.5 \times 10^{-4}}$ $D/\epsilon = 345.33$

$K = (0.026)(50) = 1.3$

$h_L = K(v^2/2g) \rightarrow 1.3\left(\frac{13.175^2}{64.4}\right) \rightarrow h_L = 3.503$

$N_R = vD/\nu \rightarrow \frac{13.175 \times 0.0518}{1.59 \times 10^{-4}} = 4292.232$

$f = 0.0415$ $h_f = f \times L/D \times v^2/2g \rightarrow 0.0415 \times 8/0.0518 \times \frac{13.175^2}{64.4}$
$= 17.275 ft$

$p_1 - p_2 = \gamma(h_L + h_f)$
$= (68.47)(20.778)$
$= 1422.669 \, lb/ft^2 \, (1/144)$
$= \underline{9.87 psi}$

10.39 Darcy's equation - energy loss due to friction

$h_L = f \, L_e/D * v^2/2g$ flow area - appendix F

$A = 0.05132 \, mm^2$

$V = Q/A \rightarrow V = 0.40/0.05132 = 7.794 \, ft/s$

Table 10.4 → $L_e/D = 20$

Table 10.5 → $f = 0.017$

$h_L = f \, L_e/D \; V^2/2g = (0.017)(20)\frac{(7.794)^2}{64.4} = 0.32 \, ft$

10.43 proposal 1 1L/min → $0.0125\, m^3/s$

diameter → $d = D - 2t$ $d = 50 - 2\times2$

$= 46\,mm \rightarrow 0.046\,m$

$A = \pi d^2/4 \rightarrow 6.648\times10^{-3}/4 = 1.662\times10^{-3}\,m^2$

$v = Q/A$ $v = 0.0125/1.662\times10^{-3} = 7.52\,m/s$

radius of tube 10.27 textbook

$r/D = 750/46 = 16.3$ $L_e/D = 43$

8.2 textbook → $\varepsilon = 1.5\times10^{-6}\,m$

$N_R = vD\rho/\eta$ $\eta = 1.92\times10^{-3}\,Pa\cdot s$ $\rho = 802\,kg/m^3$

$N_R = 7.52 * 0.046 * 802/1.92\times10^{-3} = 144,493.67$

Roughness $= D/\varepsilon \rightarrow 0.046/1.5\times10^{-6} = 30,666.67$

Moody's diagram for roughness and reynold's number, respectively $= f_T = 0.0095$, $f = 0.0162$

Resistance Factor → $k = f_T(L_e/D) \rightarrow k = 0.0095(43) = 0.4085$

Energy loss → $h_L = K\, v^2/2g \rightarrow 0.4085 * 56.55/19.62 = 1.177\,m$

proposal 2 relative radius → $r/d = 150/46 = 3.261$

given: $L_e/D = 13$

Loss due to bend → $f_T\, \frac{L_e}{D}\, \frac{v^2}{2g} = 0.0095\times13\times2.88 = 0.356\,m$

head loss $h_{tube} \rightarrow f\, \frac{L}{D} * \frac{v^2}{2g} \rightarrow 0.0162 * 26.087 * 2.88$

$= 1.218\,m$

$h_L = 0.356 + 1.218 = \underline{1.574\,m}$

10.46 Energy loss between points 1 and 2

pipe 1 inside diameter $d_1 = D_1$(outer diameter)$- 2t_1$(thickness of pipe 1)

$d_1 = 50-4 = 46mm = 0.046m$

Cross Sectional area of pipe 1 $A_1 = \pi/4 \times d_1^2$

$\rightarrow 6.6476 \times 10^{-3}/4$

$\rightarrow 1.662 \times 10^{-3}\ m^2$

pipe 2 inside diameter

CSA of pipe 2 $A_2\ \pi/4\,(0.093^2)$

$0.0272/4 \rightarrow 6.8 \times 10^{-3}\ m^2$

Flow velocity (pipe 1)

$V_1 = 6.0 \times 10^{-3} / 1.662 \times 10^{-3}\ m^2 \rightarrow 3.61\ m/s$

$V_2 = 6.0 \times 10^{-3} / 6.8 \times 10^{-3}\ m^2 \rightarrow 0.8823\ m/s$

Rewrite bernoulli's according to problem

$h_L = P_1 - P_2/\gamma + (z_1 - z_2) + V_1^2 - V_2^2/2g$

Table acquired values: $\gamma = 9.69\ kN/m^3$ | $\gamma_m = 132.8\ kN/m^3$

Elevation difference $= -1.20m$

Difference in pressure $= P_1 - P_2 = \gamma_m(0.35) + \gamma_m(0.85)$

$$h_L = 5.65 - 1.20 + \frac{3.61^2 - 0.8823^2}{2 * 9.81}$$

$$\frac{P_1 - P_2}{\gamma_w} = \frac{132.8(0.35)}{9.69} + \frac{9.69(0.85)}{9.69}$$

$5.65 - 1.20 + 0.6245$

$= 5.0745m$

$= 5.65m$

10.46 cont'd calculate resistance $h_L = K(v^2/2g)$

$5.0745 = K\left(\frac{3.61^2}{2*9.81}\right)$ $5.0745 = 0.6642K$

$K = 5.0745/0.6642 = 7.64$ resistance coefficient

10.48 Energy Loss → $h_L = K(v^2/2g)$

Flow area → $A = 6.409\times10^{-3} ft^2$

Inner flow diameter $D = 0.09033 ft$

Relative radius $r/D = \frac{3.25 * 1/12}{0.09033}$ → 2.998 | $L_e/D = 12.5$

$\epsilon = 1.5\times10^{-4} ft$ D/ϵ $0.09033/1.5\times10^{-4}$ → 602.2

$K = f_T(L_e/D)$ → $K = (0.0222)(12.5)$ → $K = 0.2775$

Velocity $v = Q/A$ → $Q = 27.5\times0.1337\times1/60$ → $0.06127 ft^3/s$

$v = \frac{0.06127}{6.409\times10^{-3}}$ → $9.559 ft/s$

$h_L = K(v^2/2g)$ → $0.2775\left(\frac{9.559^2}{64.4}\right) = h_L = 0.3937 ft$