King Fahd University of Petroleum & Minerals
Chemical Engineering Department
CHE 204 – Transport Phenomena I
2004 - 2005 (041)

1st Major Examination

Saturday, October 23, 2004

Time: 8:30-10:30 p.m.

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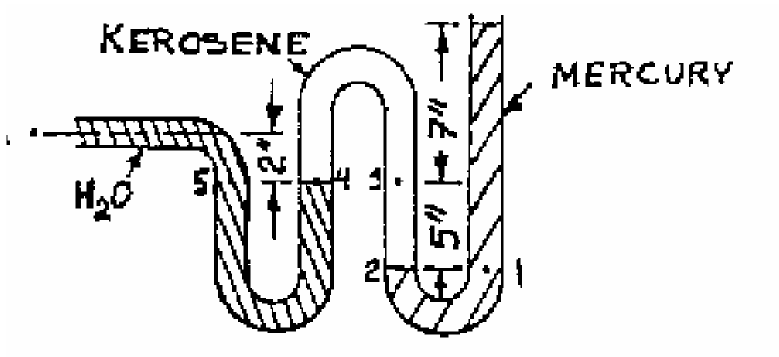
Name: ___________________________________ I.D.___________________

Section: 1 2 3 4

	Maximum	
Q1	25	
Q2	25	
Q3	25	
Q4	25	
Total	100	

Problem 1

Find the pressure at point A.



$$\rho_{water} = 1000 \, {}^{kg}/_{m^3} \qquad \rho_{kerosene} = 47.6 \, {}^{lb_m}/_{ft^3} \qquad \rho_{mercury} = 845 \, {}^{lb_m}/_{ft^3}$$

$$P_1 = P_2 \qquad P_1 = P_{atm} + \rho_m g(12in)$$

$$P_3 = P_4 \qquad P_2 = P_3 + \rho_k g(5in)$$

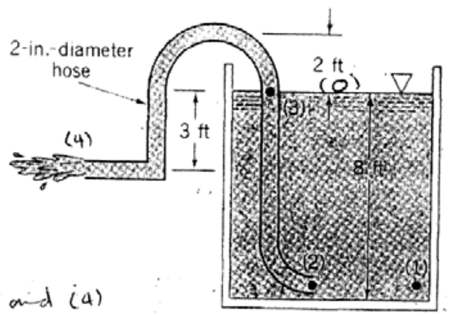
$$P_4 = P_5 \qquad P_4 = P_A + \rho_w g(2in)$$

$$P_A = P_{atm} + 32.2\frac{ft}{s^2}\left[(845\frac{lb_m}{ft^3})(\frac{12}{12}ft) - (47.6\frac{lb_m}{ft^3})(\frac{5}{12}ft) - (62.4\frac{lb_m}{ft^3})(\frac{2}{12}ft)\right]\frac{lb_f \cdot s^2}{32.2 lb_m \cdot ft}\frac{ft^2}{144in^2} =$$

$$= P_{atm} + 5.66\, psig = 20.36\, psia$$

Problem 3

Water is siphoned from a **huge** tank as shown in the figure below. Determine the flow rate from the tank and the pressures at pints 1, 2, and 3. **Neglect friction**



B.E. between (0) and (4)

$$\frac{P_4 - P_0}{\rho} + g(z_4 - z_0) + \frac{u_4^2 - u_0^2}{2} = 0$$

$P_4 = P_0$, $z_4 - z_0 = -3\,ft$, $u_0 = 0$

+7

$\Rightarrow -3 * 32.2 + \frac{u_4^2}{2} = 0 \quad \Rightarrow u_4 = \sqrt{6 * 32.2} = 13.90\ ft/s.$

$Q_4 = \frac{\pi}{4} D_4^2 u_4 = \frac{\pi}{4} * \left(\frac{2}{12}\right)^2 * 13.90 = 0.303\ ft^3/s.$

B.E. between (0) and (1)

$$\frac{P_1 - P_0}{\rho} + g(z_1 - z_0) + \frac{u_1^2 - u_0^2}{2} = 0$$

+6

$z_1 - z_0 = 8\ ft$, $u_1 = u_0 = 0$

$\therefore P_1 = P_0 + \rho g(z_0 - z_1) = 0 + 62.4 * 32.2 * 8 * \frac{1}{32.2} = 499.2\ \frac{lb_f}{ft^2}$

$= 3.47\ Psig.$

+6

B.E. (0) and (2):

$$\frac{P_2 - P_0}{\rho} + g(z_2 - z_0) + \frac{u_2^2 - u_0^2}{2} = 0$$

$$\Rightarrow P_2 = P_0 + \rho g (z_0 - z_2) - \rho \frac{u_2^2}{2}$$

$P_0 = 0$ gauge $\quad z_0 - z_2 = 8\,ft \quad u_2 = u_4 = 13.90\ ft/s$

$$\therefore P_2 = 0 + 62.4 * 32.2 * 8/32.2 - 62.4 * \frac{13.90^2}{2} * \frac{1}{32.2} = 312\ \frac{lb_f}{ft^2}$$

$$= 2.17\ Psig.$$

+6

B.E. (0) and (3):

$$\frac{P_3 - P_0}{\rho} + g(z_3 - z_0) + \frac{u_3^2 - u_0^2}{2} = 0$$

$u_3 = u_4 = 13.90\ ft/s$

$z_0 - z_3 = 0$

$P_0 = 0$ gauge

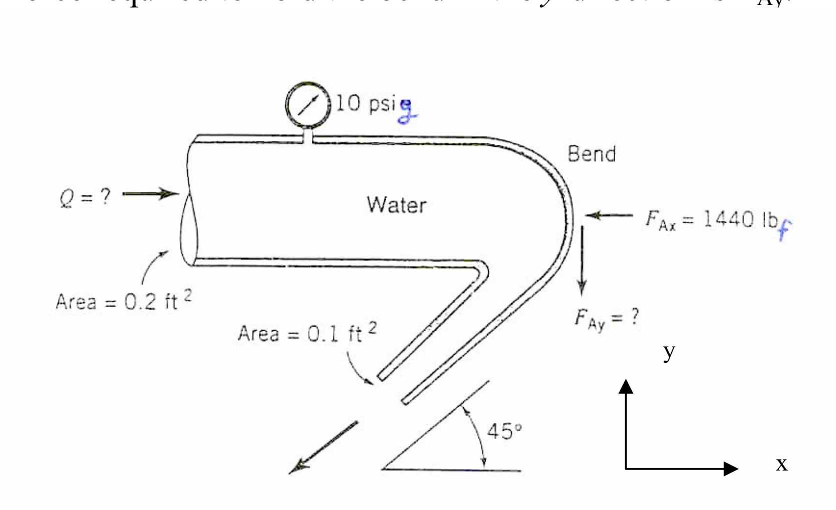
$$\Rightarrow P_3 = P_0 + \rho g (z_0 - z_3) - \rho \frac{u_4^2}{2}$$

$$\therefore P_3 = -\rho \frac{u_4^2}{2} = -187.2\ \frac{lb_f}{ft^2} = -1.30\ Psig.$$

Problem 3

Water (ρ_w = 62.4 lb_m/ft^3) flows through a horizontal bend and discharges into the atmosphere as shown in the figure below. When the pressure gauge at the inlet reads 10 psig, the magnitude of the force required to hold the bend in the *x*-direction is $|F_{Ax}|$ = 1440 lb_f. Calculate the following:

(a) The volumetric flow rate of water through the bend.
(b) The force required to hold the bend in the *y*-direction is F_{Ay}.



(a) Steady state momentum balance in x-direction

$$\dot{M}_{in}\big|_x - \dot{M}_{out}\big|_x + \sum F\big|_x = 0$$

$$\Rightarrow \quad (\dot{m}_1 u_1) - (-\dot{m}_2 u_2 \cos(45)) + P_1 A_1 + P_2 A_2 \cos(45) - |F_{AX}| = 0$$

$$Q = u_1 A_1 = u_2 A_2, \quad \dot{m}_1 = \dot{m}_2 = \rho u_1 A_1, \quad u_2 = u_1 \frac{A_1}{A_2} \text{ and } P_2 = P_{atm} = 0\,psiq$$

Substitute: $\rho A_1 u_1^2 + \frac{\rho A_1^2 u_1^2}{A_2}\cos(45) + P_1 A_1 - |F_{AX}| = 0$

Solve for u_1: $\quad u_1 = \sqrt{\frac{(|F_{AX}| - P_1 A_1)}{\rho A_1\left[1 + \frac{A_1}{A_2}\cos(45)\right]}}$

$$\Rightarrow \quad u_1 = \sqrt{\frac{\left[1440 lb_f * 32.2\frac{lbm\ ft}{1b_F S^2} - 10\frac{1b_f}{in^2} * 144\frac{in^2}{ft^2} * 0.2\,ft^2 * 32.2\frac{1bm\ ft}{lb_f S^2}\right]}{\left(62.4\frac{lb_m}{ft^3} * 0.2\,ft^2\left[1 + \frac{0.2}{0.1}\cos(45)\right]\right)}} = \sqrt{1231.2\left(\frac{ft^2}{s^2}\right)} = 35.08\frac{ft}{s}$$

$$\Rightarrow Q = u_1 A_1 = 7.02 \frac{ft^3}{s}$$

(b) **Steady state momentum balance in y-direction**

$$\dot{M}_{in}\Big|_y - \dot{M}_{out}\Big|_y + \Sigma F\Big|_y = 0$$

$$\Rightarrow \quad (0) - \left(-\dot{m}_2 u_2 \cos(45)\right) + P_2 A_2 \cos(45) + F_{Ay} = 0$$

$$\dot{\mathrm{m}}_2 = \rho\, \mathrm{u}_1 \mathrm{A}_1 ,\; u_2 = u_1\, A_1 / A_2 ,\; P_2 = 0\,\mathrm{psig}$$

$$\Rightarrow F_{Ay} = -\rho\, u_1^2 A_1^2 / A_2$$

$$F_{Ay} = -(62.4)\left(\frac{lb_m}{ft^3}\right)(35.08)^2 \frac{ft^2}{s^2} (0.2)^2 ft^4 \cos(45) \Big/ 0.1 ft^2 = -21719.45 \; \frac{lb_m ft}{s^2} \frac{1}{32.2 \dfrac{lb_m ft}{lb_f s^2}} = -674.5 \; lb_f$$

Problem 4

A liquid flows with a velocity (v) through a hole in the side of a large tank. Assume that $v = f(h, g, \rho, \sigma)$ where h is the depth of the fluid above the hole, g is the acceleration of gravity, ρ the fluid density, and σ the surface tension. Perform the dimensional analysis of the problem to find the **dimensionless** groups.

Dimensions

$h \,[=]\, L$

$g \,[=]\, LT^{-2}$

$\rho \,[=]\, ML^{-3}$

$\sigma \,[=]\, MT^{-2}$

$V \,[=]\, LT^{-1}$

No. of Variables = 5

No. of Dimensions = 3

No. of dimensionless groups = 2

Repeated Variables : h, g, ρ

unrepeated " : V, σ

Dimensionless π groups

$\pi_1 = h^{a_1} g^{b_1} \rho^{c_1} V$

$\pi_2 = h^{a_2} g^{b_2} \rho^{c_2} \sigma$

Now replace variables by their dimensions

Π_1

$$M^0 L^0 T^0 = (L)^{a_1} (LT^{-2})^{b_1} (ML^{-3})^{c_1} (LT^{-1})$$

$$M^0 L^0 T^0 = M^{c_1} L^{a_1+b_1-3c_1+1} T^{-2b_1-1}$$

$\therefore c_1 = 0$

$a_1 + b_1 - 3c_1 + 1 = 0$

$-2b_1 - 1 = 0$

$\therefore b_1 = -1/2$

$a_1 = -1/2$

$$\therefore \Pi_1 = \frac{V}{g^{-1/2} h^{-1/2}} = \frac{V}{\sqrt{gh}}$$

Now Π_2

$$M^0 L^0 T^0 = (L)^{a_2} (LT^{-2})^{b_2} (ML^{-3})^{c_2} (MT^{-2})$$

$$= M^{c_2+1} L^{a_2+b_2-3c_2} T^{-2b_2-2}$$

$c_2 + 1 = 0 \Rightarrow a_2 = -2;\ b_2 = -1;\ c_2 = -1$

$a_2 + b_2 - 3c_2 = 0$

$-2b_2 - 2 = 0 \quad \therefore \Pi_2 = \dfrac{\sigma}{h^2 g \rho}$

$$\therefore \frac{V}{\sqrt{gh}} = \phi_1\left(\frac{\sigma}{h^2 g \rho}\right) \text{ or, } \frac{V}{\sqrt{gh}} = \phi_2\left(\frac{\rho g h^2}{\sigma}\right)$$