Name: ______________________________ Student ID ______________

Prince of Songkla University
Faculty of Engineering

Exam: Final Exam, Semester I **Academic Year: 2006 – 07**
Date: October 11, 2006 **Time: 13:30 – 16:30**
Subject: 230-391 – Basic Chemical Engineering I **Room: R300**

ทุจริตในการสอบโทษขั้นต่ำคือ ปรับตกในรายวิชาที่ทุจริต และพักการเรียน 1 ภาคการศึกษา

Instructions: There are a total of 5 problems. The points for each problem are not distributed evenly. Place your name and the student ID number on every page. Students are allowed to use only a pen or pencil, a calculator, and one page of A4 note front and back into the examination. Student can use the Conversions Table. No exams are allowed to leave the room.

Points Distribution (For Grader Only)		
Problem	Points Value	Score
1	20	
2	30	
3	15	
4	20	
5	15	
Total	100	

Exam prepared by
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October 6, 2006

PLEASE CHECK TO MAKE SURE THAT
YOU HAVE ALL 6 PAGES OF THE EXAM BEFORE BEGINNING
(not including the cover sheet).
GOOD LUCK!

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1. A viscous incompressible fluid is flowing in a slit formed by two parallel walls a distance 2B apart. **(20 Points Total)**

   (a) What is the Reynolds number of the falling film if the velocity is 5 cm/s, the viscosity is 5 cp, the density is 1.8 g/cm^3, W = 10 cm, B = 0.4 cm, and L = 40 cm. **(10 points)**

   (b) Make a differential momentum balance and obtain the expressions for the distributions of momentum flux given below: **(10 points)**

$$\tau_{xz} = \left(\frac{P_o - P_L}{L} \right) x$$

Hint: Write a momentum balance (momentum in, momentum out, gravity force, pressure force, shear stress force) then convert it to a differential ($d\tau_{xz}/dx$) by taking the limit as $\Delta x \to 0$.

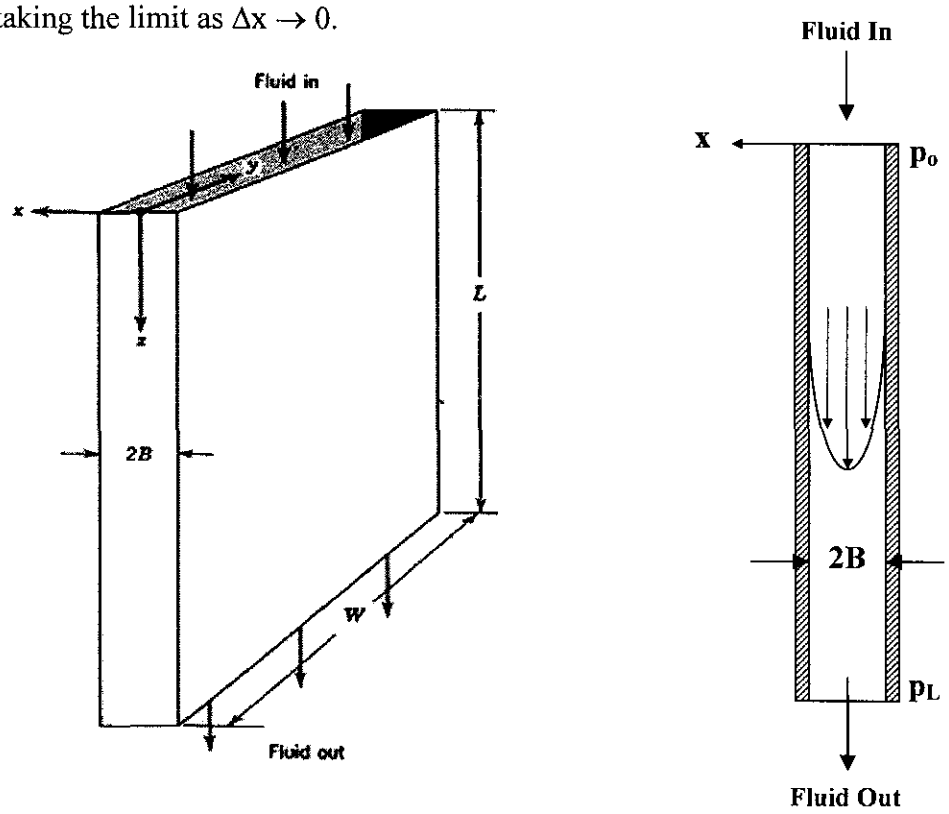

Figure 1: Falling film through a slit.

2. Water is being pumped through a coaxial annular conduit 20.3 ft long at a rate of 240 US gal/min. The inner and outer diameters are 3 in. and 7 in., respectively. The inlet is 5 ft lower than the outlet. The inside of the pipe is smooth, determine the following information. **(30 Points Total)**

   (a) Determine average velocity inside the pipe (in **ft/s**). **(5 points)**
   (b) Is the flow laminar or turbulent (μ = 1 cp and ρ = 62.4 lbm/ft^3)? **(10 points)**
   (c) Determine the power requirement in **horsepower**. Assuming that the initial velocity at point 1 is 0.0 m/s and the final velocity at point 2 is equal to the average velocity inside the pipe. **(15 points)**

Useful Tips: Begin with the Bernoulli Equation and state all assumptions. Use the mean hydraulic radius to solve the problem. Assume the pressure at the pump inlet and outlet are the annular outlet are the same. (There is no sudden expansion and e_v for 90° elbow = 0.5.)

Work of Pump is given by:

$$Wp = w\hat{W}$$

where, Wp = work of pump (convert to hp),
w = mass flow rate (lb_m/s)
$\hat{W}$ = work per unit mass(ft^2/s^2)

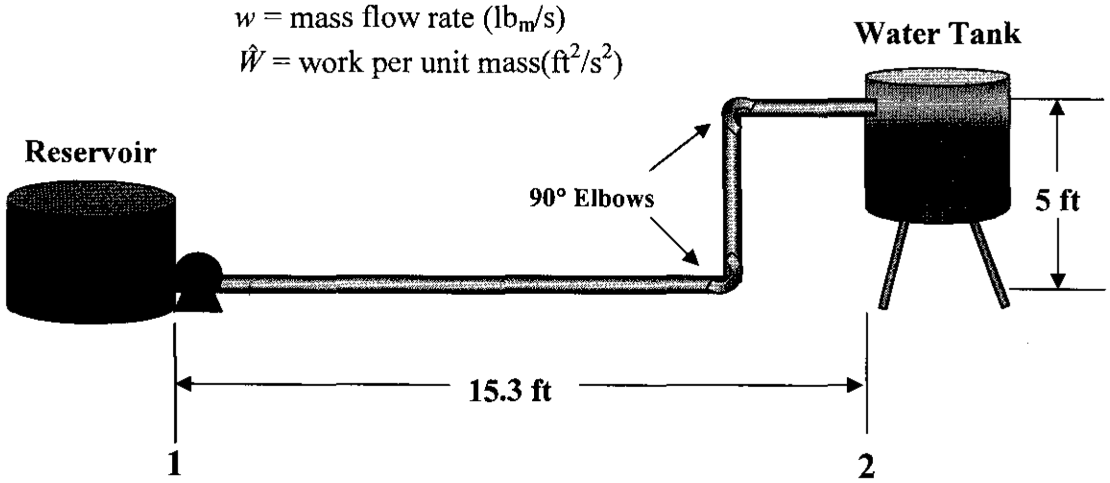

Figure 2: Flow of water through an annular conduit.

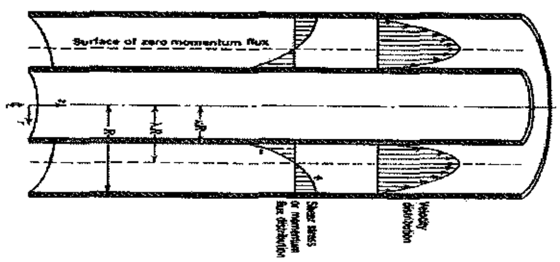

Figure 3: Picture of annular conduit in Problem 1.

3. A frame and plate filter press is used to filter calcium carbonate from a slurry containing 4.5 lb of dry solid per cubic foot of solid free liquid at a constant pressure difference of 6.5 psi. The specific cake resistance for the slurry and the volume of the filtrate obtained are given by the equations below:

$$\alpha = 1.85\,\Delta P^{0.3} \quad [\mathrm{lb_f\text{-}h/(lb_m\text{-}ft)}]$$

$$V^2 = \frac{2\Delta P A^2 \theta}{\alpha W}, \text{ where } \Delta P \text{ is in } \mathrm{lb_f/ft^2}$$

Determine the number of plates needed if each filtering cloth is 12 in. x 12 in. when 60 ft^3 of filtrate is obtained in 15 minutes. Assuming 1 ft^3 of filtrate is obtained for every cubic foot of solid-free liquid entering the unit. The resistance of the press and the cloth may be neglected, and the filtrate may be assumed to completely free of all solid materials. Also assume that each plate has one piece of filtering cloth.
(15 Points Total)

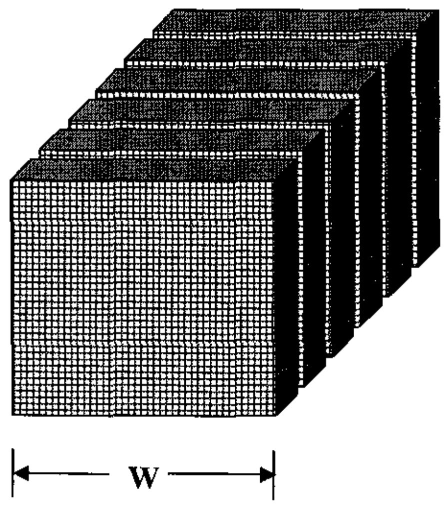

Figure 4: Frame and plate filter press arrangement.

4. If the density of the fluid is 1.2 g/cm^3, the density of particle A is 8.50 g/cm^3 and the density of particle B is 2.40 g/cm^3, answer the following questions: **(20 Points Total)**

   (a) For the particle settling velocity of components A and B shown below, which region will produce a pure fraction of A and which region will produce a pure fraction of B? **(5 points)**
   (b) If the diameter of particle B is 0.75 cm, what is the diameter of particle A that is falling at the same rate? **(5 points)**
   (c) What is the terminal velocity of particle A (given $\mu = 1.20$ cp)? **(10 points)**

Assume that the particle is falling under Newton's Regime and $C_D = 0.44$.

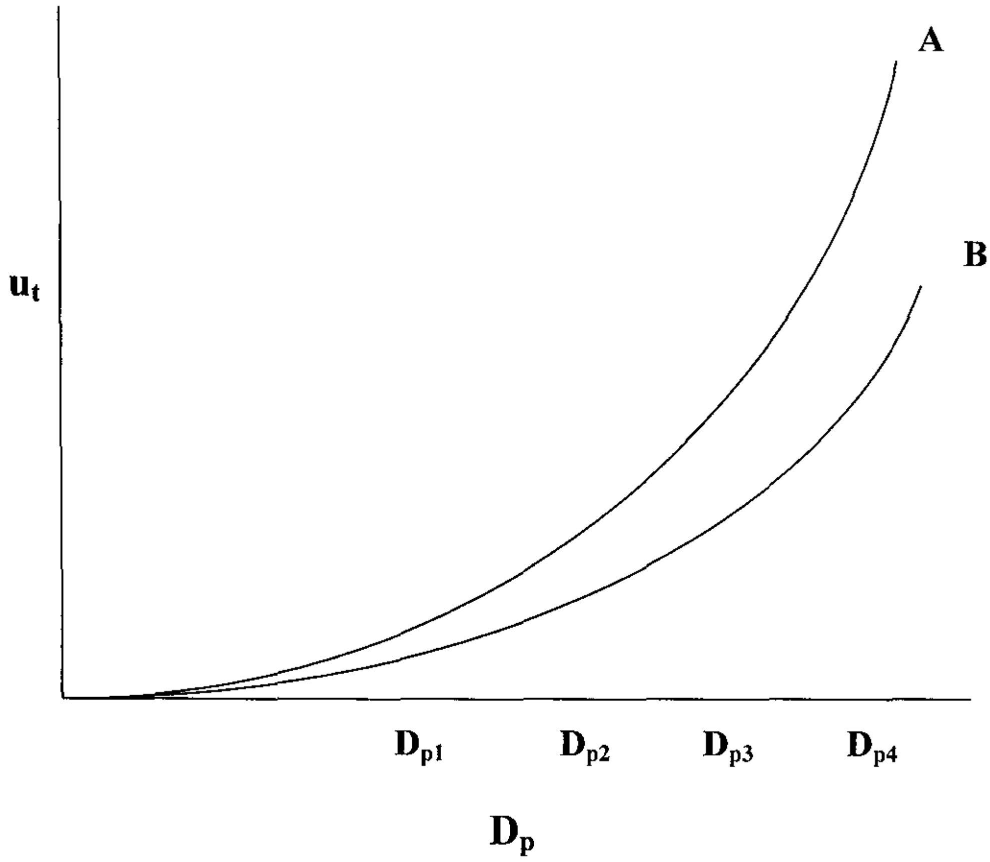

Figure 5: Terminal velocity as a function of particle diameter for components A and B.

5. A lube oil is flowing through a 5-inch Schedule 40 steel pipe. Inserted in this pipe is a 3.5-inch sharp-edged orifice attached to a mercury manometer. If the manometer reading is 4 in., (a) what is the pressure drop and (b) what is the mass flow rate of oil? Use the following data to compute your answer. **(15 Points Total)**

   Specific gravity of oil = 0.87
   Inside diameter of the pipe = 5.057 in.
   Orifice discharge coefficient (C_D) = 0.61
   Specific gravity of mercury = 13.6

   The pressure drop using a manometer can be computer by:

$$P_1 - P_2 = h_m g(\rho_{mercury} - \rho_{oil})$$

   where h_m = manometer reading.

Bonus Question: Which one of the following is my baby's favorite food? **(5 points)**

(a) Swenzen's Chocolate Ice Cream
(b) KFC French Fries
(c) Sizzler's Cream of Mushroom Soup
(d) Fuji's Steamed Egg Custard or "Kai Toohn"
(e) S&P's Shrimp Wonton Soup

END OF EXAM!
CONGRATULATIONS!
HAVE A GOOD SEMESTER BREAK!

Useful Information

Conversions:

$g_c = 32.2$ ft-lb$_m$ /(lb$_f$-s^2)	1 in. = 2.54 cm
$g = 9.81$ m/s^2	1 N = kg-m/s^2
1lb$_m$ = 0.454 kg	1 cp = 1 x 10^{-2} g/cm-s
1 psia = 6.89476 kPa	1 Pa = 1 N/m^2 = 1 kg/m-s^2
1 m^3 = 264.172 gal	1Btu = 1055 J
1 N·m = 0.737562 ft-lb$_f$	1 hp = 550 ft-lb$_f$/s

Bernoulli Equation:

$$\Delta\frac{1}{2}\langle\bar{v}\rangle^2 + g\Delta h + \int_{p_1}^{p_2}\frac{1}{\rho}\,dp + \hat{W} + \sum_i\left(\frac{1}{2}\langle\bar{v}\rangle^2\frac{L}{R_h}f\right)_i + \sum_i\left(\frac{1}{2}\langle\bar{v}\rangle^2 e_v\right)_i = 0$$

$$\sum_i\left(\frac{1}{2}\langle\bar{v}\rangle^2\frac{4L}{D}f\right)_i = \frac{2\langle\bar{v}\rangle^2 f}{D}\sum_i L_i$$

Flow through an Orifice:

$$w = C_D S_o\left(\frac{2\rho(P_1 - P_2)}{1-\left(\frac{S_o}{S}\right)^2}\right)$$

Reynold's Number:

$$N_{\mathrm{Re}} = \frac{\rho V D}{\mu}, \textbf{ where } D = 4R_h$$

Flow in Circular Tube:

$$\tau_{rz} = -\mu\left(\frac{dV_z}{dx}\right) \qquad v_z = \left(\frac{(P_0 - P_L)R^2}{4\mu L}\right)\left[1-\left(\frac{r}{R}\right)^2\right] \qquad Q = \left(\frac{(P_0 - P_L)\pi R^4}{8\mu L}\right)$$

Terminal Falling Velocity for a Sphere:

$$u_t = \sqrt{\frac{4g(\rho_p - \rho)D_p}{3C_D\rho}} \qquad \frac{D_{p,A}}{D_{p,B}} = \sqrt{\frac{\rho_{pB} - \rho}{\rho_{pA} - \rho}} \quad \textbf{Stoke's Regime}$$

$$N_{\mathrm{Re},p} = \frac{\rho u_t D_p}{\mu} \qquad \frac{D_{p,A}}{D_{p,B}} = \frac{\rho_{pB} - \rho}{\rho_{pA} - \rho} \quad \textbf{Newton's Regime}$$

CONVERSION FACTORS
(Read across)

VOLUME EQUIVALENTS

in.^{3}	ft^3	U.S. gal	liters	m^3
1	5.787×10^{-4}	4.329×10^{-3}	1.639×10^{-2}	1.639×10^{-5}
1.728×10^{3}	1	7.481	28.32	2.832×10^{-2}
2.31×10^{2}	0.1337	1	3.785	3.785×10^{-3}
61.03	3.531×10^{-2}	0.2642	1	1.000×10^{-3}
6.102×10^{4}	35.31	264.2	1000	1

MASS EQUIVALENTS

avoir oz	pounds	grains	grams
1	6.25×10^{-2}	4.375×10^{2}	28.35
16	1	7×10^{3}	4.536×10^{2}
2.286×10^{-3}	1.429×10^{-4}	1	6.48×10^{-2}
3.527×10^{-2}	2.20×10^{-3}	15.432	1

LINEAR MEASURE EQUIVALENTS

meter	inch	foot	mile
1	39.37	3.2808	6.214×10^{-4}
2.54×10^{-2}	1	8.333×10^{-2}	1.58×10^{-5}
0.3048	12	1	1.8939×10^{-4}
1.61×10^{3}	6.336×10^{4}	5280	1

POWER EQUIVALENTS

hp	kW	(ft)(lb$_f$)/sec	Btu/sec	J/sec
1	0.7457	550	0.7068	7.457×10^{2}
1.341	1	737.56	0.9478	1.000×10^{3}
1.818×10^{-3}	1.356×10^{-3}	1	1.285×10^{-3}	1.356
1.415	1.055	778.16	1	1.055×10^{3}
1.341×10^{-3}	1.000×10^{-3}	0.7376	9.478×10^{-4}	1

HEAT, ENERGY, OR WORK EQUIVALENTS

(ft)(lb$_f$)	kWh	hp-hr	Btu	calorie*	Joule
0.7376	2.773×10^{-7}	3.725×10^{-7}	9.484×10^{-4}	0.2390	1
7.233	2.724×10^{-6}	3.653×10^{-6}	9.296×10^{-3}	2.3438	9.80665
1	3.766×10^{-7}	5.0505×10^{-7}	1.285×10^{-3}	0.3241	1.356
2.655×10^{6}	1	1.341	3.4128×10^{3}	8.6057×10^{5}	3.6×10^{6}
1.98×10^{6}	0.7455	1	2.545×10^{3}	6.4162×10^{5}	2.6845×10^{6}
74.73	2.815×10^{-5}	3.774×10^{-5}	9.604×10^{-2}	24.218	1.0133×10^{2}
3.086×10^{3}	1.162×10^{-3}	1.558×10^{-3}	3.9657	1×10^{3}	4.184×10^{3}
7.7816×10^{2}	2.930×10^{-4}	3.930×10^{-4}	1	2.52×10^{2}	1.055×10^{3}
3.086	1.162×10^{-6}	1.558×10^{-6}	3.97×10^{-3}	1	4.184

*The thermochemical calorie = 4.184 J.

PRESSURE EQUIVALENTS

mm Hg	in. Hg	bar	atm	kPa	psia
1	3.937×10^{-2}	1.333×10^{-3}	1.316×10^{-3}	0.1333	1.934×10^{-2}
25.40	1	3.386×10^{1}	3.342×10^{-2}	3.386	0.4912
750.06	29.53	1	0.9869	100.0	1.415×10^{-3}
760.0	29.92	1.013	1	101.3	14.696
75.02	0.2954	1.000×10^{-2}	9.872×10^{-3}	1	0.1451
51.71	2.036	6.893×10^{-2}	6.805×10^{-2}	6.893	1

IDEAL GAS CONSTANT R

1.987 cal/(g mol)(K)
1.987 Btu/(lb mol)(°R)
10.73 (psia)(ft^3)/(lb mol)(°R)
8.314 (kPa)(m^3)/(kg mol)(K) = 8.314 J/(g mol)(K)
82.06 (cm^3)(atm)/(g mol)(K)
0.08206 (L)(atm)/(g mol)(K)
21.9 (in Hg)(ft^3)/(lb mol)(°R)
0.7302 (ft^3)(atm)/(lb mol)(°R)

MISCELLANEOUS CONVERSION FACTORS

To convert from	To	Multiply by
angstrom	meter	1.000×10^{-10}
barrel (petroleum)	gal	42
centipoise	(newton)(s)/m^2	1.000×10^{-3}
torr (mm Hg, 0°C)	newton/meter^2	1.333×10^{2}
fluid oz	cm^3	29.57

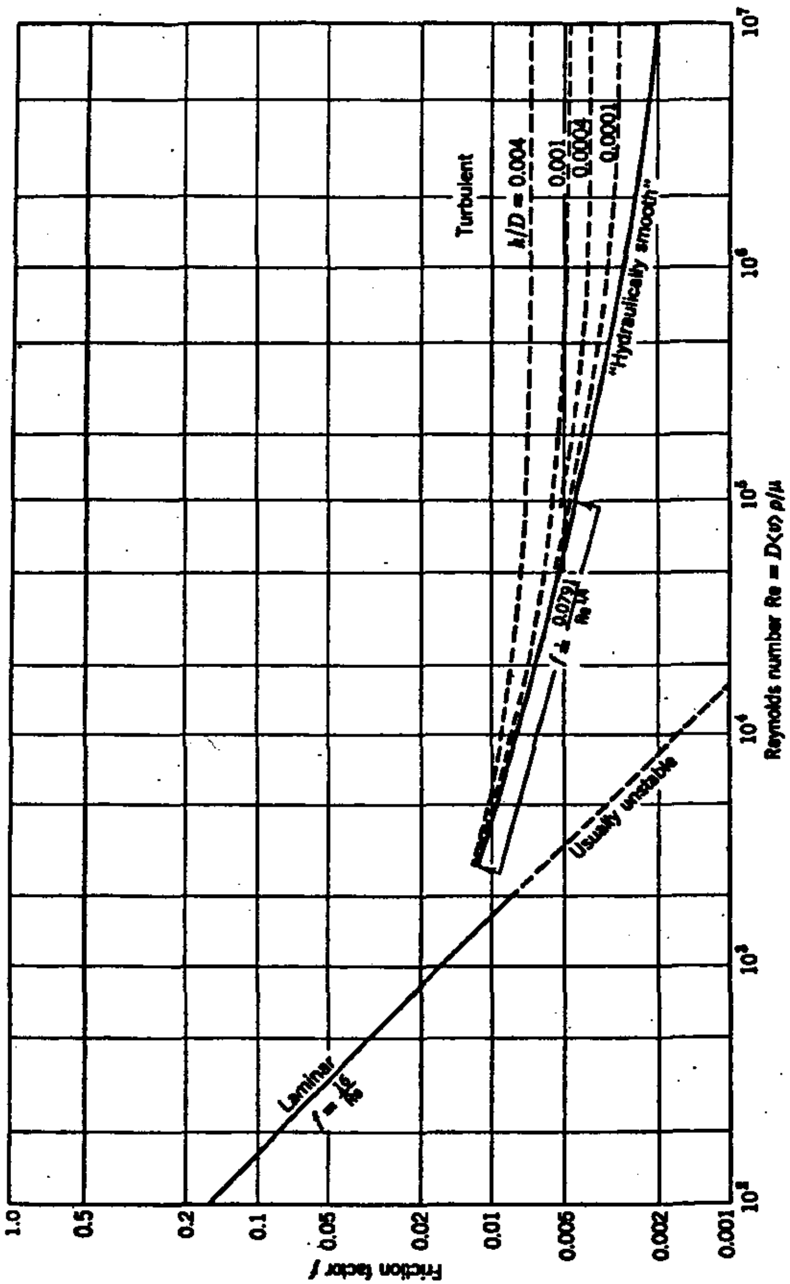

Fig. 6.2-2. Friction factors for tube flow (see definition of f in Eqs. 6.1-2 and 6.1-3. [Curves of L. F. Moody, *Trans. ASME*, **66**, 671 (1944) as presented in W. L. McCabe and J. C. Smith, *Unit Operations of Chemical Engineering*, McGraw-Hill, New York (1954).]

Here R_h is the mean hydraulic radius defined in Eq. 6.2-16, f is the friction factor defined in Eq. 6.1-4, and e_v is the friction loss factor given in Table 7.4-1. Note that the $\langle \bar{v} \rangle$'s in the first terms refer to the average velocities at the planes "1" and "2"; the $\langle \bar{v} \rangle$ in the first sum indicates the average velocity in the ith pipe segment; and the $\langle \bar{v} \rangle$ in the second sum is the average flow velocity *downstream* from the ith fitting, valve, or other obstacle.

TABLE 7.4-1

BRIEF SUMMARY OF FRICTION LOSS FACTORS FOR USE WITH EQ. 7.4-10.

(Approximate Values for Turbulent Flow)[a]

Obstacles	e_v
Sudden Changes in Cross-Sectional Area[b]	
Rounded entrance to pipe	0.05
Sudden contraction	$0.45(1 - \beta)$
Sudden expansion[c]	$\left(\frac{1}{\beta} - 1\right)^2$
Orifice (sharp-edged)	$2.7(1 - \beta)(1 - \beta^2)\frac{1}{\beta^2}$
Fittings and Valves	
90° elbows (rounded)	0.4–0.9
90° elbows (square)	1.3–1.9
45° elbows	0.3–0.4
Globe valve (open)	6–10
Gate valve (open)	0.2

[a] Taken from H. Kramers, *Physische Transportverschijnselen*, Technische Hogeschool, Delft, Holland (1958), pp. 53–54.

[b] β = (smaller cross sectional area)/(larger cross sectional area)

[c] See derivation from the macroscopic balances in Example 7.5-1. When $\beta = 0$, $\hat{E}_v = \frac{1}{2}\langle \bar{v} \rangle^2$ where $\langle \bar{v} \rangle$ is the velocity *upstream* from the enlargement.

Example 7.4-1. Power Requirements for Pipe-Line Flow

What is the horsepower needed to pump the water in the system shown in Fig. 7.4-1? Water ($\rho = 62.4\ \text{lb}_m\ \text{ft}^{-3}$; $\mu = 1.0$ cp) is to be delivered to the upper tank at a rate of 12 ft^3 min^{-1}. All of the piping is 4-in. internal diameter smooth circular pipe. Assume that the pipes run full of liquid.

Solution. The average velocity in the pipe is

$$\langle v \rangle = \frac{Q}{\pi R^2} = \frac{(12/60)}{\pi(1/6)^2} = 2.30\ \text{ft sec}^{-1}$$