Name: ______________________________ Student ID ______________

Prince of Songkla University
Faculty of Engineering

Exam: Final Exam, Semester I **Academic Year: 2004 – 05**
Date: October 9, 2004 **Time: 13:30 – 16:30**
Subject: 230-391 – Basic Chemical Engineering I **Room: A401**

ทุจริตในการสอบโทษขั้นต่ำคือ ปรับตกในรายวิชาที่ทุจริต และพักการเรียน 1 ภาคการศึกษา

Instructions: There are a total of 4 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 no pages of notes 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	15	
2	35	
3	25	
4	25	
Total	100	

Exam prepared by
Ram Yamsaengsung
October 4, 2004

PLEASE CHECK TO MAKE SURE THAT
YOU HAVE ALL 5 PAGES OF THE EXAM BEFORE BEGINNING
(not including the cover sheet).
GOOD LUCK!

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1. A rotary drum filter is used to filter calcium carbonate from a slurry containing 5.5 lb of dry solid per cubic foot of solid free liquid at a constant pressure difference of 4.5 psi. The specific cake resistance for the slurry and the volume of the filtrate obtained are given by the equations below:

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

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

Determine the diameter of the filtering drum (in inches) if the width of the drum is 2 feet and 40 ft^3 of filtrate is obtained in 5 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 as completely free of all solid materials. **(15 Points Total)**

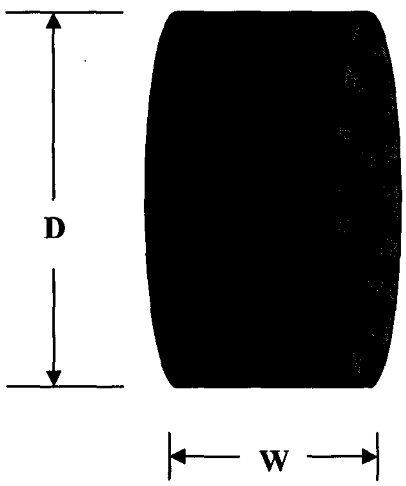

Figure 1: Rotary drum filter.

2. Six hundred gal/hr of water is being pumped from a reservoir to a storage tank located 20 meters away. The pipe has an internal diameter of 5 cm. Assuming the inside of the pipe is smooth, determine the following information. **(35 Points Total)**

   (a) Determine the average velocity inside the pipe (in **m/s**). **(5 points)**
   (b) Is the flow laminar or turbulent? **(5 points)**
   (c) Determine the pressure drop from the reservoir to the water tank (in **Pa**). **(10 points)**
   (d) 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. **Begin with the Bernoulli Equation and state all assumptions. (15 points)**
   (e) **For Graduate Students ONLY or BONUS for Bio-Tech Students**: Derive the equation for the Shear Stress at the wall of the pipe (at r = R). Begin with the velocity profile and show that force at the wall $F = \Delta P \pi R^2$. **(10 points)**

Work of Pump is given by:

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

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

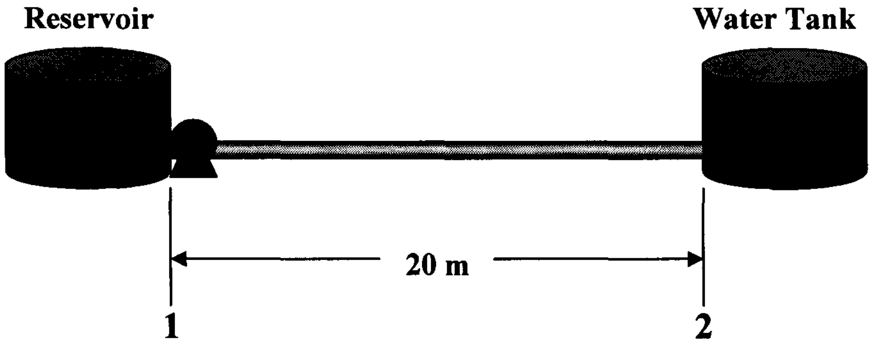

Figure 2: Flow of water through a circular pipe.

3. A viscous incompressible fluid is flowing in a slit formed by two parallel walls a distance 2B apart. **(25 Points Total)**

(a) What is the Reynolds number of the falling film if the velocity is 3 cm/s, the viscosity is 10 cp, the density is 1.5 g/cm^3, W = 6 cm, B = 0.5 cm, and L = 20 cm. **(10 points)**

(b) Make a differential momentum balance and obtain the expressions for the distributions of momentum flux given below: **(15 points)**

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

where $P = p + \rho g h = p - \rho g z$

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 $\Delta x \rightarrow 0$.

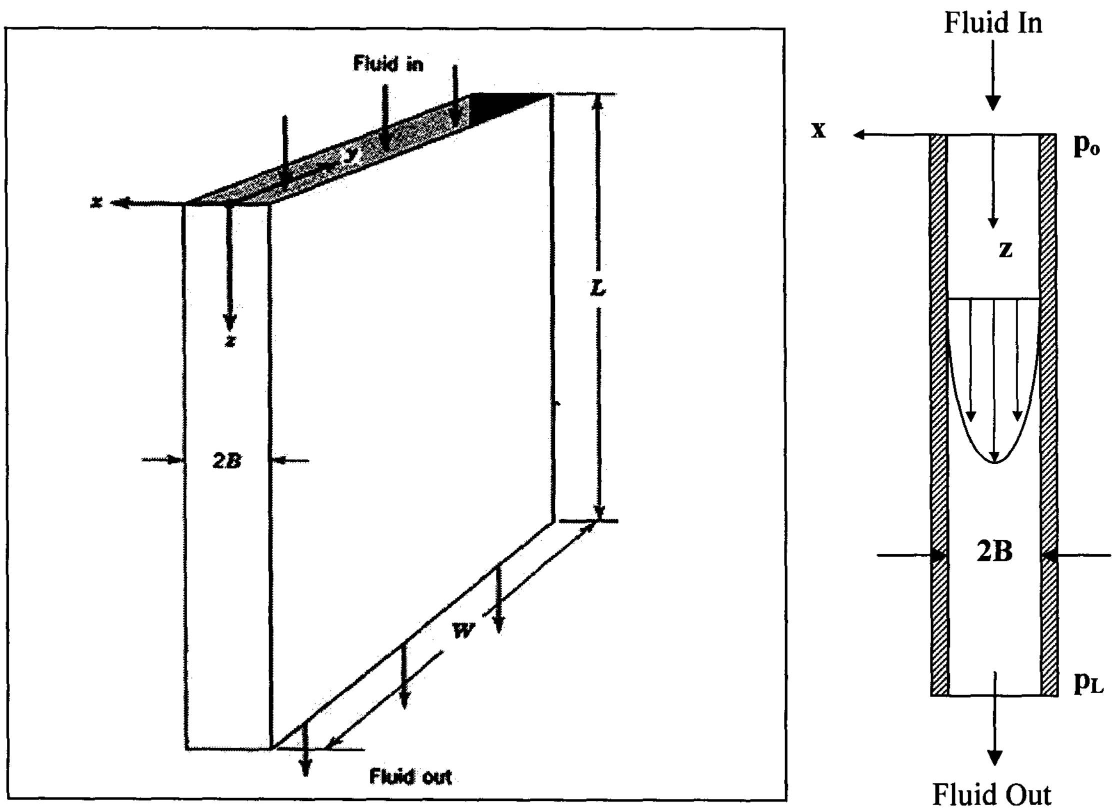

Figure 3: Falling film through a slit.

4. If the density of the fluid is 1.2 g/cm^3, the density of particle A is 5.50 g/cm^3 and the density of particle B is 1.85 g/cm^3, answer the following questions: **(25 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? **(10 points)**
(b) If the diameter of particle B is 0.25 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? **(10 points)**

Assume that the particle is falling under Stoke's Regime and $C_D = \frac{24}{N_{\mathrm{Re},p}}$.

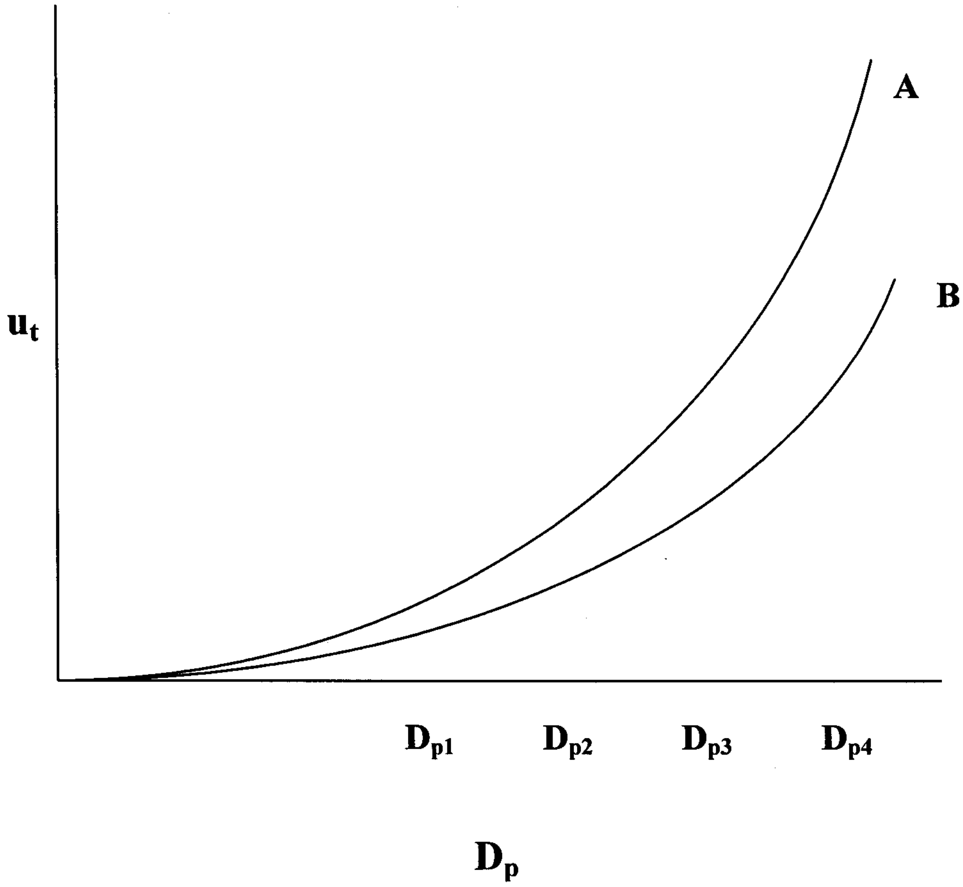

Figure 4: Terminal velocity as a function of particle diameter for components A and B.

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

Useful Information

Conversions:

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

Bernoulli Equation:

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

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

Pressure Drop versus friction factor:

$$\left(\frac{P_0 - P_L}{\frac{1}{2}\rho\langle v\rangle^2}\right) = \left(\frac{L}{R_h}\right)f$$

Reynold's Number:

$$N_{Re} = \frac{\rho VD}{\mu}, \text{ where } D = 4R_h$$

Flow in Circular Tube:

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

Terminal Falling Velocity for a Sphere:

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

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

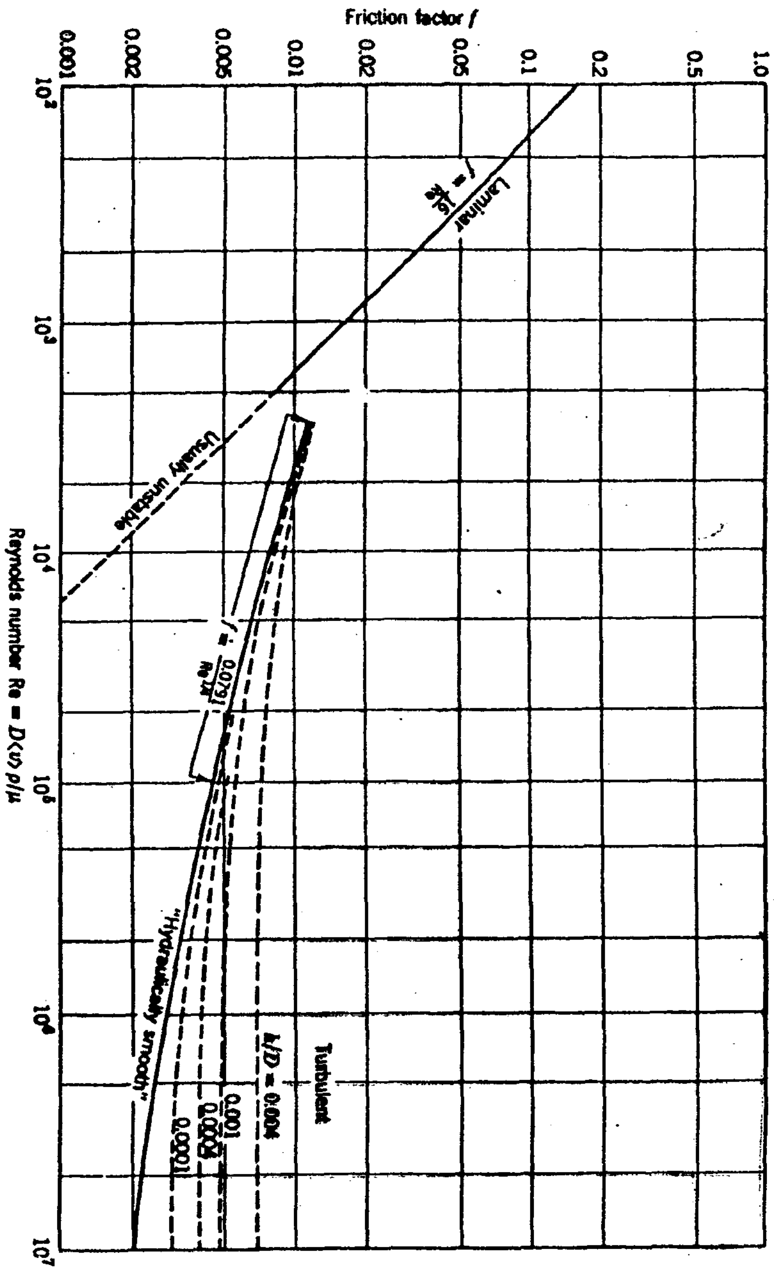

Fig. 6.2-2. Friction factors for tube flow (see definition of f in Eqs. 6.1-2 and 6.1-3. [Curves of L. F. Moody, *Trans. ASME*, **66**, 671 (1944) as presented in W. L. McCabe and J. C. Smith, *Unit Operations of Chemical Engineering*, McGraw-Hill, New York (1954).]

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

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

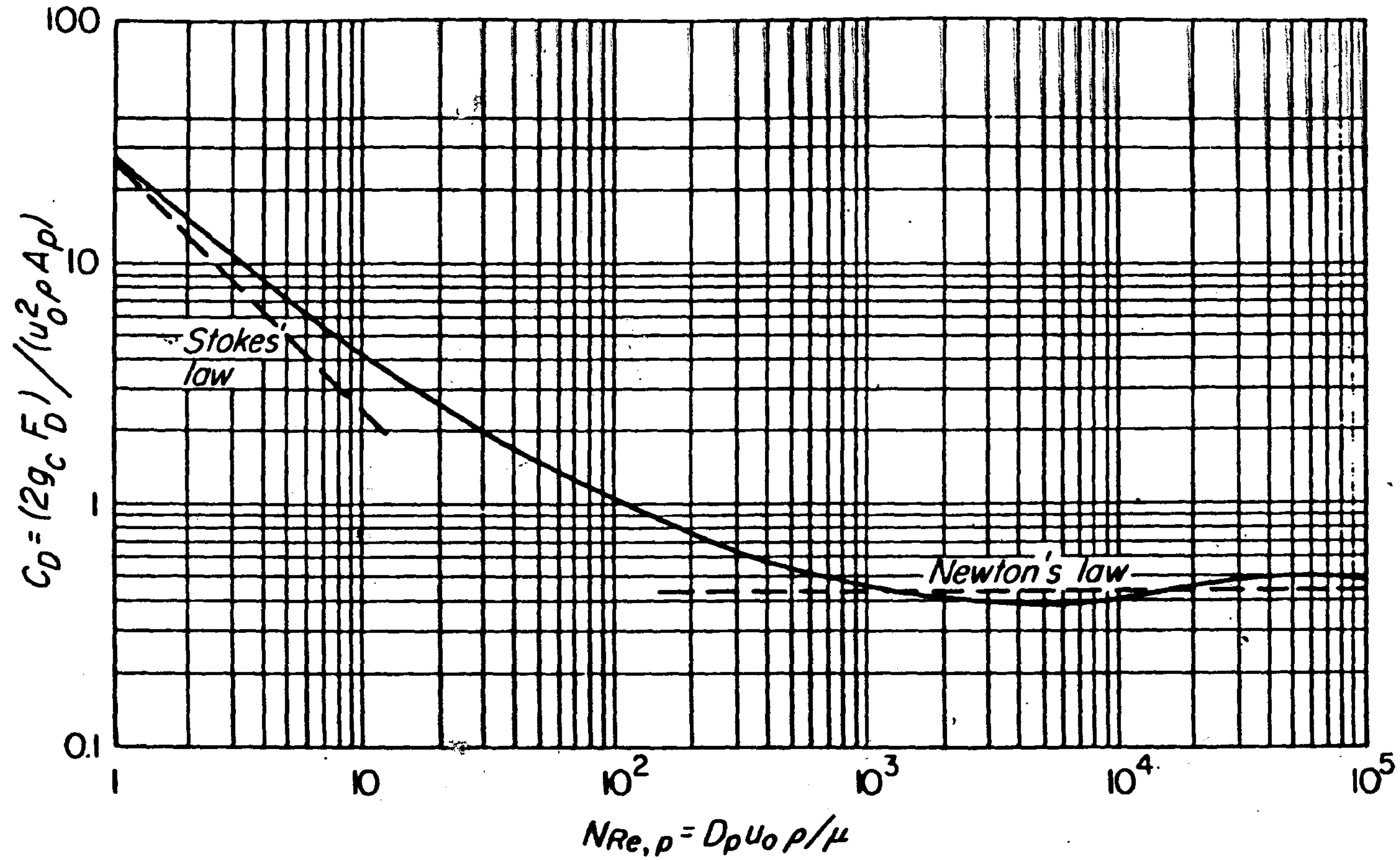

FIGURE 7.6
Drag coefficients for spheres.