Problem 1 (20%)

Ammonia in a gas stream is treated by ammonia-free water in a counter-current absorption process to reduce its concentration. Gas stream containing 2 mol% NH_3 enters the absorber at a molar flow rate of 1000 mol/s. The equilibrium relationship of NH_3 in the gas/liquid phases at the operating condition is represented by $y=0.8x$, where x and y are the molar fractions of ammonia in liquid and gas phases, respectively.

a) If he exit gas is to contain 0.2 mol% NH_3, what will be the minimum liquid flow rate?
5%

b) If the entering water flow rate is 2000 mol/s, and the exit gas contains 0.2 mol% NH_3,
5% calculate the number of transfer unit, N_{oy}.

c) The liquid side and gas side heights of transfer unit (Hy and Hx) are estimated to be 0.32 m
5% and 1.1 m, respectively, for the column. What is the height of packing needed for the task in (b)?

d) If the entering water flow rate is 2000 mol/s, and the column is equivalent to 2 theoretical
5% plates, calculate the mole fraction of NH_3 in the exit gas.

Problem 2 (20%)

A tomato plant needs two liters of water each day of the growing season to produce good crop. In order to water the plant automatically, I would connect a long plastic tube 0.4 mm I.D. to the faucet (自來水管水龍頭) at my home where the water pressure is 100 k Pa above atmospheric pressure and lead it to the plant. Assuming the plant root and the faucet are on the same level, determine how long the tube would have to be to deliver 2 liters/day of water?

a) Give the mechanical energy balance between points 1 and 2 (see Figure).
10%

b) Calculate for the length of tube giving friction factor equations as follows,
10%

$f_F=16/Re$, $Re<2100$

$f_F=0.079\ Re^{-1/4}$ $2100<Re<100,000$

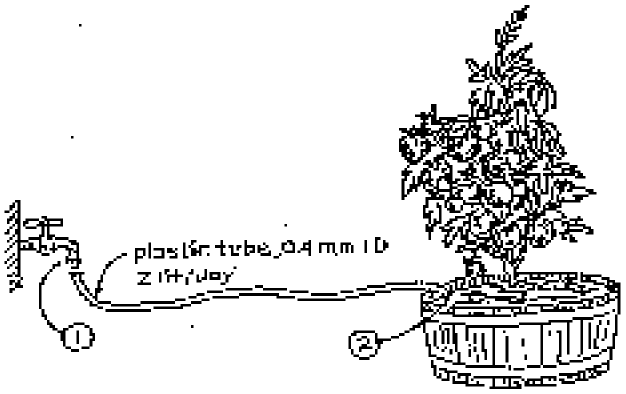
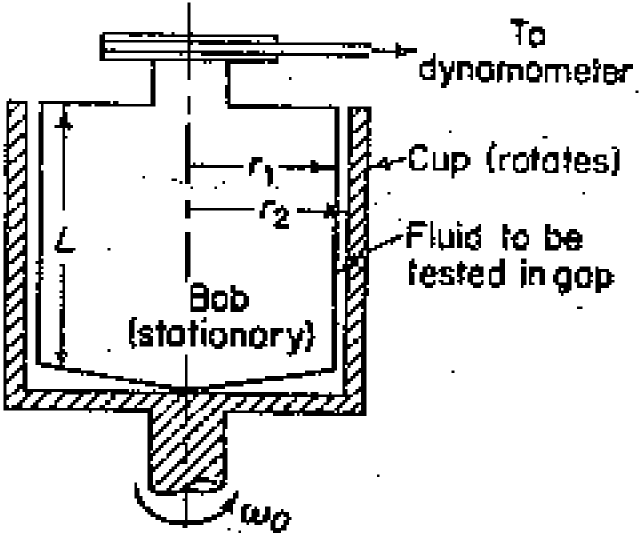


Fig. Watering Tomato Plant

Problem 3 (20%)

a) 15% In this problem, we wish to determine the velocity distribution of a Newtonian incompressible-flowing fluid in the annular region and the torque acting on the inner cylinder for the system shown in the following figure. Start with the Navier-Stokes equations in cylindrical coordinates. The flow is steady, and the annular region is considered to be infinite in the z-direction.

b) 5% Using the shell momentum balance rather than starting with the Navier-Stokes equation, formulate the momentum balance equation of the problem indicated in (a).



Couette viscometer.

八十四學年度 化學工程研究 所 甲 組碩士班研究生入學考試

科目 輸送現象及單元操作 科號 1601 共 4 頁第 3 頁 *請在試卷【答案卷】內作答

THE EQUATIONS OF MOTION FOR CONSTANT μ AND ρ IN CYLINDRICAL COORDINATES (r, θ, z)

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r-Direction

$$\rho\left(\frac{\partial v_r}{\partial t} + v_r\frac{\partial v_r}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta} - \frac{v_\theta^2}{r} + v_z\frac{\partial v_r}{\partial z}\right)$$

$$= -\frac{\partial p}{\partial r} + \rho g_r + \mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_r)\right) + \frac{1}{r^2}\frac{\partial^2 v_r}{\partial \theta^2} - \frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta} + \frac{\partial^2 v_r}{\partial z^2}\right] \quad \text{(a)}$$

θ-Direction

$$\rho\left(\frac{\partial v_\theta}{\partial t} + v_r\frac{\partial v_\theta}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r v_\theta}{r} + v_z\frac{\partial v_\theta}{\partial z}\right)$$

$$= -\frac{1}{r}\frac{\partial p}{\partial \theta} + \rho g_\theta + \mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_\theta)\right) + \frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial \theta^2} + \frac{2}{r^2}\frac{\partial v_r}{\partial \theta} + \frac{\partial^2 v_\theta}{\partial z^2}\right] \quad \text{(b)}$$

z-Direction

$$\rho\left(\frac{\partial v_z}{\partial t} + v_r\frac{\partial v_z}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta} + v_z\frac{\partial v_z}{\partial z}\right)$$

$$= -\frac{\partial p}{\partial z} + \rho g_z + \mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 v_z}{\partial \theta^2} + \frac{\partial^2 v_z}{\partial z^2}\right] \quad \text{(c)}$$

SCALAR COMPONENTS OF THE VISCOUS STRESS TENSOR FOR NEWTONIAN FLUIDS

Cylindrical Coordinates[a] (r, θ, z)

$$\tau_{rr} = 2\mu\left(\frac{\partial v_r}{\partial r}\right) + [(\kappa - \tfrac{2}{3}\mu)\nabla\cdot\mathbf{v}] \quad \text{(a)}$$

$$\tau_{\theta\theta} = 2\mu\left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r}{r}\right) + [(\kappa - \tfrac{2}{3}\mu)\nabla\cdot\mathbf{v}] \quad \text{(b)}$$

$$\tau_{zz} = 2\mu\left(\frac{\partial v_z}{\partial z}\right) + [(\kappa - \tfrac{2}{3}\mu)\nabla\cdot\mathbf{v}] \quad \text{(c)}$$

$$\tau_{r\theta} = \tau_{\theta r} = \mu\left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right) + \frac{1}{r}\frac{\partial v_r}{\partial \theta}\right] \quad \text{(d)}$$

$$\tau_{\theta z} = \tau_{z\theta} = \mu\left(\frac{\partial v_\theta}{\partial z} + \frac{1}{r}\frac{\partial v_z}{\partial \theta}\right) \quad \text{(e)}$$

$$\tau_{zr} = \tau_{rz} = \mu\left(\frac{\partial v_z}{\partial r} + \frac{\partial v_r}{\partial z}\right) \quad \text{(f)}$$

[a] In these equations, $\nabla\cdot\mathbf{v} = \frac{1}{r}\frac{\partial}{\partial r}(r v_r) + \frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{\partial v_z}{\partial z}$

Problem 4 (20%)

A heated sphere of radius R is suspended in a large motionless body of fluid of temperature 300 K. The radius of the sphere is 5 cm and the temperature of the sphere is 500 K. It is assumed that the temperature of the sphere can be kept constant and the free convection can be neglected. You are asked to calculate the temperature at the position five times of radius far from the sphere surface (i.e. at 5R) when

a). the thermal conductivity of the fluid is 0.01 cal/s.cm.K,

b). the thermal conductivity of the fluid is 0.05 cal/s.cm.K,

and to compare these two results.

Problem 5 (20%)

The diaphragm cell is one of the best ways to measure diffusion coefficients (shown in attached figure). The cell consists of two well-stirred volumes separated by a thin porous diaphragm (i.e. membrane). To measure a diffusion coefficient with this cell, we fill the lower compartment with a solution of known concentration (single solute) and the upper compartment with pure solvent. After a known time, we sample both compartments and measure their solute concentrations.

(a) 6% Derive the steady state flux equation in terms of solute concentrations in both compartments. Assume Henry's law type of equilibrium between solution and membrane surface, i.e. c=HC (where c is concentration at membrane surface and C is the concentration in solution);

(b) 14% Derive and explain the equation that can help to calculate the diffusion coefficient. Assume that the steady state flux can be reached quickly.

Define every symbol you used.