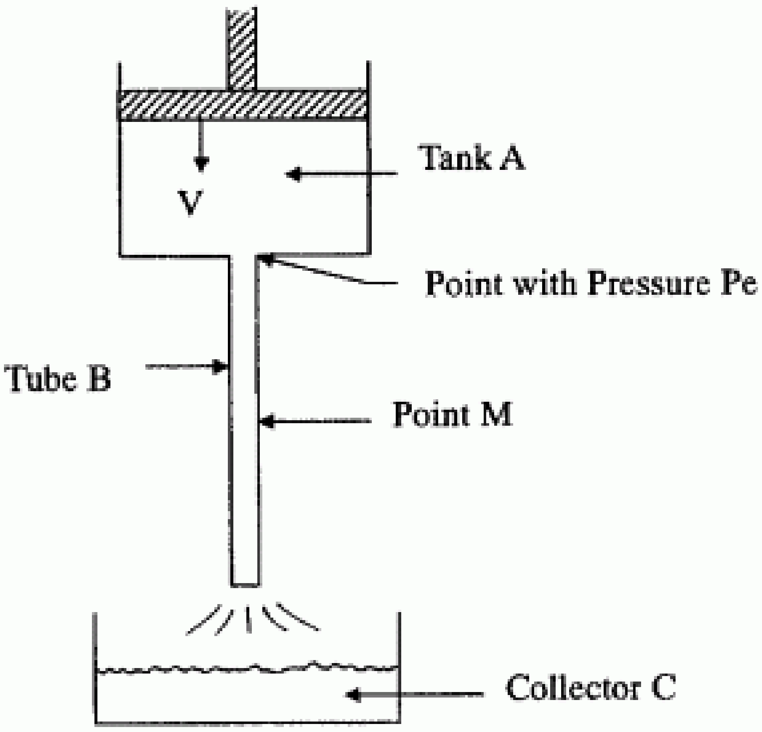
Problem 1 (20%)

A viscous Newtonian liquid with viscosity μ and density φ is pushed by a piston to flow from tank A into a narrow tube B then falls onto an open collector C as shown in the Figure. The piston is moving at a slow but constant speed V. The diameter of Tank A is D and the height of Tank A is 1.5D. The diameter and the length of the narrow tube B are 0.05D and 3D, respectively.

(1) Is the flow in Tank A one-dimensional (1D), 2D or 3D? Please explain. (5%)

(2) Can you estimate the pressure Pm at Point M? Which is just the middle point of the tube. (10%)

(3) The pressure at the entrance of the narrow tube is Pe. There are three possibilities, i.e., (a)Pe=2Pm. (b)Pe<2Pm. (c)Pe>2Pm. Which is correct? Please explain. (5%)



九十三學年度 化學工程學 系（所） 組碩士班入學考試

科目 輸送現象及單元操作 科號 1401 共 4 頁第 2 頁 *請在試卷【答案卷】內作答

Problem 2 (20%)

We wish to investigate the effect of viscous dissipation for temperature distribution in laminar flows. In the flowing fluid, the rate of irreversible conversion to internal energy per unit volume can be expressed as $(-\underline{\underline{\tau}}:\underline{\nabla}\underline{v})$. The constitutive equation for Newtonian fluids is as follows,

$$\underline{\underline{\tau}} = -\mu\left(\underline{\nabla}\underline{v} + (\underline{\nabla}\underline{v})^T\right) + \underline{\underline{\delta}}\left(\frac{2}{3}\mu - \kappa\right)(\underline{\nabla}\cdot\underline{v}),$$

where $\underline{\underline{\tau}}$ is the stress tensor, $\underline{\underline{\delta}}$ the unit tensor, μ the shear viscosity, and κ the bulk viscosity. Now, consider an incompressible Newtonian fluid flowing in laminar condition in a horizontal cylindrical pipe. Take r, θ, and z as the radial, angular, and axial axes, respectively of the cylindrical coordinates. Assume that the flow is fully developed such that $v_z = v_z(r)$, $v_r = v_\theta = 0$, and

$$v_z(r) = 2 < v_z > \left(1 - \frac{r^2}{R^2}\right) \quad .$$

Here, $< v_z >$ is the cross section average velocity and R is the radius of the pipe. Also assume constant shear viscosity and thermal conductivity, k.

(a) Give the SI unit of the term $-\underline{\underline{\tau}}:\underline{\nabla}\underline{v}$. (2%)

(b) Give an expression for $-\underline{\underline{\tau}}:\underline{\nabla}\underline{v}$ for the present problem and explain physically why the expression always gives positive values. (3+2%)

(c) The pipe is maintained at a constant wall temperature, T_w . Set up a governing equation, with the shell energy balance procedure, for $T(r)$ taking into account heat conduction in the radial direction and the viscous dissipation contribution. Give also appropriate boundary conditions. The resulting governing equation takes the form of $\frac{d^2T}{dr^2} + Ar^2 = 0$ with A a function of μ, k, $<v_z>$, and R. (8%)

(d) Solve the boundary value problem obtained in part (c) and derive an expression for the temperature rise $T(r) - T_w$. Explain physically why the temperature rise is non-negative within the fluid domain. (3+2%)

Given in cylindrical coordinates:

$$\begin{pmatrix} \tau_{rr} & \tau_{r\theta} & \tau_{rz} \\ \tau_{\theta r} & \tau_{\theta\theta} & \tau_{\theta z} \\ \tau_{zr} & \tau_{z\theta} & \tau_{zz} \end{pmatrix} = -\mu \begin{pmatrix} 2\frac{\partial v_r}{\partial r} & \frac{\partial v_\theta}{\partial r} + \frac{\partial v_r}{\partial \theta} & \frac{\partial v_z}{\partial r} + \frac{\partial v_r}{\partial z} \\ \frac{\partial v_\theta}{\partial r} + \frac{\partial v_r}{\partial \theta} & 2\frac{\partial v_\theta}{\partial \theta} & \frac{\partial v_z}{\partial \theta} + \frac{\partial v_\theta}{\partial z} \\ \frac{\partial v_z}{\partial r} + \frac{\partial v_r}{\partial z} & \frac{\partial v_z}{\partial \theta} + \frac{\partial v_\theta}{\partial z} & 2\frac{\partial v_z}{\partial z} \end{pmatrix}$$

$$\underline{\underline{\tau}}:\underline{\nabla}\underline{v} = \tau_{rr}\left(\frac{\partial v_r}{\partial r}\right) + \tau_{\theta\theta}\left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r}{r}\right) + \tau_{zz}\left(\frac{\partial v_z}{\partial z}\right) + \tau_{r\theta}\left[r\frac{\partial}{\partial r}\left(\frac{v_\theta}{r}\right) + \frac{1}{r}\frac{\partial v_r}{\partial \theta}\right] + \tau_{\theta z}\left(\frac{1}{r}\frac{\partial v_z}{\partial \theta} + \frac{\partial v_\theta}{\partial z}\right) + \tau_{rz}\left(\frac{\partial v_z}{\partial r} + \frac{\partial v_r}{\partial z}\right)$$

Problem 3 (20%)

(a) Fick's first law for a binary mixture (A+B) can be expressed as:

$$\underline{N}_A = x_A(\underline{N}_A + \underline{N}_B) - cD_{AB}\underline{\nabla}x_A \ ,$$

Where $\underline{N}_i$ is the molar flux of specie i relative to stationary coordinates, x_i the mole fraction of species i, c molar concentration of the mixture, and D_{AB} the binary diffusion coefficient. Apparently, there are two contributions for $\underline{N}_A$. Explain the physical meaning of the two terms on the right hand side. (6%)

(b) Component A diffuses through a stagnant film to the catalytic surface where it is instantaneously converted to A_n by the reaction $nA \rightarrow A_n$. The product A_n diffuses back out through the stagnant film. The catalytic surface is considered a flat surface. The thickness of the stagnant film is δ and the mole fraction of A outside the stagnant film is x_{A0}. Determine the rate at which A enters the stagnant film if this is a steady-state process and evaluate the concentration profile of A in the stagnant film. (14%)

Problem 4 (20%)

A double-pipe heat exchanger is to cool 0.03 kg/s of benzene from 372K to 310K with a counterflow of 0.02 kg/s of water at 290K.

(1) If the inner tube outside diameter is 2 cm and the overall heat transfer coefficient based on the outside area is 650 W/m^2K, determine the heat transfer rate (W), water exit temperature and the required length of the exchanger. Take the specific heat of benzene and water as 1880 and 4175 J/kg K, respectively. (10%)

(2) Is it possible to use a co-current flow arrangement for this job? Explain. (ln 2=0.693, ln 3=1.099, ln 5=1.61, ln 7=1.95) (10%)

Problem 5 (20%)

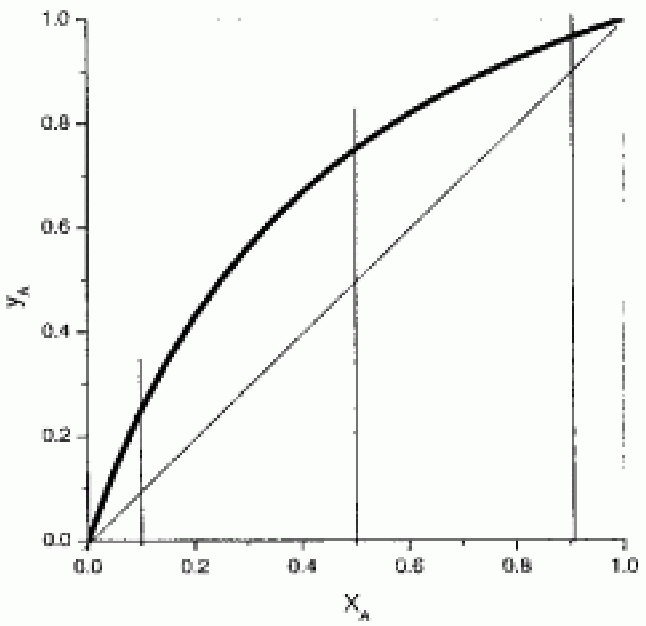
(a) A ttached is a y-x diagram of a binary liquid mixture containing A. Assume that a total condenser is used.

(1) What is the *minimum number of stage* when a mixture of 50 mol% A is separated into a stream containing 90 mol% A, and another stream containing 10 mol% A?

(2) What is the *minimum reflux ratio* when a saturated liquid mixture of 50 mol% A is separated into a stream containing 90 mol% A, and another stream containing 10 mol% A?

(3) What is the *minimum reflux ratio* when a saturated vapor mixture of 50 mol% A is separated into a stream containing 90 mol% A, and another stream containing 10 mol% A?

Provide graphical sketch of how you obtain the answers



(b) A packed column is used to remove a solute A from a gas stream by absorption by a solvent B. The gas feed (total 100 mol/s P=1atm) contain 1 mol% of A. The Henry's Law Coefficient is given $H_A=y_AP/x_A=0.1$ atm. Calculate the minimum clean solvent rate required to reduce the concentration of A the exit gas to 0.001 mol percent.