國立成功大學
110學年度碩士班招生考試試題

編　號：74

系　所：化學工程學系

科　目：單元操作與輸送現象

日　期：0203

節　次：第 1 節

備　註：可使用計算機

※ 考生請注意：本試題可使用計算機。 請於答案卷(卡)作答，於本試題紙上作答者，不予計分。

Equations

Navier-Stokes equation and Vorticity in cylindrical coordinates

r direction

$$\rho\left(\frac{\partial v_r}{\partial t} + v_r\frac{\partial v_r}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta} - \frac{v_\theta^2}{r} + v_z\frac{\partial v_r}{\partial z}\right)$$
$$= -\frac{\partial P}{\partial r} + \rho g_r + \mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_r)\right) + \frac{1}{r^2}\frac{\partial^2 v_r}{\partial \theta^2} - \frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta} + \frac{\partial^2 v_r}{\partial z^2}\right]$$

θ direction

$$\rho\left(\frac{\partial v_\theta}{\partial t} + v_r\frac{\partial v_\theta}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r v_\theta}{r} + v_z\frac{\partial v_\theta}{\partial z}\right) = -\frac{1}{r}\frac{\partial P}{\partial \theta} + \rho g_\theta$$
$$+ \mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_\theta)\right) + \frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial \theta^2} + \frac{2}{r^2}\frac{\partial v_r}{\partial \theta} + \frac{\partial^2 v_\theta}{\partial z^2}\right]$$

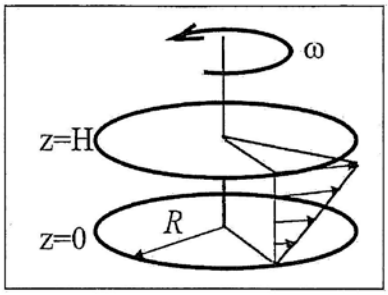
z direction

$$\rho\left(\frac{\partial v_z}{\partial t} + v_r\frac{\partial v_z}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta} + v_z\frac{\partial v_z}{\partial z}\right)$$
$$= -\frac{\partial P}{\partial z} + \rho g_z + \mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 v_z}{\partial \theta^2} + \frac{\partial^2 v_z}{\partial z^2}\right]$$

$$\nabla \times \vec{v} = \left(\left(\frac{1}{r}\frac{\partial v_z}{\partial \theta} - \frac{\partial v_\theta}{\partial z}\right)\vec{e}_r + \left(\frac{\partial v_r}{\partial z} - \frac{\partial v_z}{\partial r}\right)\vec{e}_\theta + \left(\frac{1}{r}\frac{\partial}{\partial r}(r v_\theta) - \frac{1}{r}\frac{\partial v_r}{\partial \theta}\right)\vec{e}_z\right),$$

Questions

1. A rotational or torsional fluid flow between two disks is shown below. The Newtonian fluid fills the space between the two disks. The upper disk is rotating about the z axis at a constant rotational speed ω. Consequently, the fluid between the two disks is in a rotational or torsional flow. The fluid flow is steady and laminar, with constant density ρ and viscosity μ. No-slip condition is applied on the surface of the disks and the radial flow is neglected.



(a) By eliminating the components of fluid velocity that are zero, only the θ component $\upsilon_\theta(r,z)$ exists and is a function of r and z. Please explain the reason. (6%)

(b) Write down the simplified Navier-Stokes equation and boundary conditions. (7%)

(c) The trial solution for the Navier-Stokes equation is

$\upsilon_\theta(r,z) = Cr^n g(z)$ by using separation of variable method. It was found that $d^2g(z)/dz^2 = 0$. Please determine the exponent n and the velocity profile of the fluid between the disks. (8%)

(d) Derive the torque required to maintain the rotation speed. (4%)

(e) Please check if the fluid flow is irrotational. (5%)

2. The extended surface, or fin, is used to increase the energy transfer between the surface and adjacent fluid. What factors will affect the fin efficiency? (5%)

3. What is the lumped parameter analysis? (5%)

4. (a) Water at temperature T_0 flows through a circular tube with diameter and length D and L, respectively. The flow rate is v and the wall temperature is kept constant at T_s. Derive the formula for the exit temperature, T. h is the heat transfer coefficient, C_p is the specific heat of water. (12%)

   (b) If the friction factor is 0.006, find the exit temperature, T, using the Reynolds analogy. (T_0: 20 °C, T_s: 100 °C, L: 250 cm, D: 2 cm) (3%)

5. It is desired to remove water vapor from an air–water vapor mixture that contains 20 percent water vapor by mole. The mixture diffuses into a section of still air with 1.2 m in length, after which water vapor is completely removed from the mixture by absorption. At the absorption plane, the water vapor concentration is small enough to be neglected. The system operates at 1.5 atm and 50 °C.

   (a) State reasonable assumptions for the mass-transfer processes associated with water vapor that allow for appropriate simplification of the general differential equation for mass transfer, and Fick's flux equation. (4%)

   (b) Develop the differential forms of the general differential equation for mass transfer and Fick's flux equation for water vapor within the process. Combine the general differential equation for mass transfer and Fick's flux equation to obtain a second-order differential equation in terms of the mole fraction of water vapor. (6%)

   (c) Obtain the general expression for the flux of water vapor in terms of log-mean average concentration of air. (4%)

   (d) Obtain the general expression for the flux of water vapor in terms of pressures. (2%)

   (e) Assume that the diffusivity of water vapor in air is 3×10^{-5} m^2/s, determine the rate of water vapor diffusing through the air layer. (4%)

6. A continuous fractionation column is designed to separate a binary mixture containing a component of X_F in concentration. The concentrations of the overhead and bottom products are X_D and X_B, respectively, and the feed rate (F) and producing rates (D, B) are fixed.

   (a) If the feed stream has a constant thermal condition, a design indicates that the operation cost is too high.

How to decrease it? (7%)

(*Please describe the detail reasons with the help of a figure if necessary*).

(b) For a constant reflux ratio, If the feed stream is pre-heated from sub-cooled liquid to saturated liquid, how about this change on the number of ideal plate and the total energy cost? (6%)

7. A continuous countercurrent solid-leaching process (shown below) was used to extract oil from a solid meal. Pure benzene was used as the solvent. The unit is to treat 1000 kg dry solid per hour. The untreated meal contains 500 kg of oil and was contaminated with 100 kg of benzene. After the extraction, the oil concentration of the solution adhering to the solid is 0.1. The solution retained by the solid is 0.3 (kg liq. retained/kg solid) and is independent of the weight concentration (x) of the solution. Please answer the following questions:

(a) The mass of oil removed from the solid input by the leaching process. (4%)

(b) What is the minimum solvent required to achieve this result? and what is the number of ideal stage required? (8 %)