Problem 1 (25 points)

(a) Please give the SI units of the following physical quantities (2 points each):

(1) kinematic viscosity

(2) Sherwood number

(3) pipe roughness

(4) diffusivity

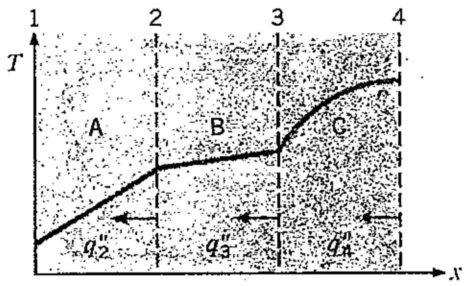
(5) momentum flux

(b) Does the viscosity of liquid usually increase or decrease with increasing temperature? Why? (5 points)

(c) Please give the physical meaning of each term of the Navier-Stokes equation (5 points)

$$\rho \partial \vec{v} / \partial t + \rho \vec{v} \bullet \nabla \vec{v} = -\nabla P + \rho \vec{g} + \mu \nabla^2 \vec{v}$$

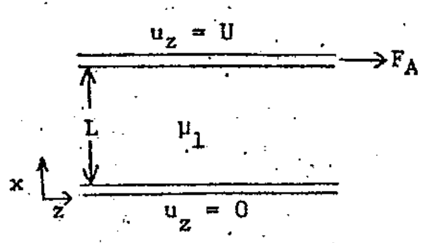
(d) A steady-state temperature distribution in a composite plane wall of three different materials, each of constant thermal conductivity, is shown on the right. Comment on the relative magnitudes of the heat flux q"$_2$, q"$_3$ and q"$_4$, and explain why you think so. (5 points)



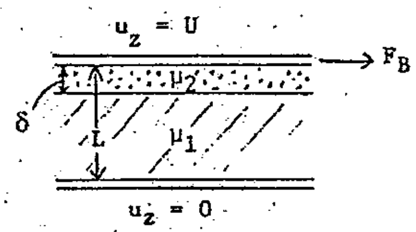
Problem 2 (20points)

Consider the steady state, one-dimensional flow field shown below. In case A, a Newtonian fluid with a viscosity of μ_1 fills the space between the upper moving plate and the lower fixed plate. In case B, a layer of thickness δ of another fluid (viscosity μ_2) is placed between the μ_1 fluid and the upper plate. Derive an equation for the ratio of F_A/F_B as a function of δ, L, μ_1, μ_2, where F_A is the force per unit area required to keep the plate moving with a velocity of U in case A, and F_B is the force required to maintain the same plate velocity in case B. The fluids are incompressible and Newtonian. And the velocity depends only on x. Please note that there is no pressure gradient in the flow direction.

Case A



Case B



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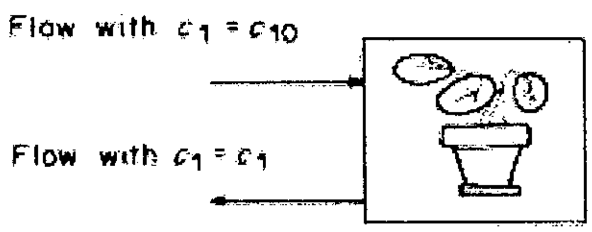
Problem 3 (10 points)

The apparatus shown below was used to study the rate of oxygen taken by a green plant. At an air flow of 1 mol/h, the inlet oxygen concentration was 21%, and the outlet concentration was 16%. At an air flow of 3 mol/h, the inlet oxygen concentration was the same, but the outlet one was 19%. The leaves had a total area of 400 cm^2. All the data were measured after the steady state had been reached. In addition, the temperature was maintained at 25^{0}C and the system pressure was kept at 1 atm.

(a) Find the oxygen mass fluxes taken by the plant at the two flow rates.

(b) According to the data, the rate of oxygen taken by the green plant depended on the air flow rate. It is also known that the oxygen rate taken by a plant depends on its metabolic rate. Therefore, a student concluded from the data that the air flow rate can change the metabolism of the plant. Do you agree with his conclusion? No matter whether or not you agree with him, please briefly explain your reason.



Problem 4 (25points)

Consider a steady, laminar boundary layer developed on an isothermal flat plate of temperature T_s. The external flow has constant velocity v_∞ and constant temperature T_∞. The kinematic viscosity and the thermal diffusivity of the fluid are ν and α, respectively. The velocity and temperature profile are assumed to be linear functions of (y/boundary layer thickness). Using the given condition, one has derived the momentum boundary thickness and the velocity profile to be $\delta = \sqrt{12\nu x/v_\infty}$ and $v = v_\infty y/\delta$. Please answer the following questions:

(a) Give the definition of the Prandtl number (Pr), the local Reynolds number (Re_x) and the local Nusselt number (Nu_x). (9 points)

(b) Use the energy integral equation given below to determine the thickness of the thermal boundary layer δ_t. (10 points)

$$\frac{d}{dx}\left[\int_0^{\delta_t}(T_\infty - T)v_x dy\right] = \alpha \left.\frac{\partial T}{\partial y}\right|_{y=0}$$

(c) Obtain the expression for the local Nusselt number Nu_x in terms of Re_x and Pr for this problem. (6 points)

Problem 5 (20 points)

An aqueous solution containing a valuable solute is colored by small amount of impurity. The impurity is to be removed by adsorption using activated carbon which adsorbs impurity but not the solution. The adsorption isotherm can be described by the Freundlich equation:

$$Y = 1.0 \times 10^{-4} X^{1.5}$$

where X is the mass of impurity (in g) to the mass of carbon (in kg) and Y is the mass of impurity (in g) to the mass of fluid (in kg). It is desired to reduce the impurity in the solution from 9.6g/kg to 0.96g/kg.

(a) Is this isotherm favorable or unfavorable? Why? (5%)

(b) Determine the quantity of fresh carbon required for purifying 1000kg of solution by a single-stage (batch) operation. (7%)

(c) If a two-stage co-current (cross-current) operation is employed, what is the minimum total amount of carbon to be used? (8%)

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