1. **(25 points)** Figure 1 shows a Bingham fluid (with a constant density and a yield stress τ) flowing down along an inclined plate (width W and length L) at an angle θ to the horizontal. This kind of flow is often encountered in the applications such as wetted-wall tower, coating, evaporation and gas adsorption experiments. The flow is laminar and steady with a constant thickness δ.

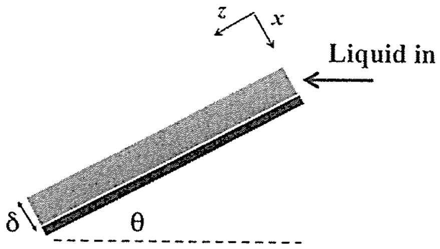

Figure 1

(a) State the momentum balance equation and boundary conditions. **(5 points)**

(b) Sketch the velocity profile v_z and the shear stress profile τ_{xz}. Provide justification for the shapes of the profiles. **(6 points)**

(c) Derive an expression for the net liquid flow rate Q (per unit width). **(9 points)**

(d) Derive an expression for the skin friction between the plate surface and the flowing fluid. **(5 points)**

2. **(10 points)** On a TV interview, Taipei Mayor KoP said, "according to the principles of fluid mechanics, the resistance is directly proportional to the length, and is inversely proportional to the fourth power of the radius". Please comment on Ko's statement. If it is correct, specify the situation at which his statement is valid. If his statement is not totally correct, modify it and specify the situation at which your modified statement is valid. Please write down relevant equations.

3. **(15 points)** Write down the principles of the following unit operations:
(1) Distillation (2) Extraction (3) Chromatography (d) Crystallization (5) Absorption
Specify which unit operation(s) you will use for the following separations:
(a) Removal of ammonia from a gas stream
(b) Recovery of Penicillin from a dilute aqueous fermentation broth
(c) Isolation of $MgSO_4$ from its solution
(d) Separation of benzene and toluene
(e) Separation of C_1 to C_5 n-alkyl bromides

4. **(15 points)** A spherical, stainless steel canister is used to store reacting chemicals that provide for a uniform heat flux q_i'' to its inner surface (Figure 2). The canister is suddenly submerged in a liquid bath of temperature $T_\infty < T_i$, where T_i is the initial temperature of the canister wall.

a. Assuming negligible temperature gradients in the canister wall and a constant heat flux q_i'', develop an equation that governs the variation of the wall temperature if $q_i'' = 5\times10^4$ W/m^2. **(10 points)**

b. What is the steady –state temperature of the wall? **(5 points)**

Stainless Steel, AISI 302: $\rho = 8055$ kg/m^3, $c_p = 535$ J/kg·K

見背面

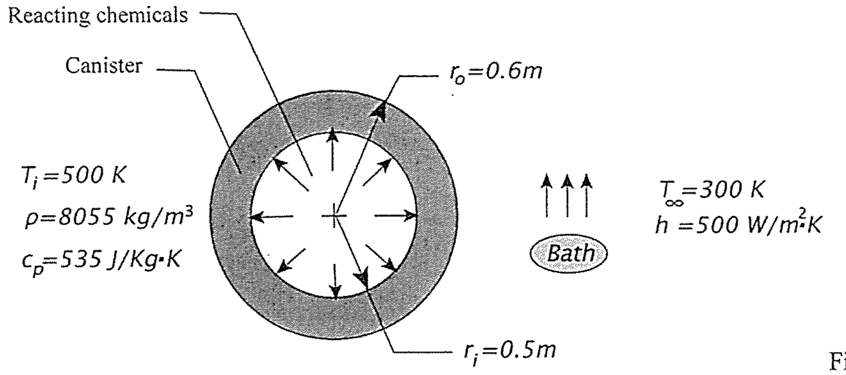

Figure 2

5. **(10 points)** For flow over a flat plate of length L, the local heat transfer coefficient h_x is known to vary as $x^{-1/2}$, where x is the distance from the leading edge of the plate. What is the ratio of the <u>*average Nusselt number*</u> for the entire plate ($\overline{Nu}_L$) to the <u>*local Nusselt number*</u> (Nu_L) at $x = L$?

6. **(10 points)** Consider the case that both forced convection and natural convection should exist. Please answer the following questions
   a. *Grashof number* (Gr_L) is usually used to describe natural convection. What is the physical meaning of Gr_L? **(2 points)**
   b. Combined free and forced convection is likely to happen. Please use the ratio of $Gr_L / Re_{L\infty}^2$ to identify for each case. **(3 points)**
   c. Following-up with b, how is the *Nusselt number* expressed? (Use proper dimensionless groups to describe your answer) **(3 points)**
   d. When describing heat transfer in combined convection, the *Nusselt number* can be expressed as the form:

$$Nu^n = Nu_F^n \pm Nu_N^n$$

   Where Nu_F is the *Nusselt number* for forced convection, and Nu_N is for natural convection. Please describe how the plus (+) and minus (-) signs are determined? **(2 points)**

7. **(15 points)** *Reynolds analogy* relates the key engineering parameters of velocity, thermal, and concentration. If the velocity parameter is known, the analogy may be used to obtain the other parameter, and vice versa. Consider a turbulent flow on a flat plate, and the local friction coefficient may be expressed from the *Blasius relation* as:

$$C_{fx} = \frac{0.0576}{Re_x^{1/5}}$$

Please use the modified *Reynolds analogy* (or called *Chilton-Colburn analogy*), which is of the form,

$$\frac{C_f}{2} = St Pr^{2/3}$$

to find out the expression for the *local Nusselt number* (Nu_x), and the *average Nusselt number* ($\overline{Nu}_L$).

試題隨卷繳回