National Exams December 2009

04-CHEM-B1, Transport Phenomena

3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. The examination is an OPEN BOOK EXAM.
3. Candidates may use any **non-communicating** calculator.
4. All problems are worth 25 marks. **One problem** from **each** of sections A, B, and C must be attempted. A **fourth** problem from **any section** must also be attempted.
5. **Only the first four** questions as they appear in the answer book will be marked.
6. State all assumptions clearly.

Section A: Fluid Mechanics

A1 **[25 marks overall]** A fluid flowing through a circular pipe is being heated so that a temperature gradient exists from one end of the pipe to the other. This axial gradient in the z-direction is given by:

$$T_z = 250 \cdot [1 - \exp(-0.1z)]$$

T_z is the temperature in °C at a given point z which is measured from the inlet in the flow direction. The fluid velocity on the centerline is 0.3 m/s. At a particular time, the temperature of the fluid is increasing at 3°C/s at a point 1 m from the inlet. A thermocouple that can move along the centerline is used to measure the temperature. Based on the definitions of the three kinds of time derivative (partial-, total-, and substantial time derivative), calculate the time rate of increase of temperature measured by the thermocouple at a point 1 m from the inlet when:

(a) **[5 marks]** the thermocouple is stationary at that point;
(b) **[10 marks]** the thermocouple is moving past the point at a velocity of 1 m/s; and
(c) **[10 marks]** the thermocouple is moving at the fluid velocity.

A2 **[25 marks overall]** An inclined tube manometer with a large-diameter reservoir is used to measure the pressure difference in a pipeline carrying oil with a specific gravity of 0.91 as shown in Fig. A1. The pipe is inclined at an angle of 60° to the horizontal and the oil is flowing uphill. The manometer tube is inclined at an angle of 20° to the horizontal. The diameter of the reservoir is 8 times the diameter of the manometer tube and the manometric fluid is water (density 62.4 lb_m/ft^3). The pressure taps in the pipe are a distance L = 5-inches apart. If the reading on the manometer is s = 3-inches and we neglect the displacement of the fluid in the reservoir, what is the pressure difference ($\Delta P = P_2 - P_1$) in psi between stations 1 and 2 in the pipe. Work this problem in *fps* (*i.e.* English engineering units) units throughout.

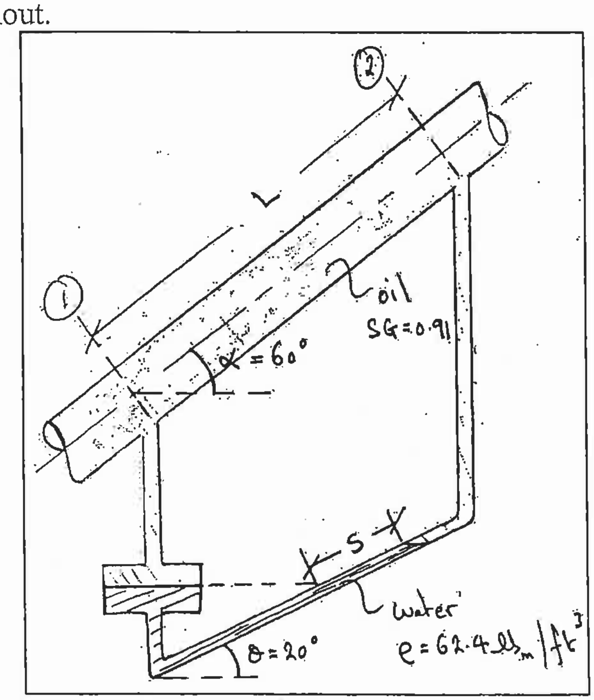

Fig. A1: Inclined manometer

Section B: Heat Transfer

B1 **[25 marks overall]** Consider a hollow cylindrical heat transfer medium of length L having inside and outside radii of r_i and r_0 with corresponding temperatures T_i and T_0. If the thermal conductivity varies linearly with temperature according to:

$$k(T) = k_0(1+\beta T)$$

show that the steady-state rate of heat transfer in the radial direction $(\dot{Q}_r)$ is given by:

$$\dot{Q}_r = \frac{2\pi L k_0}{\ln(r_0/r)}\left[1+\frac{\beta}{2}(T_i - T_0)\right]\cdot(T_i - T_0)$$

B2 **[25 marks overall]** Consider the composite wall shown in Fig. B1. The concrete and brick sections are of equal thickness. Assuming one-dimensional heat flow, draw the thermal circuit for the wall and identify all the thermal resistances.

(a) [20 marks] Determine T_1, T_2, and the heat flux through the wall.
(b) [5 marks] What percentage of the heat flux flows through the brick?

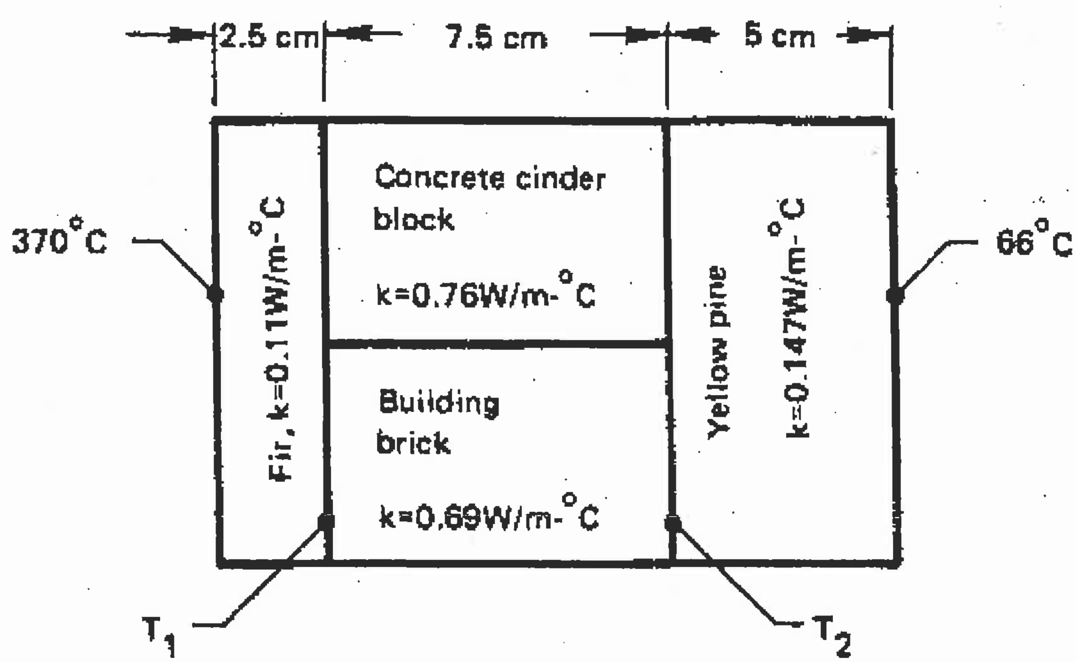

Fig. B1: Composite wall

Section C: Mass Transfer

C1 **[25 marks overall]** Figure C1 shows a liquid falling as a film under laminar flow down a vertical flat surface while being exposed to a gas (A) which dissolves in the liquid. The liquid contains a uniform concentration of A (C_{A0}) at the top ($z = 0$). At the liquid surface ($x = 0$), the concentration of the gas is C_{Ai}. Show that the governing differential equation for the problem is:

$$\left\{\rho g_z \delta^2 \frac{\left[1-(x/\delta)^2\right]}{2\mu}\right\}\frac{\partial C_A}{\partial z} = \frac{\partial^2 C_A}{\partial x^2}$$

Define the boundary conditions **but** do not attempt to solve the equation.

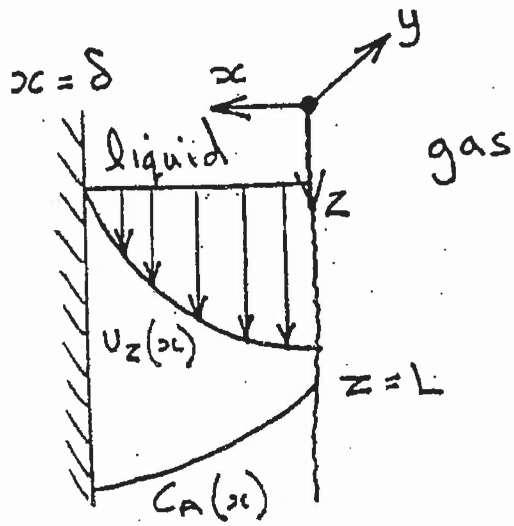

Fig. C1: A falling liquid film

C2 **[25 marks overall]** A distillation column separates alcohol A from alcohol B at 1 atm. and 327 K. At a particular location in the column, the liquid pase and the gas phase contain 30 mol % A and 40 mol % A, respectively. Assuming that the resistance to mass transfer is in the gas-phase film of thickness 0.3 mm, calculate the molar flux of A from the liquid to the gas phase. Under these conditions the diffusion coefficient is 5.4×10^{-6} m^2/s and Henry's law constant $H_A = 0.7056$ atm.