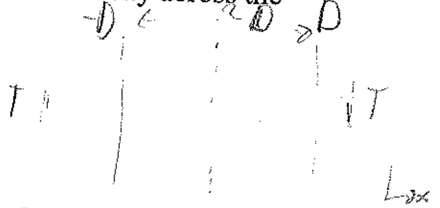
ta3220 Fluid Flow, Heat and Mass Transfer
Final Exam
23 January 2008
Write your solutions *on your answer sheet*, not here. In all cases **show your work**.
Use SI units throughout.

1. A Newtonian fluid flows through a narrow slit of thickness 2D; that is, in the x direction the slit extends from +D to -D. One side of the slit is heated and the other side cooled, which introduces a steady-state temperature difference across the slit. Because viscosity depends on temperature, there is a non-uniform viscosity across the slit:

$$\mu = \frac{\mu^*}{1 + A(x/D)} \qquad -D \leq x \leq D$$



where μ^* is a constant, and A is a constant with a value between 0 and 1.

   a. You will notice that this problem is similar, but not identical, to the flow of a Newtonian fluid with constant viscosity solved in your text *FTI* on pp. 236 *ff.* (handed out with your exam). For this part, answer only this question:

      What is the *last* equation in the derivation on those pages of *FTI* that applies directly to the problem posed above?

      Write that equation number on your answer sheet.

   b. Starting with that equation, proceed to derive the steady-state velocity $v_y(x)$ as a function of x within the slit as described above. Use the coordinate system and symbol definitions from *FTI* except as modified above.

(20 pts)

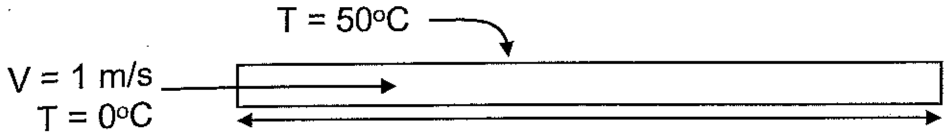
2. An engineer measures flow rate $Q_1 > 0$ of a given liquid in a horizontal tube with a pressure difference ΔP_1 across the length of the tube. When she doubles the flow rate to $2Q_1$, the pressure difference increases to a value *less than* $2(\Delta P_1)$. Which of the following could be an explanation for this? Indicate the letter of the possible explanations on your answer sheet. It could be that more than one explanation may be possible; if so, list all possible explanations.

   a. The fluid is a Newtonian fluid in laminar flow at the first flow rate.
   b. The fluid is a Newtonian fluid in highly turbulent flow at the first flow rate.
   c. The fluid is a shear-thinning power-law fluid in laminar flow at both flow rates.
   d. The fluid is a shear-thickening power-law fluid in laminar flow at both flow rates.
   e. The fluid is a Bingham plastic in laminar flow at both flow rates.

(10 pts)

3. Water flows through a tube 1 cm in diameter and 10 cm long at a velocity of 1 m/s.
   a. What is the heat-transfer coefficient between water and the wall of the tube?
   b. Suppose water at 0°C flows into this tube with the wall temperature is maintained at 50°C all along the tube length. What is the temperature of the water as it exits the tube?
   c. What is the steady-state rate of heat transfer between the water and the wall of the tube?

(20 pts)



<u>properties of water</u>

$\rho = 1000$ kg/m^3 $C_p = 4190$ J/(kg K) $k = .680$ W/(m K) $\mu = 0.001$ Pa·s

4. A large (i.e., infinite) block of steel has an initial temperature of 50°C. This block has a cylindrical hole 1 cm in diameter drilled through it. Suppose the inner surface of the hole were suddenly cooled to 0°C and maintained at that temperature. What is the rate of heat transfer between the surface of the tube and the solid, per m length of the hole, after 10 min?

(15 pts)

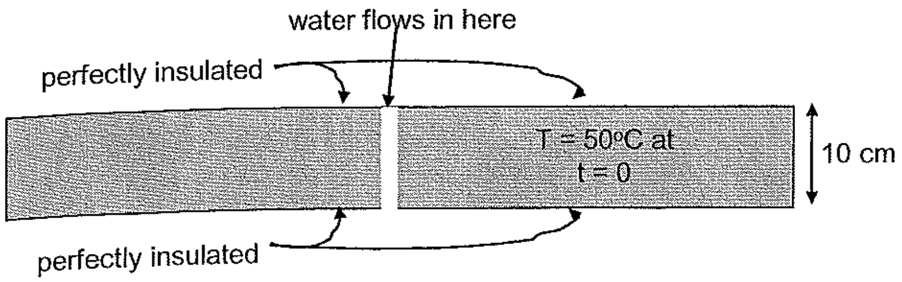
<u>properties of steel</u>

$\rho = 7600$ kg/m^3 $C_p = 470$ J/(kg °K) $k = 46.9$ W/(m °K)

5. A finite-width slab of steel extends from $y = 0$ to $y = 0.1$ m in the y direction and infinitely in the x and z directions. The block has an initial temperature of 50°C. This block is perfectly insulated on the surfaces at $y = 0$ and $y = 0.1$ m. The block has a cylindrical hole 1 cm in diameter drilled through it in the y direction. Starting at time $t = 0$ water at 0°C flows into the hole at a velocity of 1m/s. Flow continues for 10 min. Based on your answers to problems 3 and 4, which aspect of this problem controls the cooling of the slab after 10 min.: heat transfer between the water and the tube wall, or heat conduction within the solid? Briefly justify your answer.

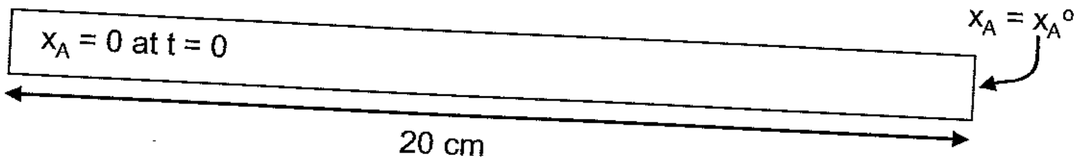
   If you are unable to reach numerical answers to problems 3 and 4, tell clearly how you would answer this question *if* you had those numerical answers. Be specific in exactly how you would use those numerical values.

(10 pts)



6. We recently hosted a seminar at the Department where the speaker discussed a way to measure diffusion coefficients in gases. A narrow tube 20 cm in length, open at one end and closed at the other, is filled with gas with zero concentration of component A. A number of such tubes are placed into a chamber where the gas contains mole fraction x_A^o of component A. Sitting in the chamber, each tube is exposed at its open end to this mole fraction x_A^o of component A. The other surfaces of the tubes are impermeable to component A and there is no reaction of component A with the tube wall. There is assumed to be no convection within the tube. Over time, the tubes are removed from the chamber and the gas within the tubes is analyzed.

Suppose after 2 hours the mole fraction of component A in the gas at the closed end of the tube is $0.5\ x_A^o$. What is the diffusion coefficient of A in the gas?
(15 pts)



7. Consider again the experimental apparatus in Problem 6. Suppose the tube starts with gas with zero mole fraction of component A. It is placed into a chamber where the surrounding gas contains mole fraction x_A^o of component A. Then, after 2 hours, the tube is placed in another chamber where the surrounding gas has zero mole fraction of component A, and left there for another 2 hours. Assume the diffusion coefficient is that you found in problem 6. What is the mole fraction of component A at the closed end of the tube after sitting in the second chamber for 2 hours?
(10 pts)