ta3220 Re-Examination
Spring 2011
29 June 2011

Write your solutions *on your answer sheet*, not here. In all cases ***show your work***. To avoid any confusion, state the equation numbers and figure numbers of equations and figures you use. Beware of unnecessary information.

1. Water flows through a horizontal 10-cm length of tubing of inner diameter 1.5 mm, with a pressure difference of 10^6 Pa over the length of the tube. The scale of the roughness is 0.05 times the diameter of the tube. What is the flow rate of water through the tube?

(13 pts)

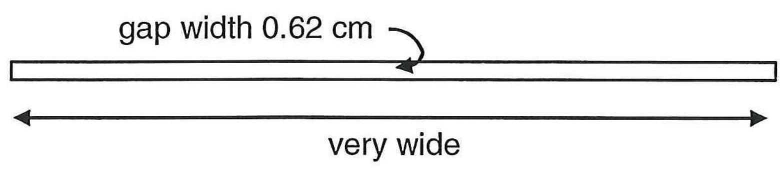
<u>properties of water</u>

$\rho = 1000$ kg/m^3 $\quad$ $\mu = 0.001$ Pa s $\quad$ $k = 0.680$ W/(m K) $\quad$ $C_p = 4190$ J/(kg K)

2. Beneath a door in my former house in the U.S. was an air-filled gap 6.2 mm-wide in one direction and very wide in the other direction. In the third direction, perpendicular to the page in the diagram below, the gap was much longer than 6.2 mm. Air flowed through that gap (i.e., perpendicular to the page). After I noticed the gap, I partially blocked it with a solid strip, reducing the gap width to 1 mm. Assume flow through the gap is driven by a constant pressure difference across the gap (i.e., perpendicular to the page).
   a. By how much (give a fraction, or a %) would this reduce the air flow rate Q if the flow of air through the gap were laminar?
   b. By how much (give a fraction, or a %) would this reduce the air flow rate Q if the flow of air through the gap were highly turbulent (Re → ∞)? Assume the gap has finite roughness.
   c. Properties of air are given below. For the 6.2 mm gap, what is the highest velocity through the gap for which *laminar* flow applies?

(22 pts)

Cross-section view



<u>properties of air</u>

$\mu = 1.75 \times 10^{-5}$ Pa s $\quad$ $k = 0.025$ W/(m K) $\quad$ $\rho = 1.26$ kg/m^3

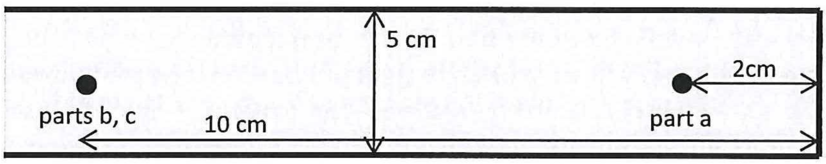
$c_p = 1006$ J/(kg K)

3. A cylindrical sample of sandstone rock is has diameter 5 cm and extends from a flat surface at x = 0 for a very large distance. Initially the rock is at a uniform temperature of 20°C. Starting at time t=0, the flat end and the cylindrical surface are both raised to 320°C. Assume that there is no convection in the sandstone.
   a. What is the temperature of the rock at its central axis, 2 cm from the flat end, after 2 min of heating?
   b. How long does it take for a point on the central axis, 10 cm from the end, to heat to 290°C?
   c. Now consider a different problem. A cylindrical solid of the same dimension has initially zero concentration of chemical A. Starting at time t=0 the flat end and the cylindrical surfaces are exposed to concentration C_A^o. The diffusion coefficient of chemical A in the solid is 10^{-9} m^2/s. How long does it take the concentration of chemical A to reach (0.9 C_A^o) at a point on the central axis, 10 cm from the end?

(20 pts)

properties of sandstone

k = 2.61 W/(m K) ρ = 2270 kg/m^3 c_p = 999 J/(kg K)

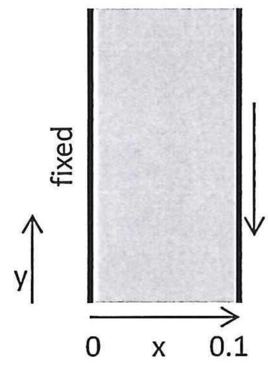


4. In a geothermal project, heat transfer from produced water to the cooler rock as water moves up the well comprises at least three steps: convective heat transfer from water to the pipe wall; conduction through the pipe wall; and unsteady conduction radially outwards from the well to the surrounding rock layer. Consider that overall problem in two parts. For this problem, we assume conduction through the pipe wall is not important.
   a. A geothermal well, of inner diameter 0.3 m, has a flow rate of 0.05 m^3/s. The water flows in at a temperature of 80°C. The well flows through sandstone at 40°C. Assuming the inner surface of the pipe is maintained at 40°C along its length, what is the temperature of the water after 100 m of flow in the pipe? What is the average rate of heat transfer from water to the pipe wall, as represented by the temperature rise in the water? Use the properties of water as given in problem 1.
   b. A rock layer has an initial uniform temperature of 40°C. Starting at time t=0, a cylindrical hole of diameter 0.3 m is maintained at a uniform temperature of 80°C, and heat is conducted outwards into the rock. Assume there is no convection in the rock. One year later, what is the total rate of heat loss from the hole into the rock layer? Use the same properties of rock as are listed for sandstone in problem 3.
   c. Based on your answers to (a) and (b), which is more important in controlling heat loss from water in this geothermal project: convective heat transfer within the well, or heat conduction into the surrounding rock? Briefly justify your answer. If you were unable to answer parts (a) or (b), explain how you would answer this question if you were able to finish those parts.

(25 pts)

5. A Newtonian fluid with density ρ and viscosity μ fills the gap between two vertical, solid surfaces. One surface, at $x = 0$, is motionless. The other surface, at $x = \delta$, is moving downwards with velocity V. (Since the wall is moving downwards, and the y axis points up, $V < 0$.) There is no pressure force driving the flow, but of course gravity pulls downward (in the negative y direction, since here the y axis points upwards). Note: this problem is easier if you keep the coordinate system shown than if you move $x = 0$ to the middle of the gap.
   a. Derive an equation for velocity v_y as a function of x within the gap between the plates.
   b. Is there ever an occasion where the fluid exerts a force *upwards* on the moving plate, i.e. against its downward motion? Explain in words how this could happen, and then how you would verify this mathematically. *Don't spend too long on this part.*

(20 pts)



at $x = 0$ $v = 0$

at $x = 0.1$ (δ) $v = -V$