ta3220 Final Examination (special re-sit) - 5 November 2013

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

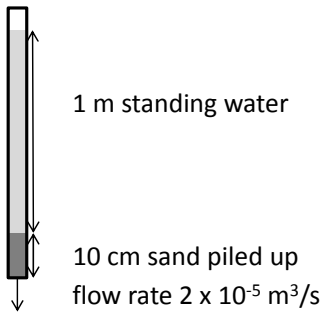
1. A Bingham plastic coats a vertical solid surface in a layer of uniform thickness δ. We want to know the maximum thickness of the layer that would *not* flow downward under gravity.
   a. You might notice that this problem is similar to that of the falling film in BSL Section 2.2. The relevant pages are appended to the back of this exam. What is the *last* equation from the derivation in Section 2.2 that could be applied directly to this problem? In other words, what is the last equation before that derivation deviates from this problem? Write that number on your answer sheet.
   b. Derive a formula for the maximum layer thickness δ_{max} that would *not* flow downward under gravity, in terms of the physical parameters of the Bingham plastic.
   c. A given paint has a yield stress τ_o of 1.3 Pa, plastic viscosity μ_o of 0.01 Pa s, and density ρ of 1200 kg/m^3. How thick is the layer you derive in part (b)?
   (17 points)

2. A rock formation is penetrated by a fracture 3 mm wide. Hot water (with properties given below) flows through the fracture at a velocity of 1 m/s. Assume the rock walls are maintained at a uniform and constant temperature of 40°C, and the water flows in at a temperature of 90°C. How far does the water flow before its temperature has decreased to 45°C? Treat the fracture as a rectangular slit.
   (18 pts)

properties of water

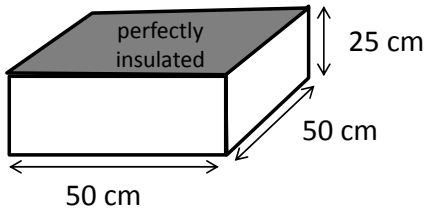
ρ = 1000 kg/m^3 μ = 0.001 Pa s k = 0.680 W/(m K) C_p = 4190 J/(kg K)

3. A vertical cylindrical pipe of inner diameter 5 cm, attached to the side of a house, is designed to carry away rainwater from the roof. The owner of the house believes that this pipe is plugged by sand or gravel near the bottom. Suppose the sand is piled to a depth of 10 cm in the pipe, and has porosity 0.35. On a particularly violent rainstorm, for a time water flows through the pipe at a rate of 2 x 10^{-5} m^3/s (one liter every 50 seconds). During this rain, water sits in the pipe at a level 1 m above the top of the plugged region. If the owner of the house is correct, what is the diameter of the sand grains in the plugged region? Use the properties of water given in problem 2.
   (20 points)



4. A rectangular solid slab of steel (properties given below) is 25 cm on one edge, and 50 cm along the two other edges as shown below. At t = 0 it is at a uniform temperature of 100°C. Starting at time t = 0 all surfaces but one are instantaneously cooled to 0°C. One of the large, flat surfaces (the one on top) is perfectly insulated, as shown.
   a. What location in the solid is the slowest to cool down? Indicate this either *clearly* in words, or by drawing a diagram on your answer sheet with that point indicated by a large dot.
   b. What is the temperature at that location after 1 hour?

   (20 points)



properties of steel

ρ = 7820 kg/m^3 k = 17 W/(m K) C_p = 461 J/(kg K)

5. Consider the same solid as shown in problem 4. Suppose this solid has in addition a layer of plastic (k = 0.16 W/(m K)), 2 mm thick, coating all sides. (One large flat surface remains perfectly insulated, as above.)
   a. Suppose heat conduction through the layer of plastic is the limiting process in heat conduction. Simplify the problem by assuming that temperature in the solid is uniform at all times. As before, the solid is initially at 100°C and suddenly at time t = 0 the outer surface *of the plastic* is cooled to 0°C. What is the temperature of the solid after 1 hour?
   b. For the plastic-coated solid, which answer is better, the one you derived in problem 4 or the answer derived in part(a) above? Briefly justify your answer. If you aren't able to answer part (a), tell clearly how you would answer the problem if you did solve part (a).

   (25 points)