AESB2320, 2017-18

Part 2 Examination - 4 July

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
along with the text you are using (BSL1, BSL2 or BSLK).
Beware of unnecessary information in the problem statement.

The first three problems in this examination are related to the design of an apparatus in our laboratory intended to maintain temperature in a cylindrical rock core as water flows through the core.

1. We want to preheat the water before it enters the apparatus. Before the water enters the cylindrical rock core, it flows through a tube 2 cm long, of inner diameter 1.6 mm, at a flow rate 1 ml/min (1.67×10^{-8} m^3/s). Around the tube is a cylindrical steel jacket, of diameter 4 cm. (In other words, in effect the inner diameter of the tube is 1.6 mm and the outer diameter is 4 cm.) On the outer wall of the jacket, temperature is held constant.
   a. What is the heat-transfer coefficient between water inside the tube and the tube wall?
   b. What is the overall heat-transfer coefficient between the heated outer surface and the fluid inside the tube?
   b. If water enters the tube at 20°C, and the outer surface of the jacket is maintained at 90°C, what is the temperature of the water when it leaves the tube?

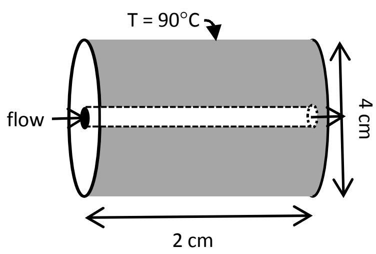
   (30 points)

<u>Properties of water</u>

ρ = 1000 kg/m^3 C_p = 4180 J/(kg K) μ = 0.001 Pa s k = 0.60 W/(m K)

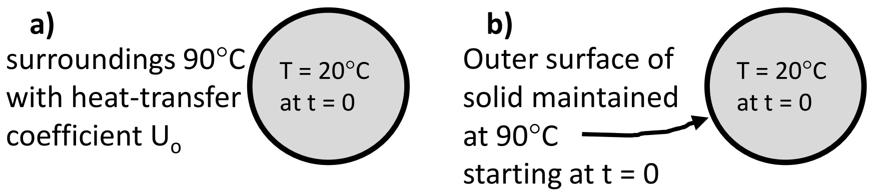
<u>Properties of steel</u>

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



2. A cylindrical rock core is initially at a uniform temperature of 20°C and is to be heated to 90°C (with no fluid flowing through it). For this problem, treat the core simply as a cylindrical solid, 4 cm in diameter, infinitely long. The properties of the core are given below. Consider two possible simplifications of this problem.
   a. The solid is initially at a uniform temperature of 20°C. Starting at time t = 0 its outer surface is exposed to an environment of 90°C with the overall heat-transfer coefficient of U_o = 14 W/(m^2 K). Assume that the solid remains at uniform temperature at all times as it heats. How long does it take the solid to heat to 80°C? See figure (a) below.
   b. Instead, assume that the solid is initially at a uniform temperature of 20°C. Starting at time t = 0 its outer surface is raised to and maintained at 90°C. Unsteady heat conduction warms the interior of the core. How long does it take the solid to heat to 80°C along its central axis (r = 0?)? See figure (b) below.
   c. Which is the better estimate of the actual time to heat the solid, (a) or (b)? Briefly justify your answer.

(35 points)



<u>Properties of rock</u>

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

3. Consider the core in Problem 2 again, making the assumption in Part (b). It is desired to heat the core up faster. The core is initially at 20°C. Starting at time t = 0 the outer surface is raised in temperature to 120° and maintained there. Then, at t = 60 s, the outer surface is cooled to 90°C and maintained there. What is the temperature of the center of the solid at time t = 120 s after the *first* change in surface temperature?

(10 points)

4. Inside a rectangular solid of thickness δ heat is released at a rate S (in W/m^3). The solid has thermal conductivity k, density ρ and heat capacity per unit mass C_p. The bottom surface of the solid is maintained at temperature T_0. Cooling is applied to the top surface such that the heat flux is fixed at q* over time. (Note that because heat is given off in the (-x) direction, $q^* < 0$.) After some time, the solid attains a steady-state temperature profile T(x).
   a. Derive a formula for the steady-state heat flux q_x in the solid as a function of x.
   b. Derive a formula for the steady-state temperature of the solid T(x).
   c. If the rate of cooling at the top surface is sufficient (i.e., if q* is sufficiently negative), the steady-state temperature is less than T_o throughout the solid. What is the smallest (least negative) heat flux q* for which this happens? Briefly justify your answer. [This part is only 5 pts. Don't spend too long on it if you don't get it.]

   (25 points)