BENG 37303 Transport Phenomena in Biological Systems
Homework #3

Assigned: September 18, 2024
Due: September 25, 2024- 4:35 PM

1. A food manufacturer is using a coolant (ethylene glycol) to cool a chilled water system. The coolant is pumped from the chiller outside the building into the plant in 2" (ID) stainless steel (AISI 316) pipe, (Standard, Schedule 40 pipe). The coolant has a temperature (T_∞) of -3°C and an h of 27 W/m^{2}K. The pipe needs to be covered in insulation to keep condensation from forming. Because the plant is located in the South where dewpoints can reach 24°C at the peak of summer, the temperature at the exterior surface of the insulation must be >= 24°C. The insulation material for the pipe has a thermal conductivity of 0.03 W/mK. Since this is a long pipe, this is conduction in one dimension; assume steady state.
    a. Draw the cross-section of the pipe system and identify (label clearly) the temperatures and known conditions (include those properties available in standard tables as knowns). Cite references for the properties not explicitly given.
    b. Draw a thermal resistance model and label the known conditions and values obtained from other sources. What is missing?
    c. If the h in the room is 5 W/m^{2}K with an ambient T= 25°C, would insulation of 0.5" be sufficient to prevent condensation?
    d. Comment on this result- if the insulation is insufficient to prevent condensation, what would you suggest to ensure it works effectively. If it is adequate, is it over-engineered?
    e. What are the temperatures at each interface in the system?

2. In the supplemental lecture where Dr. Howell derived the equation for T(r) in a cylindrical shell, he had two forms of the equation based on how the boundary conditions were used to find the constants of integration.
    a. Are they truly equivalent? Plot T(r) to show this.
    b. Can they both be used? Does it matter which one you use?

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3. A spherical reaction vessel contains an immobilized media (not moving so assume conduction only and no inside convection) of animal manure that is being aerobically digested producing an exothermic reaction producing 300 W/m^3. Thermal conductivity of the immobilized manure is k = 0.5 W/m K. The inside radius of the reactor is 850 mm and the vessel is constructed of stainless steel with a wall thickness of 9mm. Assume the convection coefficient of the ambient air along the outer wall of the reactor is 15 W/m^2-K. This reaction vessel will operate in a typical processing plant environment. Make reasonable assumptions for T_∞ and T_{surr}.
   a. Find the location and magnitude of the maximum temperature of the immobilized manure in your insulated vessel assuming the outer wall of the vessel is not insulated. Be sure to account for radiation losses. Start with the governing equation for the manure (I know, I know there is a metaphor there), simplify, and derive the equation for temperature distribution in the media based on boundary conditions for this problem.
   b. You are to design the insulation surrounding the vessel wall such that the maximum temperature inside the reactor = 125 °C to optimize growth and metabolism of thermophilic bacteria. Select the proper thickness of insulation using the assumption that radiative heat transfer is negligible. Make sure to check the critical radius of insulation (r_{cr} = 2k/h see p. 110 table 3.3) to ensure there are no problems with excess heat loss due to the insulation.
   c. Calculate the temperature of the outer surface of the insulation after you have determined the proper thickness of the insulation. Was the assumption of negligible radiative heat transfer proper? Why or why not? (just answer yes or no and explain based on your judgement and the information you have already calculated)

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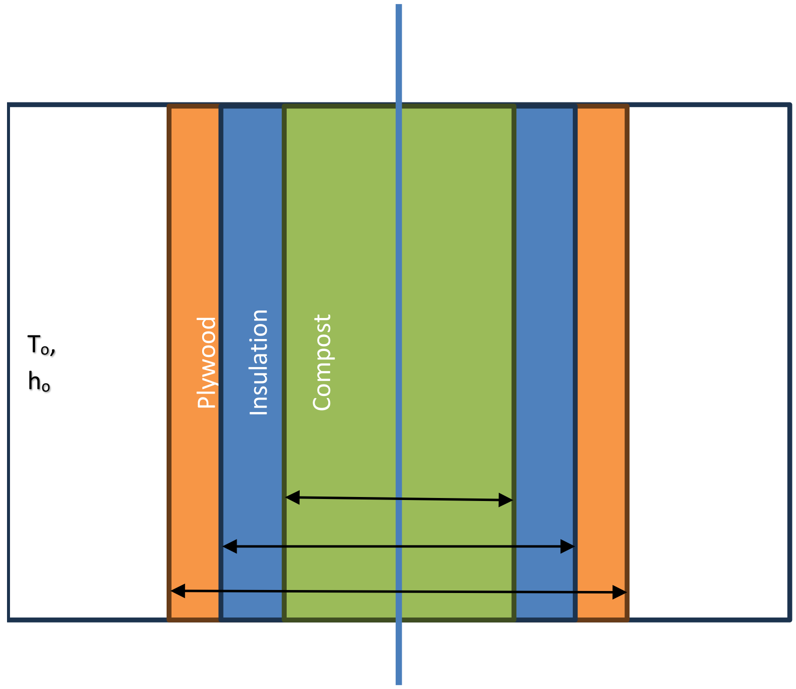
4. In class on 9/18, we evaluated a problem where heat is generated in a compost bin, It looked like the diagram shown here:



If the heat generated by the compost is 100 W/m^3 and thermal conductivity of the compost is 0.2 W/m K, T_o and h_o are 5°C and 20 W/m^{2}K, the plywood is ½" thick (k = 0.1 W/mK), and insulation is 2" thick (k = 0.05 W/mK) . Neglect radiation from outer wall.

a. Set up the heat transfer equation for this problem and show the assumptions and boundary conditions used to simplify it.
b. If L= 0.5 m (the width of the entire compost gap), solve for the temperature at each interface and the midpoint of the bin. Comment on the effect of increasing "L". Is there a width where temperatures get out of hand. What design specs might you recommend for something like this- consider the width, insulation factors, etc.
c. If this figure were a cross-section of a cylinder (compost bin is now a barrel), recreate the heat transfer equation solution in part a for cylindrical coordinates.
d. Solve for the temperature at each interface and at the middle.
e. At what L (radius) would you consider using planar/cartesian coordinates for the system solution?