8 April 2021

Homework 4 CM3110 Morrison

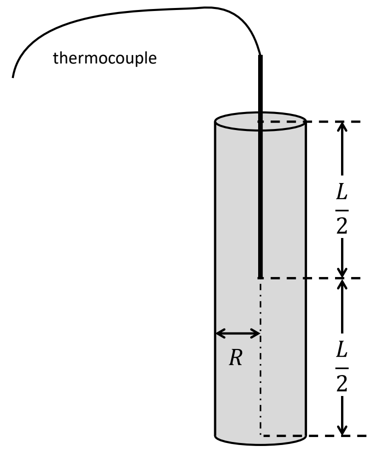
Module	Number		Assigned Problems (Geankoplis)	Stretch Problems
4	1	if assume bulk equals wall, over or underestimate	see attached	
4	2	Fourier's law	H, attached	
4	3	measuring heat transfer coefficient	see attached	
4	4	**Temp field:** wire temperature profile and heat loss	see attached	
4	5	**Temp field:** variable thermal conductivity heat flux		4.2-4, modified
4	6	**Temp field:** rod submerged in rapidly flowing bath		see attached
4	7	1D conduction: Heat loss through a wall; T's are wall temps	4.1-1	
4	8	1D conduction: steady heat conduction, temp bc	see attached	
4	9	boundary conditions (sketch) Newton's law of cooling	see attached	
4	10	1D radial: sketches	Fig 4.5-1 and 4.3-3	
4	11	1D rectangular: sketches, composite, resistance	see attached	
4	12	1D rectangular: Insulation, compound wall	see attached	
4	13	Analyze a heat exchanger: Resistances		see attached
4	14	Heat transfer in heat exchanger, material of construction	see attached	
4	15	Forced conv. h (inside tube) data correlations	J attached	
4	16	forced conv w/o radiation data correlations external tubes	L, attached	
4	17	forced conv (inside HE) data correlations		N, attached
4	18	Create a summary list of all correlations for heat transfer coefficient given in Geankoplis.	see attached	
4	19	heat exchanger design: laminar flow inside tube with heat xfer data correlations		4.5-6

Homework 4

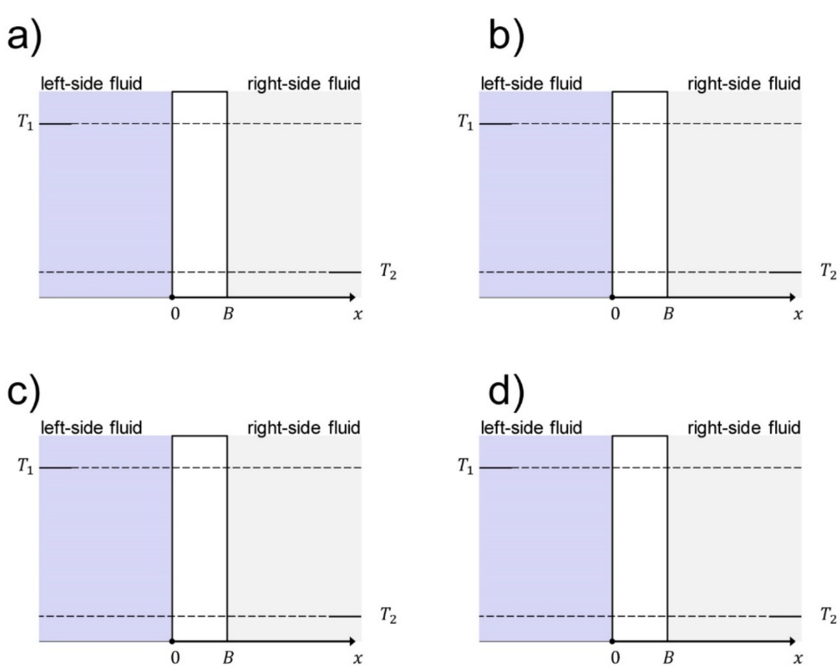
Problems:

1. A tall, wide, solid wall of brick (wall thickness =13 cm) with thermal conductivity $k = 0.60\ W/mK$ and heat capacity $841\ J/kg\ K$ separates the inside and the outside of a building on a still day (no wind). The air temperature in the building is 25^oC; the air temperature outside the building is -12^oC.
    a. If we assume that the wall temperatures on both sides of the wall are equal to the air temperatures, what is the steady state flux of heat from the building? Give your answer in W/m^2.
    b. How good is the assumption that the wall temperatures are equal to the air temperatures? Will the estimate of the flux made in part a) be an overestimate or an underestimate of the likely flux? Explain your answer in a sentence or two; provide a supporting sketch.
2. Problem H: A window is made of a single pane of glass that is 3.0mm thick. The inside temperature of the glass is measured to be 24.5^oC. The outside temperature of the glass is -3.4^oC. What is the rate of heat loss through the glass? Answer: $8.9\ kW/m^2$
3. Heat loss per area through the outside wall of a building is determined with an infrared sensor to be $140\ W/m^2$. The external surface temperature of the walls is 17^oC. On the day of the measurement, the outside air temperature is 5^oC (41^oF). Under these conditions, what is the heat transfer coefficient between the wall of the house and the environment? Answer: $12\ W/m^2K$
4. What is the steady state temperature profile in a wire if heat is generated uniformly by electric current flow? The heat is generated throughout the wire at a rate of $S_e\ W/m^3$ and the wire is in a room with bulk air temperature of T_b. You may assume that the heat transfer coefficient is h. What is the heat flux at the wire surface?
5. (stretch) Geankoplis 4.2-4, modified. A large, wide flat metal plate of thickness H has one surface maintained at T_1 and the other surface is maintained at T_2. The thermal conductivity of the metal varies with temperature according to $k = a + bT + cT^3$ (where a, b, and c are constants). What is the heat flux $\tilde{q} = q/A$ equal to in this case? You may assume steady heat transfer in the thickness direction. Hint: Begin with the version of the microscopic balance that has the flux $\underline{\tilde{q}}$ in it.
6. (stretch) What is the simplified partial differential equation and what are the boundary/initial conditions (express in a coordinate system) that must be solved in order to obtain the time-dependent temperature at the center of a steel rod subjected to the following experiment (indicate all your assumptions):

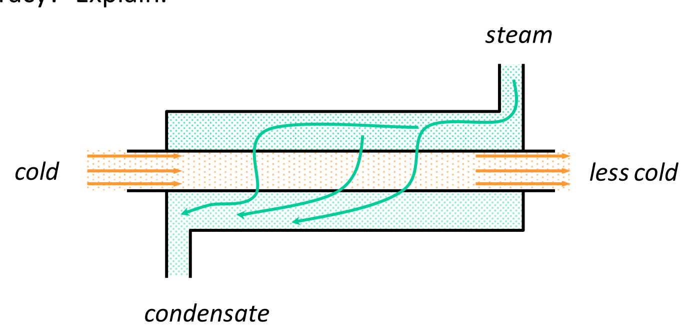
A very long cylindrical steel rod of length L and radius R is initially equilibrated in a bath of temperature T_{bath}. Suddenly, the rod is submerged in a rapidly flowing bath of water of higher temperature T_{new}. The rod has a thermocouple embedded down its axis, with the thermocouple tip lodged exactly halfway down the length of the rod, positioned to read the temperature at that point. The heat transfer coefficient from the fluid to the rod is essentially infinite.



7. Geankoplis 4.1-1. Calculate the heat loss per m^2 of surface area for a temporary insulating wall of a food cold storage room where the outside wall temperature is $299.9\ K$ and the inside wall temperature is $276.5\ K$. The wall is composed of $25.4\ mm$ of corkboard having a thermal conductivity of $0.0433\ W/mK$.
8. A solid wall (thermal conductivity $= 1.212\ W/mK$, heat capacity $= 2.11\ kJ/kgK$, wall thickness $= 8.2cm$) separates a cold room from a warmer room next door. The wall temperature in the cold room is 45^oC and the wall temperature in the warm room is 74^oC. What is the rate of heat flux through the wall? Answer: $-430\ W/m^2$
9. A very tall, very wide slab (thermal conductivity k) of thickness B is positioned between two fluids as shown in the figures provided. For each of the following five situations, sketch the steady state temperature profile, both in the fluid and in the slab itself. Use the axes shown and draw your answers carefully.
http://pages.mtu.edu/~fmorriso/cm310/2015Homework5SketchHeatTransferProblem.pdf



10. Linking temperature profiles to physics.
    A. Consider the temperature profile in Figure 4.5-1 (Geankoplis, page 259). Answer the following questions.
        a. What is the direction of heat transfer?
        b. Is the heat flux from left to right positive or negative?
        c. Put the heat fluxes in order (which is smallest, which is largest).
        d. What are the boundary conditions between the cold fluid on the left and the metal wall? What are the boundary conditions between the warm fluid on the right and the metal wall? You need to define a coordinate system to answer this question.
    B. Repeat part A for the sketch in Figure 4.3-3 on page 249
11. An oven wall ($1.0\ cm$ thick, tall and wide) made of material with thermal conductivity $0.151\ W/mK$ separates the outside air ($25^o C$) and the air inside the oven ($95^o C$).
        a. If the heat transfer coefficients both inside and outside the oven are very large, what is the heat flux through the oven wall?
        b. If the wall is insulated on the outside with $3.0\ cm$ thickness of material of thermal conductivity $0.0433\ \mathrm{W/mK}$, what is the new flux through the wall (the heat transfer coefficients and air temperatures may be assumed to stay the same as in part a).
12. A solid metal wall of thickness $15\ cm$ (thermal conductivity $= 0.040\ W/mK$) is lined with a $17\ cm$ thick piece of insulation (thermal conductivity $= 0.157\ W/mK$). The wall stands between the hot outdoor temperature ($42^o C$, insulation side) and the ambient indoor temperature ($22.0^o C$, metal side). What is the temperature at the plane where the insulation and the wall meet, that is, inside the wall where the metal meets insulation? You may assume that the heat-transfer coefficient on both sides of the compound wall is infinite. Answer: $37.5^o C$.
13. (stretch) A hydrocarbon oil flows rapidly (turbulent flow) on the inside of a counter-current double pipe heat exchanger (see figure). Steam in the outer region of the heat exchanger condenses at $95^o C$ on the outside of the pipe, for the pipe's entire length (steel pipe, inner diameter $=$ $2.067\ in$; outer diameter $= 2.375\ in$, length $= 6.0\ ft$). In a region near the middle of the heat exchanger, we measure the bulk temperature of the oil to be $79^o C$. In the middle region of the heat exchanger:
        a. What is the approximate value of the heat flux q_r/A into the oil? Give a range based on typical high and low values of heat transfer coefficient (see table in Geankoplis, p241).
        b. What is the resistance to heat flow due to the thermal conductivity of the pipe?
        c. What is the resistance to heat flow on the steam side? Give a range.
        d. What is the resistance to heat flow on the oil side? Give a range.
        e. Discuss what you see. Which resistance dominates? On which heat-transfer quantity would you spend greater resources (time, money, effort) in order to obtain with accuracy? Explain.



14. For the middle region of the heat exchanger described and operating as in the problem above, we determine that the steam side heat transfer coefficient to the pipe is $8{,}000\ W/m^2K$ and the oil-side heat transfer coefficient to the pipe is $1200\ W/m^2K$.

   a. What is the heat flux q_r/A into the oil?
   b. Describe how changing the pipe material of construction from steel to aluminum would affect the flux observed.

15. Problem J: Air flows through a tube ($25.4\ mm$ inside diameter, long tube) at $7.62\ m/s$. Steam condenses on the outside of the tube such that the inside surface temperature of the tube is $488.7\ K$. If the air pressure is $206.8\ kPa$ (ideal gas) and the mean bulk temperature of the air is $(\mathrm{T_{out}} + \mathrm{T_{in}})/2 = 477.6\ K$, what is the heat transfer coefficient (in units of W/m^2K) from the pipe wall to the air? Answer: $63.4 \frac{W}{m^2K}$. Using the heat transfer coefficient, what information do we need to calculate the total heat transferred in this problem?

16. Problem L: A horizontal pipe (Schedule 40, outer diameter 2.375 in; inner diameter 2.067 in; steel) connects two tanks in a pilot plant. The hot oil flowing in the tube heats the pipe to an outside surface temperature of $116^{\circ}\mathrm{C}$. A fan blows across the pipe, sending a steady flow of $15^{\circ}\mathrm{C}$ air (1.0 atm) across the tube at $12.0\ \mathrm{m/s}$. What is the heat loss ($\mathrm{kW/m^2}$) from the pipe?

17. Problem N (stretch; same as HW6.15) Between these two correlations for heat transfer coefficient h, which would you use in the circumstance described below? Why and with what conditions? Calculate the total heat transferred and the exit temperature.
   a. $Nu_a = \frac{h_a D}{k} = 1.86 \left(RePr \frac{D}{L}\right)^{\frac{1}{3}} \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$
   b. $\mathrm{Nu}_{lm} = \frac{h_{lm} D}{k} = 0.027 \mathrm{Re}^{0.8} \mathrm{Pr}^{\frac{1}{3}} \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$

   We plan to heat a fluid (material properties given below) by sending it through the inside pipe of a double pipe heat exchanger (inner pipe dimensions: nominal 2-in Schedule 40 steel pipe, inner radius $0.02625\ m$; outer radius 0.03016, length $= 1.6\ m$) with condensing steam flowing on the outside; due to the condensing steam, the inside surface temperature of the inner pipe is maintained constant at $95^{o}C$ along the entire length of the pipe. The fluid enters at $13^{o}C$ at a mass flow rate of $3.2\ kg/s$. We do not know what the exit temperature will be.
   The fluid's material properties, which do not vary significantly with temperature, are:
   density = $1022\ kg/m^3$
   heat capacity = $4.3\ kJ/kgK$
   thermal conductivity = $0.605\ W/mK$
   viscosity = $8.3 \times 10^{-4}\ Pa\ s$)

18. Create a summary list of all the correlations for heat transfer coefficient given in your text. See lecture notes for an example.
19. Geankoplis 4.5-6. A hydrocarbon oil having the same physical properties as the oil in Example 4.5-5 enters at 175^{o}F inside a pipe having an inside diameter of $0.0303 ft$ and a length of $15 ft$. The inside pipe surface temperature is constant at $325^{o}F$. The oil is to be heated to $250^{o}F$ in the pipe. How many lb_m/h oil can be heated (hint: trial and error solution; first flow rate guess suggested is $\dot{m} = 75 lb_m/h$). Answer $84 lb_m/h$

Notes:

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15. We need to be able to calculate the log mean temperature driving force since that is the driving force used by Seider and Tate in the data correlation we use. Can you calculate it if I give you $T_{in} = 471.8K$ and $T_{out} = 483.4K$? How long is the pipe? Answers: $q = 69.4W,\ 1.37m$
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