Michigan Tech
CM3110 Morrison HW 5

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5	3	double-pipe heat exchanger	4.5-4	
5	4	change to 1-2 shell-and-tube heat exchanger	4.5-4, modified, see attached	
5	5	heat exchanger design	see attached, parts a,b	see attached, parts c-f
5	6	double pipe HE effectiveness	see attached	
5	7	heat transfer from hot pipe including radiation	4.10-3	
5	8	heat transfer from hot flat surface	see attached	
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1. Geankoplis 4.7-1 The oven wall in Example 4.7-1 is insulated so that the surface temperature is $366.5K$ instead of $505.4K$. Calculate the natural convection heat transfer coefficient and the heat transfer rate per meter of width. Us both the full and simplified equations. Note that radiation is being neglected in this calculation.
2. Geankoplis 4.7-3. A horizontal tube carrying hot water has a surface temperature of $355.4K$ and an outside diameter of $25.4mm$. The tube is exposed to room air at $294.3K$. What is the natural convection heat loss for a one meter length of pipe?
3. Geankoplis 4.5-4: (assume double-pipe heat exchanger; note Geankoplis' use of an improbable number of sig figs)
4. Geankoplis 4.5-4, except with 1-2 shell-and-tube heat exchanger: $T_1' = 299.5^oC, A = 97m^2$. How does the 1-2 shell-and-tube compare to the double pipe?
5. You are asked to design a counter-current double-pipe heat exchanger capable of raising the temperature of water from 17^oC to 45^oC (flow rate of water is 3.5 gpm). In the outside chamber of the heat exchanger will be saturated steam (pressure= $84.55\ kPa$), condensing on the outside wall of the inner pipe, through which the water flows.
    a. How much heat (kW) needs to be removed at steady state to achieve the desired temperature change?
    b. What is the average driving force for heat transfer for this heat exchanger?
    c. The inner pipe is to be 2-inch schedule 40 steel pipe (inner diameter= $2.067\ in$, outer diameter $2R_o = 2.375\ in$). What is a good design estimate for the performance of a double-pipe heat exchanger using this pipe? I am asking you to calculate the expected overall heat transfer coefficient U_o (based on the outer diameter $2R_o$) for a device with the stated pipe on the inside. You will need to construct your answer from steam-side (h_2) and water-side (h_1) heat transfer coefficients obtained from data correlations associated with the appropriate heat-transfer physics (forced convection? natural convection? radiation? condensing vapor? other?). We desire the length of the heat exchanger to be no more than $1.8\ m$. *(HINT: The steam-side heat transfer coefficient is most easily found using a correlation in Perry's (section on heat transfer with change of phase; Perry's section on thermal design of heat transfer equipment has some typical values of U to check your work.))*
6. Water flowing at a rate of $0.723\ kg/s$ enters the inside of a countercurrent, double-pipe heat exchanger at $300.\ K$ and is heated by an oil stream that enters at $385K$ at a rate of $3.2\ kg/s$. The heat capacity of the oil is $1.89 kJ/kg\ K$ and the average heat capacity of water over the temperature range of interest is $4.192\ kJ/kgK$. The overall heat-transfer coefficient of the exchanger is $3.0 \times 10^2\ W/m^2K$, and the area for heat transfer is $15.4\ m^2$. What is the total amount of heat transferred? *Answer*: 175kW.
7. Geankoplis 4.10-3. A horizontal oxidized steel pipe carrying steam and having an OD of $0.1683m$ has a surface temperature of $374.9K$ and is exposed to air at $297.1K$ in a

large enclosure. Calculate the heat loss for $0.305m$ of pipe from natural convection plus radiation. For the steel pipe use an emissivity of 0.70.

8. A horizontal heated plate of dimensions 1.0 by$1.0\ m$ is heated to 50^oC. The air over the plate is at a temperature of 25.0^oC. What is the total heat flux from the plate to a body that is the same temperature as the air? The emissivity of the plate is 0.89. What mechanism dominates heat transfer (if any)?
9. Geankoplis 4.11-1, section c) added. Two very large and parallel plates each have an emissivity of 0.7. Surface 1 is at $866.5K$ and surface 2 is at $588.8K$.
   a. What is the net radiation loss of surface 1?
   b. To reduce this loss, two additional radiation shields also having an emissivity of 0.7 are placed in between the original surfaces. What is the new radiation loss?
   c. How many radiation shields would be needed to drop the radiation loss to $3500\ W/m^2$? Answers:
      a. $40{,}000\frac{W}{m^2}$
      b. $4500\frac{W}{m^2}$
      c. Add 1 more radiation shield
10. Geankoplis 4.7-8: Two horizontal metal plates having dimensions of $0.8 \times 1.0m$ comprise the top of a furnace and are separated by a distance of $15mm$. The lower plate is at $400.^o\ C$ and the upper at $100.^o\ C$, and the air at atmospheric pressure is enclosed in the gap. Calculate the heat transfer rate between the plates. We need to calculate radiation and natural convection contributions to the total. *Answers*: radiation contribution 5.5kW; natural convection contribution 1.3 kW; total 6.8 kW.
11. The liquid feed stream to a reactor needs to be preheated from 25^oC to at least 63^oC. The stream has a mean heat capacity of 6.5 kJ/kg^oC and the mass flow rate is $2.44\ kg/s$. There is a hot stream from a nearby process available to use in the outside of a double-pipe heat exchanger (counter current flow) to bring about the heating. The hot stream fluid is mostly water (average density $= 997kg/m^3$; mean heat capacity= $4.2kJ/kgK$; average viscosity=$9.2 \times 10^{-4}kg/ms$), and this stream is available at approximately 90^oC, flowing at $45\ gpm$ (gallons per minute). Three heat exchangers are available from your company's usual vendor (see table below). Make the appropriate calculations to determine which of the three (if any; there also may be more than one) would be appropriate for the job. Which heat exchanger(s) do you recommend? You must justify your selection with calculations.

Heat exchanger	$U\left(\frac{kW}{m^2K}\right)$	$A(m^2)$	Flow direction
A	300	0.080	counterflow
B	330	0.090	counterflow
C	500	0.095	counterflow

12. Fouling is a serious concern with heat exchangers. We wish to evaluate the magnitude of the likely fouling effect on a double-pipe heat exchanger with city water flowing on the outside and orange juice (a vaporizing liquid) on the inside.

a. For a double-pipe heat exchanger (inner pipe made of nominal 2-inch schedule 40 steel pipe) and assuming a logarithmic middle value for the likely values of heat transfer coefficients on the inside h_i and outside h_o (see Geankoplis Table 4.102, given in the answers to HW 5; "logarithmic middle" means half-way between values on a log scale), what is your estimate of the overall heat transfer coefficient? How does your value compare with typical values for U? (see Geankoplis Table 4.9-2). Base your overall heat transfer coefficient on the outside radius of the inner pipe, U_o.

b. After some amount of time in service, we expect that heat exchanger fouling will affect the amount of heat transferred in the heat exchanger. What is your estimate of the expected change in U due to the city water fouling on the outside of the heat exchanger? What is your estimate of the expected change in U due to the orange juice fouling (vaporizing liquid) on the inside of the heat exchanger? What would be the combined effect? Comment on your answers.

13. Between these three correlations for heat transfer coefficient h, which would you use in the circumstance described below? Why and with what conditions? Is radiation important? Calculate the total heat loss including radiation if necessary.

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. $\mathrm{Nu} = \frac{hL}{k} = aGr^m Pr^{\frac{1}{3}}$

c. $\mathrm{Nu} = \frac{hL}{k} = cRe^m Pr^{\frac{1}{3}}$

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* $116^o C$*. A fan blows across the pipe, sending a steady flow of* $15^o C$ *air (*$1.0\ atm$*) across the tube at* $12.0\ m/s$*. What is the heat loss (*kW/m^2*) from the pipe?*

14. Problem K: A wide, deep rectangular oven ($1.0\ ft$ tall) is used for baking loaves of bread. During the baking process the temperature of the air in the oven reaches a stable value of $100^o F$. The oven side-wall temperature is measured at this time to be a stable $450^o F$. Please estimate the *natural convection* heat flux from the wall per unit width. (The other contribution will be *radiation*, which is important.)