CHG 2314/3314

HEAT TRANSFER OPERATIONS

FINAL EXAMINATION

DATE: Wednesday, April 28, 2004, 2:00 p.m.

DURATION: 3 hours

PROFESSOR: Dr. B. Kruczek

1) Open textbook / class notes examination
2) The examination consists of two parts:
   PART A (40%) – Attempt 2 questions out of 3, each worth 20 marks.
   PART B (60%) – Attempt 2 questions out of 3, each worth 30 marks.
3) State clearly all assumptions.
4) It is strongly recommended to describe in words the outline of your solution.

Good luck!!!

Enjoy the Summer

Part A – 40% Attempt 2 of the following 3 questions. Each question is worth 20 marks.

A1. A thermocouple, which is initially at 20°C, is inserted in a stream of hot gas at T_e. After 3 seconds the thermocouple reads 80°C while after 6 seconds it reads 110°C. Assuming applicability of the lumped thermal capacity model, estimate the temperature of the hot gas. What would be the temperature of the thermocouple after 10 seconds in the hot gas stream?

Please note that, $a \ln x = \ln x^a$

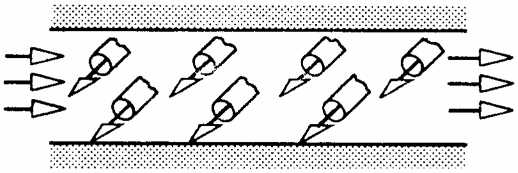
A.2 A saturated low-pressure steam flows through two thin-walled pipes of diameters D_A = 5 cm and D_B = 8 cm, respectively, made from the same material. The pipes are in a location where they are exposed to a cross flow of cold air. Assuming negligible radiation effects and applicability of Hilpert correlation, i.e.,

$$\overline{Nu}_D = C \,\mathrm{Re}_D^m \,\mathrm{Pr}^{1/3}$$

where C = 0.193 and m = 0.618, determine the ratio of heat loss from pipe A to that from pipe B, i.e., $\dot{Q}_A/\dot{Q}_B$. Discuss qualitatively how would this ratio change if the radiation losses were included?

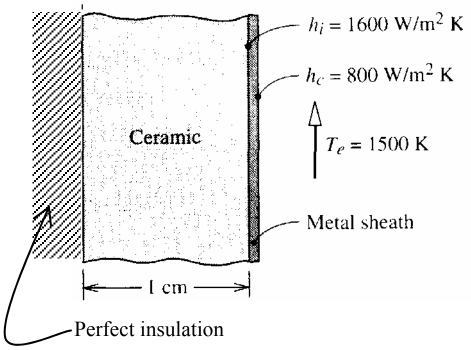
A3. A single-pass cross flow heat exchanger, shown below, is utilized to cool an oil stream at $T_{H,in}$ = 105°C using a water stream at $T_{C,in}$ = 5°C. The mass flow rates of the oil and water streams are, $\dot{m}_H$ = 5 kg/s and $\dot{m}_C$ = 8 kg/s, respectively. The oil stream flows through the tubes while the water stream flows through the shell of the exchanger. The total surface area for heat transfer in the exchanger is 150 m^2. The specific heats of oil and water are c_{pH} = 2180 J/kg K and c_{pC} = 4180 J/kg K, respectively.

i) Assuming an infinitely large overall heat transfer coefficient (U) in the exchanger, determine the minimum outlet temperature of the oil stream ($T_{H,out}$).
ii) Estimate the actual overall heat transfer coefficient if the outlet temperature of the oil stream is 10°C greater than the minimum $T_{H,out}$.



Part B – 60% Attempt 2 of the following 3 questions. Each question is worth 30 marks.

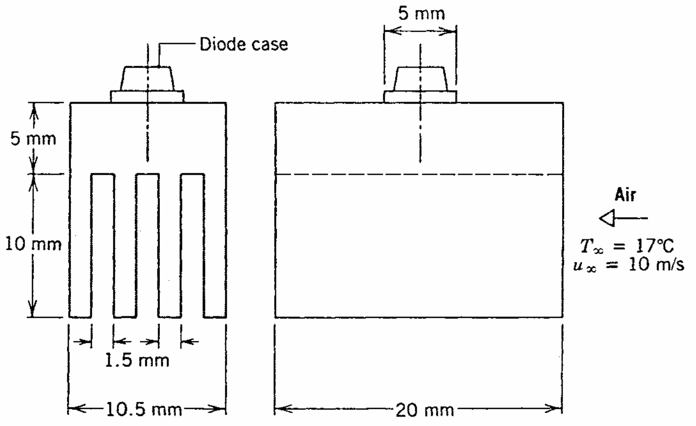
B1. A 1 cm-thick ceramic slab has a thin metal sheath for protection on one side and is perfectly insulated on the other side. The contact resistance between the ceramic and metal gives an interfacial conductance of 1600 W/m^2 K. The slab is initially at 300 K and is suddenly exposed to a hot air stream at 1500 K with a convective heat transfer coefficient of 800 W/m^2 K. Determine the temperatures of the metal sheath, ceramic–metal sheath interface, and ceramic-insulation interface after a 2 minute-exposure to hot gases.



The insulation melts at 1120 K. Would the insulation melt if after 2 minutes the flow of hot gases were stopped and the convective heat transfer coefficient become zero?

The ceramic properties are: $\rho = 2600$ kg/m^3, $c = 1150$ J/kg K, $k = 3.0$ W/m K.

B2. It is proposed to cool a power diode dissipating 5 W using a heat sink shown on the figure below. The heat sink is constructed from aluminum (k_{Al} = 177 W/m K) and the contact resistance between the diode case and the heat sink is 10^{-5} m^2 K/W. For the proper operation of the diode, its temperature cannot exceed 60°C. Can this requirement be fulfilled using the proposed heat sink?



In these preliminary calculations consider "the worst case scenario", that is, neglect radiation effects and assume that diode power will be dissipated through the four rectangular fins only. Also treat the fins as those with negligible heat transfer from the tip. Why the above specifications represent "the worst case scenario"?

Convection at the fin surface may be approximated as that corresponding to a flat plate in parallel flow. For the determination of heat transfer coefficient use the following air properties, k = 0.0274 W/m K, ν = 16.54 x 10^{-6} m^2/s, Pr = 0.69

B3. The water line has been brought into a cottage in an unfortunate manner, which exposes a part of the pipe to the cold winter blasts passing underneath the cottage. The water pipe was heavily insulated, however the insulation was torn off by a very strong wind, leaving 1.5 m of the pipe completely not insulated. The owner of the cottage realized the problem immediately. However, he could not drain the water from the pipe, and therefore, he decided to allow the water to run until he finds a suitable material and re-insulates the pipe. Unfortunately, the water pump was not in a good shape and the maximum flow rate at which it could deliver the water was 1 liter per minute, and the owner worried that the water might freeze in the pipe. Considering the data below, were the worries of the owner justified?

Outside air temperature: -20°C
Wind velocity: 50 km/h
Inside pipe diameter: 4.4 cm
Outside pipe diameter: 5.0 cm
Thermal conductivity of pipe: 14 W/m K
Temperature of water entering the exposed part of the pipe: 4°C
Properties of water: k_w = 0.556 W/m K, ρ_w = 1000 kg/m^3, μ_w = 17 x 10^{-4} kg/m s, c_{pw} = 4217 J/kg K, Pr_w = 12.9
Properties of air: k_a = 0.0242 W/m K, ν_a = 12.23 x 10^{-6} m^2/s, Pr_a = 0.69

N.B: Assume negligible entrance and variable property effects.