University of New Mexico
Mechanical Engineering
Fall 2010 PhD qualifying examination
Heat Transfer

Closed book. Formula sheet and calculator are allowed, but not cell phones, computers or any other wireless device.
Time allowed: 150 minutes.

Part 1: General knowledge questions (25 points)

1. Sometimes, your bare hand will feel "colder" when immersed in water at 5 °C than when exposed to air at -10 °C. Why?

   (a) Because your hand gets wet in water

   (b) The convection coefficient in water is much higher than in air, and as a result heat is removed from your hand at a much faster rate than in air

   (c) This is just a physiological reaction due to pores on your skin closing in water

   Answer:

2. Birds "fluff" their feathers while perching in cold weather because:

   (a) They tend to preen more in the winter because there is less to do

   (b) Feathers standing on end provide a thicker layer of still air with better insulating properties

   (c) they are trying to deter predators by looking bigger

   Answer:

3. The convection coefficient associated with nucleation boiling is much higher than with other convection processes because:

   (a) The temperature difference between the surface and the boiling fluid is very high

   (b) The phase change process absorbs a lot of energy at a fixed temperature

   (c) The phase change process, which absorbs a great deal of energy, is combined with vigorous stirring due to bubble formation and detachment

   Answer:

4. Weather reporters often cite temperatures associated with a "wind chill" factor. This can be explained as:

   (a) The temperature in still air which would produce the same amount of heat loss as in the windy condition

   (b) The difference between the wet and dry bulb temperatures in humid air

   (c) The actual air temperature due to cold winds from the Arctic

   Answer:

5. Certain frypans have a thick metal handle rather than a wooden one. This is because:

   (a) A thick metal handle dissipates heat better and is therefore cooler

   (b) The frypan can be placed directly in the oven

   (c) The frypan is better balanced

   Answer:

6. Solar swimming pool heaters are often unglazed. This is because:

   (a) The temperature difference between the water temperature and the ambient temperature is low and convective heat loss is small anyway

   (b) Glazing reflects much of the incoming solar radiation

   (c) Glass is dangerous around a pool area

   Answer:

7. Fins in most naturally convecting heat sinks for electronic devices are spaced about 7 mm apart, while fin spacing in heat sinks designed for forced convection varies greatly. This is because:

   (a) There is only one large manufacturer of extrusions used in naturally convecting fins

   (b) The optimum fin spacing is approximately 7 mm for natural convection at temperatures encountered in cooling of electronic devices

   (c) In forced convection optimum spacing is not critical, so manufacturers just use whatever fins are cheapest

   Answer:

8. In a process where heat is removed by nucleate boiling, it is generally important to make sure that the critical heat flux is not exceeded. This is because:

   (a) if critical flux is exceeded, the boiling process could become unstable and create excessive vibration on the system

   (b) Exceeding the critical flux may result in a reduction in the temperature, leading to reduced heat transfer

   (c) Exceeding the critical heat flux results in an almost instantaneous very large increase in temperature

   Answer:

9. A selective radiating surface is one which:

   (a) Has different emissivity and absorptivity depending on the temperature

   (b) Has different emissivity and absorptivity depending on the wavelength

   (c) Has an emissivity which is different from its absorptivity at a given wavelength

   Answer:

10. Many thermally radiating / absorbing surfaces are dimpled or grooved. This is because:

    (a) The surface resistance is reduced

    (b) The configuration resistance is reduced

    (c) There is no heat transfer benefit, this is just done to enhance material stiffness

Part 2: Problems (25 points per question)
Attempt all problems in this section, clearly stating any assumptions and simplifications used in your solution.

Problem 1

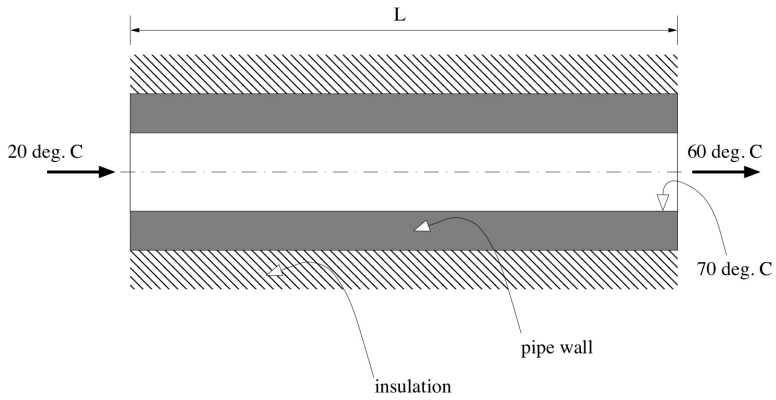
At the ribbon-cutting ceremony for the Trans-Alaska oil pipeline, the governor of Alaska cranked open a huge valve to initiate oil flow to the South. The pipeline is made of steel, and has a 1 m diameter, with a wall thickness of 40 mm, and heavy insulation on the outside. Before oil flow, the pipe was at a uniform temperature of -20 °C. Hot oil at 60 °C, rushing through the pipe, creates a convective condition corresponding to a convection coefficient of 500 $W/m^2 \cdot K$ at the inner pipe surface. As a pipeline engineer, your task is to perform calculations to determine thermal stresses in the pipe wall. Given that for steel the density ρ is 7823 kg/m^3, the heat capacity C is 434 J/kg·K, and the thermal diffusivity α is 18.8×10^{-6}, calculate:

1. The relevant Biot and Fourier numbers 8 minutes after the valve opening;
2. The temperature at the pipe wall - insulation interface, immediately after the valve is opened and after 8 minutes;
3. The heat flux from the pipe to the oil 8 minutes after the valve is opened.

State any simplifying assumptions.

Hint: consider the equivalent, symmetric condition of a plate with convection on both faces

Problem 2

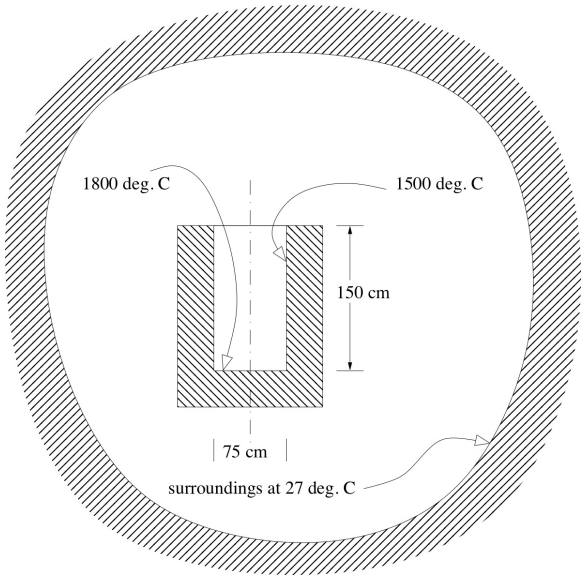


A system for heating water from an inlet temperature of 20 °C to an outlet temperature of 60 °C involves passing the water through a thick-walled tube of inner and outer diameters of 20 mm and 40 mm respectively. The outer wall is heavily insulated, while the tube wall is heated electrically, with a heat generation of 10^6 W/m^3. Calculate:

1. The length L of tube required to achieve the desired outlet temperature for a flow rate is 0.1 kg/s;
2. The local heat transfer coefficient at the outlet if the inner surface temperature is 70 °C.

The heat capacity of water is 4180 J/kg·K.

Problem 3



A large furnace cavity is in the form of a hollow cylinder with diameter of 75 cm and depth of 150 cm. It is open at one end to surroundings at 27 °C. The sides and bottom of the furnace, which can be approximated as blackbodies and are well-insulated, are heated electrically and maintained at temperatures of 1500 °C and 1800 °C respectively. Calculate:

1. The view factor from the bottom of the furnace to the opening;
2. The view factor from the sides of the furnace to the opening;
3. The total heater power needed to maintain the furnace wall temperatures.