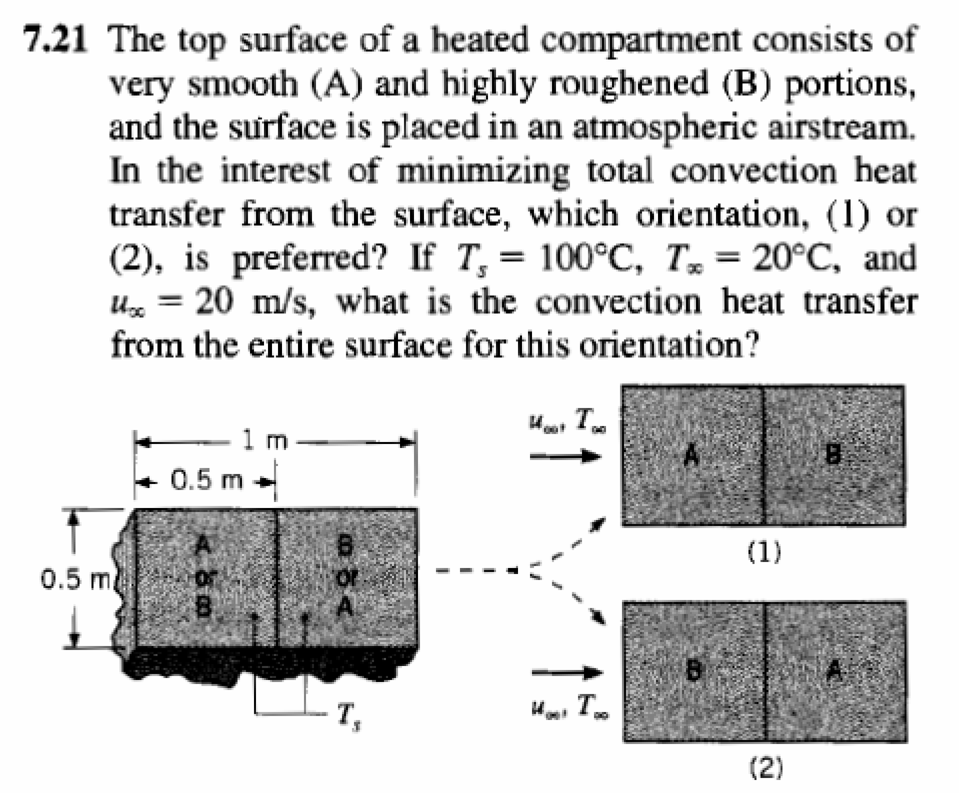
Franklin W. Olin College of Engineering
ENGR 3310: Transport Phenomena

Problem Set 9

Assigned: 11/18/04 Fall 2004
Due: 12/2/04 by 5:00 pm

Problem 1 (from Incropera and DeWitt)



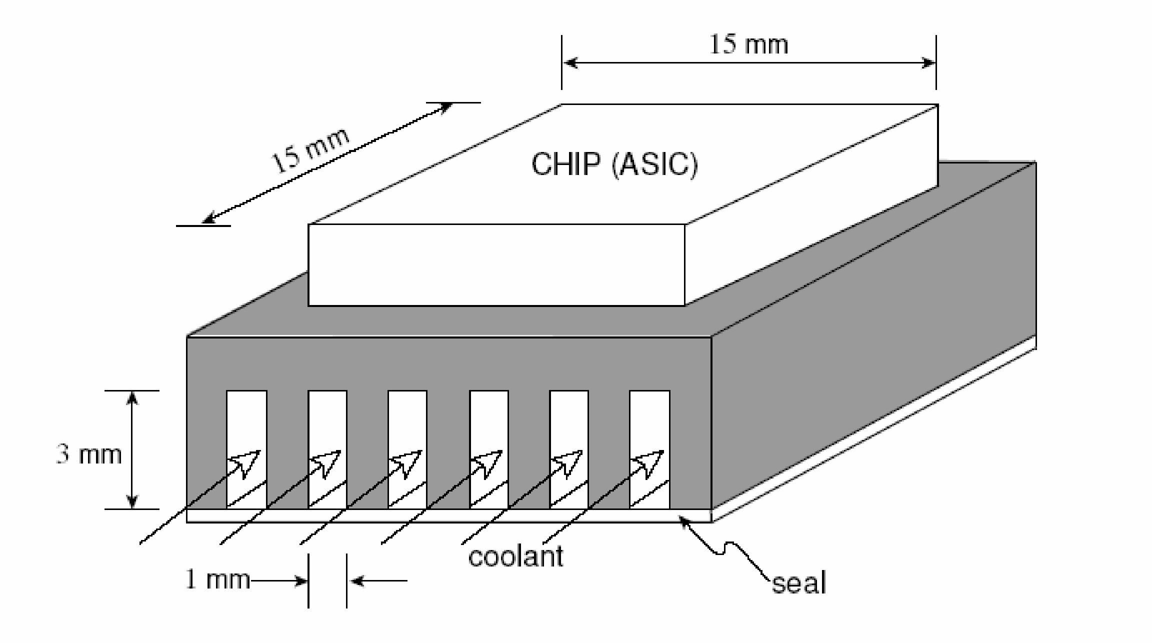
7.21 The top surface of a heated compartment consists of very smooth (A) and highly roughened (B) portions, and the surface is placed in an atmospheric airstream. In the interest of minimizing total convection heat transfer from the surface, which orientation, (1) or (2), is preferred? If $T_s = 100°C$, $T_\infty = 20°C$, and $u_\infty = 20$ m/s, what is the convection heat transfer from the entire surface for this orientation?

Problem 2
Consider a 10 meter length of pipe with an inner diameter of 2 cm. Find the average heat transfer coefficient and the bulk outlet temperature when the tube wall is at a constant temperature of 320 K and the fluid enters at $T_{b,i} = 300$ K, 1 atm pressure and flows at a velocity of 3 m/s. Consider three cases for the fluid: mercury, air, and water. Which fluid has the highest heat capacity?

Problem 3
A 1 meter high double-glazed window has an air gap of 1 cm. In a test the facing glass surfaces were measured to be at 14.2 and -10.6 °C. Calculate the convective heat transfer across the gap. (Hint: the correlation you need is provided in the MIT table I handed out in class.)

Problem 4
Convective heat transfer from next generation microchips
This is a good summary of all the work on convective heat transfer we've covered.

A microchannel heat sink is a device for cooling discrete electronic devices such as large ASIC (application specific integrated circuits). The very small length scales of the devices means that high heat transfer rates can be achieved. A liquid coolant is pumped through the narrow fluid channels and removes the power dissipated by the electronic chip sitting above the heat sink.



(a) For the configuration shown above the device dissipates 75 W. A liquid coolant with $c_p = 4$ kJ/kg_K; viscosity $\mu = 1.00 \times 10{-}3$ Pa s; density $\rho = 1000$ kg/m^3 is available from a micropump which can deliver a maximum flow rate of 0.005 kg/s. You can assume that this is divided by the manifold so that an equal mass flow rate flows down each of the six microchannels. Compute the hydraulic diameter, D_H, of a single channel and use an appropriate correlation to find the friction factor and thus the pressure drop that must be generated by the pump to achieve the maximum flow rate.

(b) For the mass flow rate of 0.005 kg/s what is the bulk temperature of the water at the outlet of the microchannels. Sketch the evolution of the temperature profile in the mircochannel walls (T_W) and the bulk temperature in each channel. Since the microchannel walls are typically aluminum or silicon (both highly conductive) you can start by ignoring resistance from thermal conduction in the walls, and assume that the heat flux from the device is uniformly distributed around the microchannels. What is the maximum temperature attained by the electronic chip?

(c) Show that your initial assumption in (b) that thermal gradients in the solid walls of the device could be ignored is a good one by reporting the value of an appropriate dimensionless group characterizing irreversibilities arising from heat transfer through the solid.

(d) If the pump circulating the fluid fails, then the only way left of cooling the device is through natural convection from the top surface. A convective plume will form in the air above the chip surface as it is heated. If the device continues to dissipate 75 W use the information given below to estimate how hot the device will get. You may assume that the surface reaches a spatially uniform temperture (T_s) and that the air above the chip is at temperature $T_\infty = 20$ °C. For convenience you may use the properties of air at 20 °C ($\mu = 1.8 \times 10{-}5$ Pa s, $\rho = 1.22$ kg/m^3, $k = 0.0255$ W/mK, $c_p = 1005$ J/kg K) even though you of course realize that in general you should evaluate the thermal properties at an (a priori unknown) average temperature $T = (T_\infty + T_s)/2$.

Do you think this is a feasible temperature at which to operate the device?

For natural convection above a heated horizontal flat plate with characteristic length scale L = A/P where A is the surface area and P is the plate perimeter:

$$Nu_L = 0.59 Ra_L^{1/4} \qquad 1 \le Ra_L \le 10^7$$

$$Nu_L = 0.15 Ra_L^{1/3} \qquad 10^7 \le Ra_L \le 10^{11}$$

Problem 5

Water boils at 5 atm pressure on a 0.8 mm diameter platinum rod heater. Determine

a) the superheat (ΔT) required for boiling inception on 7.5 μm radius nucleation sites
b) the critical heat flux (CHF)
c) the rod temperature when the heat transfer is 50% of the CHF