MIE 354 - Heat Transfer
Professor Rothstein
Final Exam
May 17, 2003

You will have 2 hours to complete the following 3 problems. The problems are given equal weight (10 points each) so make sure to use your time wisely. Please write carefully and clearly and make sure that you justify any assumption that you make. The exam is open book and open notes. Don't forget print your name at the top of this page. Good luck.

1. Fast Food Heater

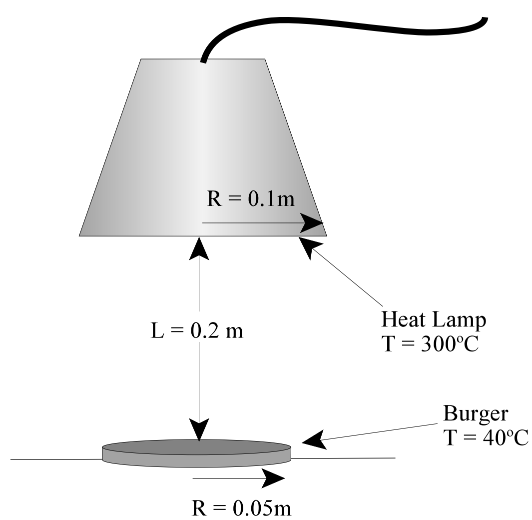
A heat lamp is often used in fast food restaurants to keep food warm after it has been prepared. Consider the heat lamp and the burger in the schematic diagram below as coaxial parallel disks spaced $L = 0.2$m apart and having radii of $R_{lamp} = 0.10$m and $R_{burger} = 0.05$m.

a) What is the view factor from the lamp to the burger, F_{LB}?

b) If you treat both the lamp and the burger as black bodies with temperatures of $T_{lamp} = 300°C$ and $T_{burger} = 40°C$ what will be the total heat transfer rate from lamp to the burger.

c) If you now assume that the burger has a thermal emissivity of $\varepsilon_{burger} = 0.5$ and the lamp is a black body, what will be the heat transfer rate to the burger? You might want to start by drawing the equivalent resistance diagram.

d) If natural convection from the burger in part (b) results in a loses $q_{conv} = 15$ W, what temperature would the heat lamp need to be to keep the burger stable at $T_{burger} = 40°C$? If you cannot change the temperature of the lamp describe some other ways you might be able to keep the burger temperature at $T_{burger} = 40°C$.



2. Alaskan Pipeline

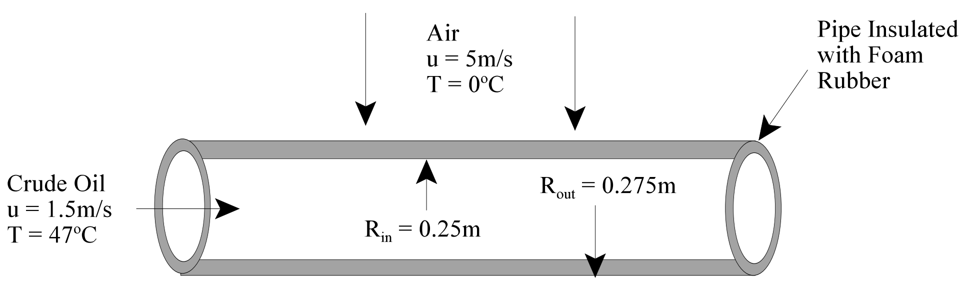
The oil in the Alaskan pipeline is routinely heated before it is pumped to reduce its viscosity and therefore the expense of pumping it through several hundred kilometers of pipeline. We are interested in determining the rate of heat lost by the crude oil. The schematic diagram below shows a section of the pipeline. The crude oil is pumped through the pipe at a mean bulk temperature of T_{oil} = 47°C and an average velocity of u_{oil} = 1.5m/s. The pipe wall is very thin an can be neglected in your analysis. The pipe is insulated with a foam rubber shell having an inner diameter of D_{in} = 0.5m and an outer diameter of D_{out} = 0.55m. Outside the pipe, a gentle breeze blows cold air past the pipeline having a temperature of T_{air} = 0°C and a velocity of u_{air} = 5m/s.

a) To determine the heat transfer rate from the oil to the air first draw the equivalent resistance network diagram. Clearly label each node and thermal resistance.

b) Evaluate each of the thermal resistances. You can assume that the flow within the pipe is fully developed.

c) What is the heat transfer rate per unit length of pipe lost from the crude oil to the air?

d) What will be the temperature of the outer surface of the pipeline? Will it be hot enough to injure wildlife such as birds or elk that might come in contact with it?



Properties of Foam Rubber	Properties Crude Oil @ 47°C	Properties of Air @ 0°C
k = 0.03 W/mK	ρ = 871 kg/m^3	ρ = 1.28 kg/m^3
	c = 1993 J/kgK	c = 1007 J/kgK
	k = 0.143 W/mK	k = 0.024 W/mK
	μ = 0.141 Ns/m^2	μ = 1.72x10^{-5} Ns/m^2
	Pr = 1965	Pr = 0.714

3. Vapor Deposition of a Mercury Solution

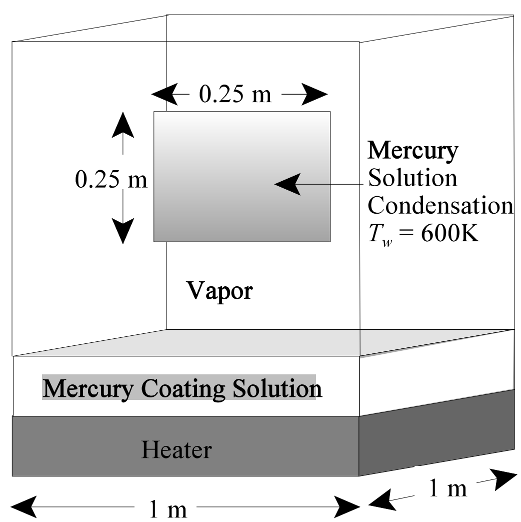
Mercury coatings are often used on the inside of fluorescent light bulbs to block out harmful ultraviolet radiation. In order to coat the inside of the light bulbs, a vapor deposition process is used. In the schematic below a simplified deposition process is shown. A mercury coating solution is placed in a sealed environmental chamber and boiled by a heater having physical dimensions of 1m x 1m. The light bulb is approximated by a vertical flat plate 0.25m x 0.25m. The saturation temperature of the mercury solution is $T_{sat} = 630$K and the temperature of the light bulb is held fixed at $T_w = 600$K. To produce an even coating, the process is designed so that the condensation is within the laminar regime.

a) What is the maximum condensation rate that can be achieved if the film is to remain laminar?

b) What is the rate of heat transfer to the light bulb?

c) Determine the surface temperature of the heater needed to run this coating process.

d) At what percent of the critical maximum heat flux is the heater operating?



<u>Properties Mercury Coating Solution</u>
$T_{sat} = 630$ K
$\rho_f = 12000$ kg/m^3
$\rho_g = 3.9$ kg/m^3
$\sigma = 0.42$ N/m (surface tension)
$k_f = 11.4$ W/mK
$\mu_f = 9.5\text{x}10^{-2}$ Ns/m^2
$c_f = 135$ J/kgK
$h_{fg} = 295{,}000$ J/kg
$Pr = 1.12$

<u>Surface-Fluid Boiling Coefficients</u>
$C_{s,f} = 0.01$
$n = 1.7$