MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF MECHANICAL ENGINEERING
2.005 Thermal-Fluids Engineering I

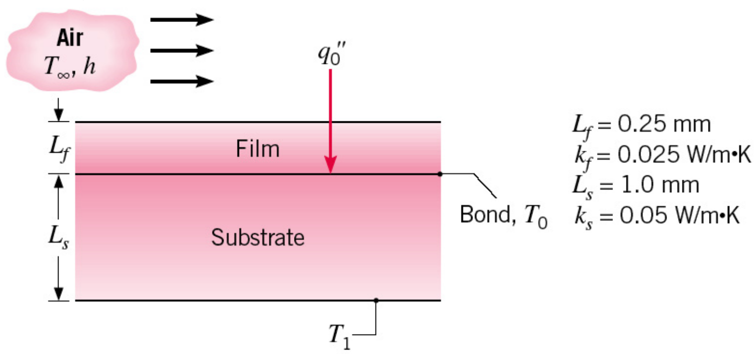
PROBLEM SET #5, Fall Term 2008
Issued: Thursday, October 2, 2008   Due: Thursday, October 9, 2008, 9:30am

Problem 0: Please read the course notes through chapter 6.5.

Problem 1 (C&S 7.8)
One kilogram of ideal gas with a constant volume specific heat c_v and gas constant R is initially at temperature T_1 and pressure P_1.

a) Please determine the maximum work transfer (ie. no dissipation) for this gas in expanding adiabatically to zero pressure.
b) Please determine the limit of the work transfer if this same gas at T_1 and P_1 were expanded isothermally to zero pressure.
c) Are the values calculated above different? If so, why?, If not, why not?

Problem 2 (I&D 3.4 mod)



In a manufacturing process, a transparent film is being bonded to a substrate as shown in the sketch. To cure the bond at a temperature T_o, a radiant source is used to provide a heat flux q_o'' (W/m^2), all of which is absorbed at the bonded surface. The back of the substrate is maintained at T_1, while the free surface of the film is exposed to air at T_∞ and a convection heat transfer coefficient h.

a) Develop a model thermal circuit representing the steady-state heat transfer situation. Label all elements, nodes, and heat rates. Leave in symbolic form.
b) Assume the following conditions: T_∞=20°C, h= 50 W/m^{2}K, T_1=30°C. Calculate the heat flux q_o'' that is required to maintain the bonded surface at T_o=60 °C.
c) Compute and plot the required heat flux as a function of the film thickness for $0 \leq L_f \leq 1$ mm
d) If the film is not transparent and all of the radiant heat flux is absorbed at its upper surface, determine the heat flux required to achieve bonding. Plot your results as a function of L_f for $0 \leq L_f \leq 1$ mm on the same plot as part c).
e) How does the heat flux vary with increasing film thickness for both cases? Explain why the heat flux with increasing film thickness is different in the two cases.

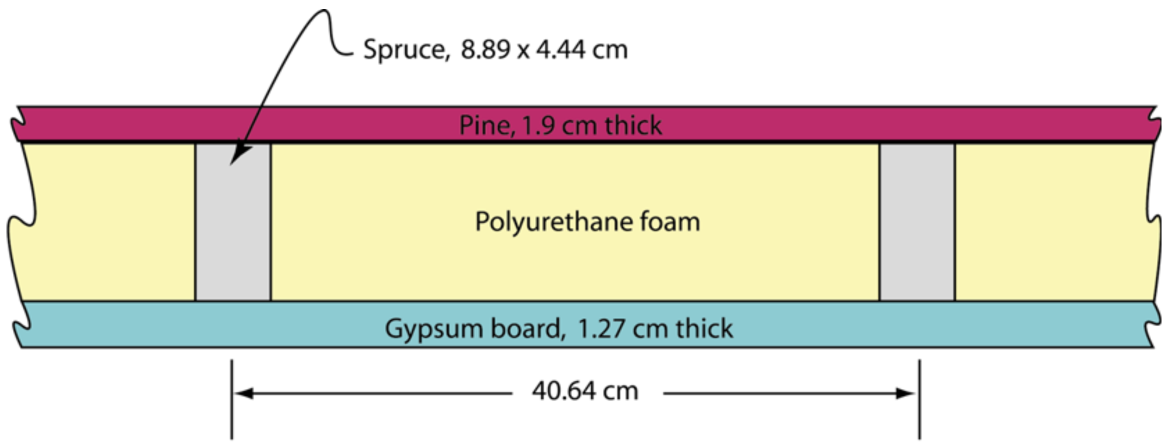
V2

Problem 3 (L&L 1.10 mod)

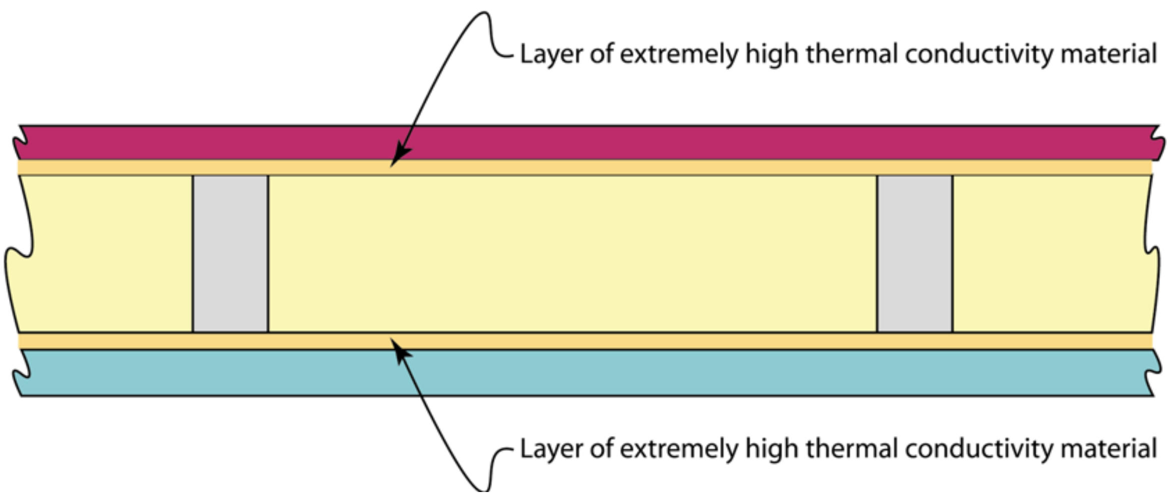
A glass (k=2 W/m K) truncated cone 8 cm high is used as a support in a given application. The top has a diameter of 5 cm and the bottom, a diameter of 3 cm. The lower surface is maintained at 5 C while the top is held at 75 C. The other surface of the cone is insulated. Please determine the heat transfer rate through the support. You may assume that the heat transfer is one dimensional.

Problem 4

a)



b)



A section of a standard wood framed wall that you might find in a house built here in New England in shown in figure "a" above. The combined convective and radiative heat transfer coefficient on the outside of the building (pine) is 10 W/m^{2}K and on the inside (gypsum) is 5 W/m^{2}K.

a) Please estimate the heat transfer rate through the wall per unit area when the outside temperature is –10 C and the inside temperature is 20 C.
b) What is the temperature of the spruce-pine interface?
c) What is the temperature of the foam-pine interface?

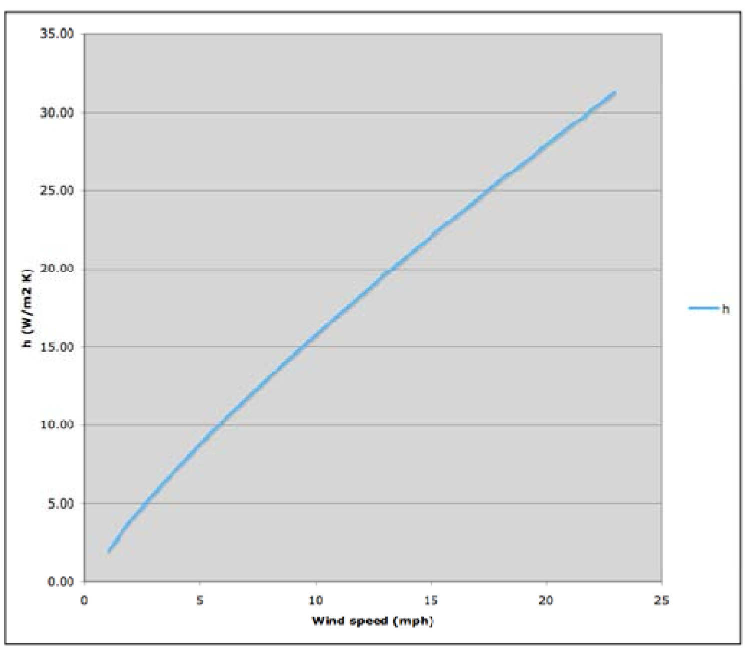
The lower diagram is a wall built in the house of an individual that is concerned over the existence of mind-control radio waves that are incident from space and from Washington. To mitigate these obvious threats, sheets of high conductivity copper have been placed in all the walls of his house, as shown above in figure "b" to provide a Faraday Cage-like effect. We will presume in our analysis that the copper has effectively infinite thermal conductivity.

d) Assuming all dimension (other than that of the copper) are the same as in figure "a", please estimate the heat transfer rate through the walls of our concerned citizen's house when the outside temperature is –10 C and the inside temperature is 20 C. How does this value compare to that of part a?
e) What is the temperature of the pine-copper interface?
f) Why is your answer in part d different from your result in part a?

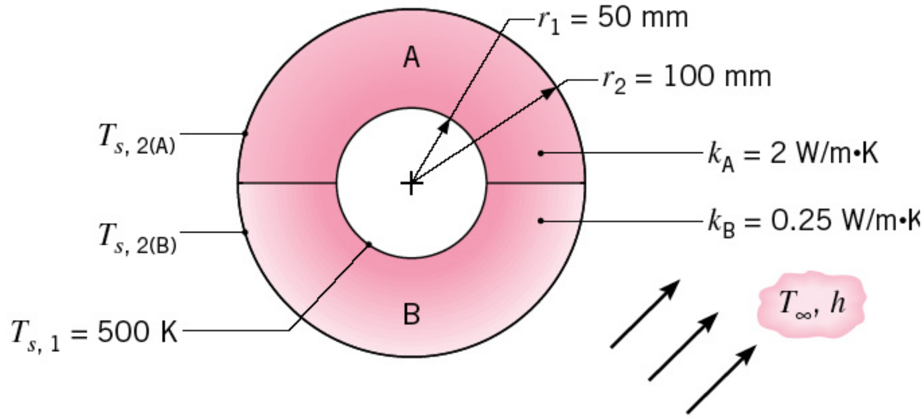
Material properties: assume k_{pine}=k_{spruce}= 0.21 W/m-K, k_{foam}=0.026 W/m-K, k_{gypsum}=0.17 W/m-K

Problem 5 (I&D 1.55 mod)
The roof of a car in a parking lot absorbs solar radiant flux of 800 W/m^2, while the underside of the roof can be modeled as perfectly insulating. The convection coefficient between the roof and the ambient air is 12 W/m^{2}K

a) Neglecting radiation exchange with the surroundings, please calculate the temperature of the roof under steady state conditions if the ambient air temperature is 20 C.
b) For the same ambient air temperature, please calculate the temperature of the roof if its surface emissivity is 0.8.
c) The convection coefficient depends on the airflow conditions over the roof. An estimate of the average convective heat transfer coefficient as a function of wind speed is shown in the plot below. Please compute and plot the temperature of the roof as a function of wind speed.



Problem 6 (I&D 3.52)



Steam flowing through a long, thin-walled pipe maintains the pipe wall at a uniform temperature of 500 K. The pipe is covered with an insulation blanket comprised of two different materials, A and B. The interface between the two materials may be assumed to have an infinite contact resistance and the entire outer surface is exposed to air for which T_∞= 300 K and h= 25 W/m^{2}K.

a) Sketch the thermal circuit of the system. Label using the symbols given above all pertinent nodes and resistances.
b) For the prescribed conditions, what is the total heat loss from the pipe?
c) What are the outer surface temperatures $T_{s2(A)}$ and $T_{s2(B)}$?