2018 Heat Transfer Midterm Exam

Sunday April 29th, 2018
19:00 to 21:00

NO NOTES OR BOOKS; USE HEAT TRANSFER TABLES THAT WERE DISTRIBUTED; ANSWER ALL 4 QUESTIONS; ALL QUESTIONS HAVE EQUAL VALUE.

Question #1

After obtaining a Masters degree from Pusan National University, you are hired soon afterwards by the Pohang Iron and Steel Company (POSCO). Your first project consists of designing an oven to anneal steel. Annealing is a form of heat treatment which causes changes in the strength, hardness, and other properties of the material. The annealing process that POSCO wishes to perform consists of first heating the steel to a temperature of 780°C and then to cool the material slowly no faster than 22°C per hour. This rate of cooling must be maintained for 5 hours. To prevent the steel from cooling too rapidly, the temperature inside the oven must be carefully adjusted as a function of time. Knowing that the effective convective heat transfer coefficient (including radiation) inside the oven corresponds to $h = 20\ \text{W/m}^2\cdot^\circ\text{C}$, that the object to be annealed is a cube with each side measuring 20 cm, determine quantitately how the temperature of the air inside the oven should be varied as a function of time in order to anneal the material properly. Then, compare graphically the temperature of the air within the oven to the average temperature of the steel for the first five hours of the annealing process.

Question #2

Consider a 0.0245m-radius sphere made in yellow-pine wood initially at a temperature of 200°C. The sphere is cooled with cold air at a temperature of $T_\infty = 20^\circ\text{C}$ and a convective heat transfer coefficient $h = 3\ \text{W/m}^2\text{K}$. Knowing that after a time Δt, the sphere loses 13.114 kJ to the environment, do the following:

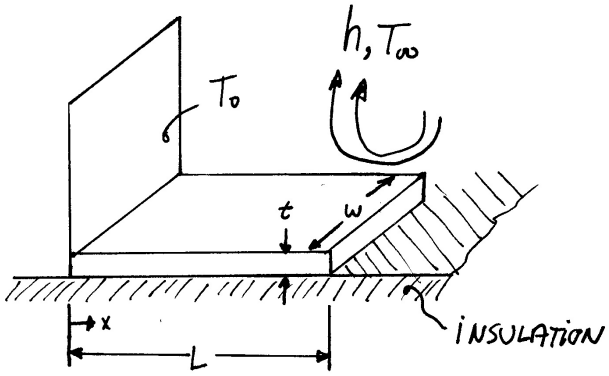
(a) Find the time elapsed, Δt, in seconds.

(b) At a time of $t = \Delta t$, find the center temperature of the sphere in Celcius.

(c) At a time of $t = \Delta t$, find the temperature on the surface of the sphere in Celcius.

Question #3

Consider a rectangular fin resting on a table as follows:



Knowing that the fin tip is **not** insulated, that $W \gg L$, and that there is no heat transfer between the fin and the table, do the following:

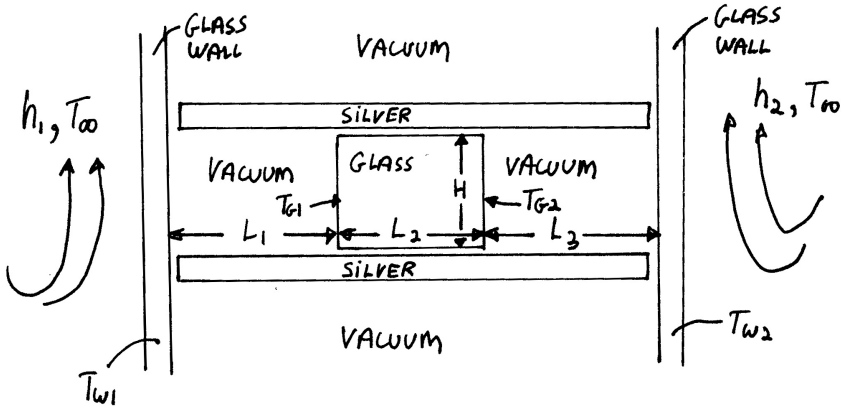
(a) Find the temperature at the fin tip (at $x = L$) as a function of T_0 and T_∞.

(b) Find the heat transfer at the fin base (at $x = 0$)

Note: you can **not** assume that the thickness t is much smaller than the length L. Outline all assumptions.

Question #4

Consider a block of glass surrounded by two silver plates and two glass walls as follows:



It is known that the distance between the silver and the glass is much less than either L_1, L_2, L_3, or H. Knowing that $L_1 = 1$ m, $L_3 = 1$ m, $H = 1$ m, that the temperature on the right side of the glass block is $T_{\mathrm{G2}} = 127^\circ\mathrm{C}$, that the temperature of the left wall is $T_{\mathrm{W1}} = 227^\circ\mathrm{C}$, that the temperature of the environment is $T_\infty = 27^\circ\,\mathrm{C}$, that the convective heat transfer coefficient on the right wall is $h_2 = 5.669\ \mathrm{W/m^2{}^\circ C}$, do the following:

(a) Find the temperature of the right wall, T_{W2}.

(b) Find the heat flux in $\mathrm{W/m^2}$ due to convective heat transfer on the right wall.

(c) Find the temperature on the left side of the glass block, T_{G1}.

(d) Find the length of the glass block, L_2.

You can use the following properties for glass and silver:

Property	Units	Glass	Silver
c	kJ/kgK	0.84	0.23
k	W/m$^\circ$C	0.8	400
ρ	kg/m^3	2700	10000
ϵ		1	0

Hints: You can assume that the walls are thin with no temperature gradient within. The temperature on the right face of the glass block is uniform.