2011 Heat Transfer Midterm Exam

Heat Transfer
Midterm Quiz
May 5th 2011
14:00 — 16:10

NO NOTES OR BOOKS; USE HEAT TRANSFER TABLES THAT WERE DISTRIBUTED; STATE CLEARLY YOUR ASSUMPTIONS FOR EACH PROBLEM; 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 $h = 15\ \mathrm{W/m^2 \cdot {}^\circ C}$, 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

An electrical current of 800 Amperes flows through a stainless steel cable having a diameter of 5 mm and an electrical resistance of $6 \times 10^{-4}\ \Omega/\mathrm{m}$ (i.e. per meter of cable length). The cable is in an environment having a temperature of 30° C, and the total coefficient associated with convection and radiation between the cable and the environment is approximately $25\ \mathrm{W/m^2 \cdot K}$.

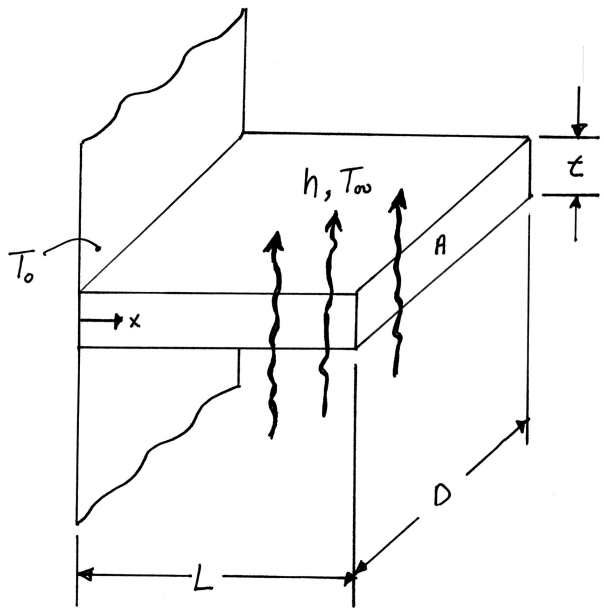
(a) If the cable is bare, what is its surface temperature?

(b) If a very thin coating of electrical insulation is applied to the cable, with a contact resistance of $0.02\ \mathrm{m^2 \cdot K/W}$, what are the insulation and cable surface temperatures?

(c) There is some concern about the ability of the insulation to withstand elevated temperatures. What thickness of this insulation ($k = 0.5$ W/m $\cdot$ K) will yield the lowest value of the maximum insulation temperature? What is the value of the maximum temperature when the thickness is used?

Question #3

Consider a fin with rectangular cross-section attached to a wall maintained at a temperature T_0. The fin is cooled by a fluid with a convective heat transfer coefficient h and a temperature T_∞ (fluid temperature far from the fin). The fin has a length L, a depth D and a thickness t. The cross-sectional area of the fin corresponds to $A = Dt$:



Given the thermal conductivity of the fin, k, and assuming that the convective heat transfer coefficient h is constant over all the fin exposed surfaces, derive an expression for the conduction heat transfer at the base of the fin (i.e., where the fin is attached to the wall). Note: the fin tip is *not* insulated.

Question #4

A solid sphere of radius $r_0 = 0.10$ m is made of a material with the following properties:

$k = 10$ W/m $\cdot^\circ$ C
$\rho = 1000$ kg/m^3
$c_p = 1000$ J/kg $\cdot^\circ$ C

The sphere is heated to a uniform initial temperature of 520° C. Is is then suddenly exposed to a cooling process with a fluid at $T_\infty = 20^\circ$ C and a heat transfer coefficient of $h = 100$ W/m$^2\cdot^\circ$C. This cooling process is terminated when the surface temperature of the sphere reaches 82.5° C.

(a) Determine the temperature of the center of the sphere at the end of the

cooling process.

(b) Determine the duration of the cooling process.

(c) At the end of the cooling process, the sphere is wrapped in an excellent insulation, so the heat loss from its surface may be assumed to be zero. What will be the temperature of the sphere after a long period of time?

Answers

1. $T_\infty = 730^\circ\text{C} - (22^\circ\text{C}/3600\text{s})t$.
2. 1007.85° C, 1007.85° C, 0.0175 m, 406.4° C
3. $$q = kA(T_0 - T_\infty)m\left(\frac{(h/km)\cosh(mL) + \sinh(mL)}{\cosh(mL) + (h/km)\sinh(mL)}\right)$$
   $$\text{with} \quad m = \sqrt{\frac{2h(D+t)}{kA}}$$
4. 120.8° C, 800 s, 95° C