2013 Heat Transfer Midterm Exam

Heat Transfer
Midterm Quiz
May 3rd 2013
14:00 — 16:30

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

Starting from the Stefan-Boltzmann equation $q''_{\text{rad}} = \sigma T^4$ with σ the Stefan-Boltzman constant, demonstrate Kirschoff's "law":

$\alpha = \epsilon$

with α the absorptivity coefficient and ϵ the emissivity coefficient of a gray body.

Question #2

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 $h = 15$ 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 #3

Consider a cylinder made of concrete with a length of 20 cm and a diameter of 10 cm. The cylinder is initially at a temperature of 500° C and is cooled by a fluid

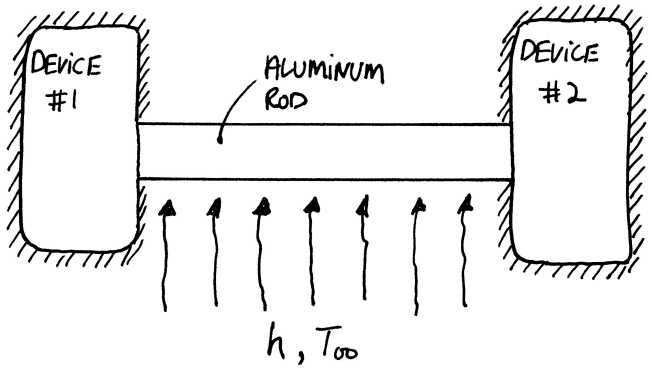
with a temperature T_∞ of 20° C and a convective heat transfer coefficient h of 10 W/m ^{2}° C. Noting that the thermal conductivity, density and heat capacity of concrete can be taken as 1.37 W/m° C, 1900 kg/m^3, and 880 J/kg° C, do the following tasks:

(a) Find the time needed for the minimum temperature within the cylinder to reach 100° C

(b) At the time found in part (a), find the average temperature within the cylinder

Question #4

Consider an aluminum rod linking two electrical devices and cooled by a fluid as follows:



Knowing that the diameter of the rod is 2 cm, that the length of the rod is 1 m, that the convective heat transfer h is 4 W/m^2° C, that the temperature of the fluid far from the devices is of 20° C, and that the power given to the first and second electrical devices is of 30 W and 50 W respectively, calculate the temperature in the rod midway between the two devices. Note: both electrical devices are insulated and lose heat to the environment only through contact with the rod.

Answers

2. 730° C − 22° C t/3600 s.
3. 5400 s, 130° C.
4. 291° C.