Problem Set # 5

Given: Monday, Oct. 15 **Recommended Completion Date:** Friday, Oct. 19
Do not submit for grading

Problem 1: During a special heat treatment process, a solid sphere of diameter D = 0.04 m is heated in a furnace to a uniform temperature of T_i = 1000°C. It is then suddenly removed from the furnace and suspended from a very fine wire in a large room filled with an inert gas at a uniform temperature of T_∞= 200°C. The surface of the sphere is highly polished, thus radiation heat transfer may be ignored. The sphere cools under the influence of natural convection. The thermal conductivity of the sphere is very high, as a result, lumped parameter analysis may be assumed to apply throughout. The convection heat transfer coefficient varies here as follows: $h = \xi(T-T_\infty)^{0.25}$, where ξ is constant, and T is the sphere temperature. The sphere has the following properties: ρ = 5000 kg/m^3; c = 1000 J/kg-°C.
The temperature of the sphere 30 min after initiation of the cooling process was measured as 523.4°C. Using this data determine the constant ξ.

Ans.: ξ = 3.54 W/m^2-°C$^{5/4}$

Problem 2: A solid sphere (D = 5 cm) made of anodized aluminum (ρ = 2707 kg/m^3; c = 896 J/kg-°C), is initially at a uniform temperature of T_i = 50°C. It is suddenly exposed to an outer space radiation environment. Assume that the effective temperature of the surroundings is T_{surr} = 0 K and there is no convection heat transfer (only radiation heat transfer). Also assume that the sphere behaves as a black body (ε = 1), and lumped parameter analysis applies. Calculate the time required for the temperature of the sphere to drop to -110°C (The Stefan Boltzmann Constant, σ = 5.669×10^{-8} W/m^2-K^4).

Ans.: 6h 37 min 29s

Problem 3: A very thick plate of stainless steel (ρ = 7817 kg/m^3; c = 460 J/kg-°C; k = 17 W/m-°C) at a uniform temperature of 300°C has its surface temperature suddenly lowered to 100°C. a) Calculate the time required for the temperature at a depth of 3 cm to attain a value of 200°C. b) At this time, what would be the heat flux at the surface of the plate?

Ans.: *(a)* t =209.1 s; *(b)* q_0'' = 60995.3 W/m^2 (outward)

Problem 4: A solid sphere made of fused-quarts has a thermal diffusivity of 9.5×10^{-7} m^2/s, a diameter of 2.5 cm, and a thermal conductivity of 1.52 W/m-°C. The sphere is initially at a uniform temperature of 25°C and is suddenly subjected to a convection heating environment characterized by T_∞= 200°C and h = 110 W/m^2-°C. Assume radiation heat transfer is negligible. After a time 4 minute into this heating process, calculate the temperatures at a) the center of the sphere; b) at a depth of 6.1 mm from the surface of the sphere.

Ans.: *(a)* 192.06 °C; *(b)* 192.83 °C

Problem 5: A long alloy steel cylinder (D= 8cm; ρ = 7900 kg/m^3; c = 480 J/kg-°C; k = 35 W/m-°C; and L>>D) is initially at T_i = 400°C. This cylinder is suddenly exposed to a convection cooling environment characterized by T_∞= 80°C and h = 450 W/m^2-°C. Assume radiation heat transfer is negligible.

a) At what time after the initiation of the cooling process will the surface temperature of the cylinder reach the value of 180°C?
b) At this time, what is the centerline temperature inside the cylinder?
c) What is the total heat loss per unit length of the cylinder (in J/m) during the following time interval: 100 s to 200 s?

Ans.: (a) 197.53 s; *(b)* 207.3 °C; (*c*) 1465689.4 J/m

Selected Problems from the Textbook (Incropera 2007, 6th Edition)

Please do the following problems:

5. 5
5.11
5.51
5.59

Selected Problems from the Textbook (Incropera 2011, 7th Edition)

Please do the following problems:

5. 6
5.16
5.64
5.74