Assignment 4: Transient Heat Conduction

1 Steel balls 12 mm in diameter are annealed by heating to 1150 K and then slowly cooling to 400 K in an air environment for which $T_\infty = 325$ K and $h = 20$ W/m$^2 \cdot$ K. Assuming the properties of the steel to be $k = 40$ W/m $\cdot$ K, $\rho = 7800$ kg/m^3, and $c = 600$ J/kg $\cdot$ K, estimate the time required for the cooling process.

2 Consider the steel balls of Problem 1, except now the air temperature increases with time as $T_\infty(t) = 325$ K $+ at$ where $a = 0.1875$ K/s.

(a) Sketch the ball temperature versus time for $0 \le t \le 1$ h. Also show the ambient temperature, T_∞, in your graph. Explain special features of the ball temperature behavior.

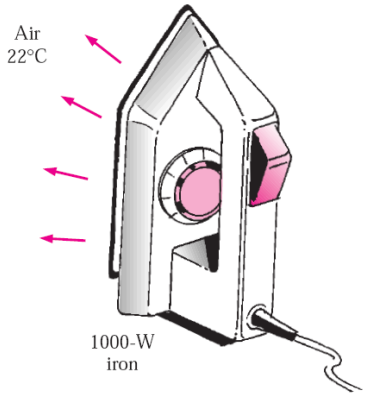
(b) Find an expression for the ball temperature as a function of time, $T(t)$, and plot the ball temperature for $0 \le t \le 1$ h. Was your sketch correct?

3 A solid steel sphere (AISI 1010), 300 mm in diameter, is coated with a dielectric material layer of thickness 2 mm and thermal conductivity 0.04 W/m $\cdot$ K. The coated sphere is initially at a uniform temperature of 500°C and is suddenly quenched in a large oil bath for which $T_\infty = 100$°C and $h = 3300$ W/m$^2 \cdot$ K. Estimate the time required for the coated sphere temperature to reach 140°C. *Hint:* Neglect the effect of energy storage in the dielectric material, since its thermal capacitance (ρcV) is small compared to that of the steel sphere.

4 The temperature of a gas stream is to be measured by a thermocouple whose junction can be approximated as a 1.2-mm-diameter sphere. The properties of the junction are $k = 35$ W/m $\cdot$ °C, $\rho = 8500$ kg/m^3, and $C_p = 320$ J/kg $\cdot$ °C, and the heat transfer coefficient between the junction and the gas is $h = 65$ W/m$^2 \cdot$ °C. Determine how long it will take for the thermocouple to read 99 percent of the initial temperature difference. *Answer:* 38.5 s

5 To warm up some milk for a baby, a mother pours milk into a thin-walled glass whose diameter is 6 cm. The height of the milk in the glass is 7 cm. She then places the glass into a large pan filled with hot water at 60°C. The milk is stirred constantly, so that its temperature is uniform at all times. If the heat transfer coefficient between the water and the glass is 120 W/m$^2 \cdot$ °C, determine how long it will take for the milk to warm up from 3°C to 38°C. Take the properties of the milk to be the same as those of water. Can the milk in this case be treated as a lumped system? Why? *Answer:* 5.8 min

6 Consider a 1000-W iron whose base plate is made of 0.5-cm-thick aluminum alloy 20218–T6 ($\rho = 2770$ kg/m^3, $C_p = 875$ J/kg $\cdot$ °C, $\alpha = 7.3 \times 10^{-5}$ m^2/s). The base plate has a surface area of 0.03 m^2. Initially, the iron is in thermal equilibrium with the ambient air at 22°C. Taking the heat transfer coefficient at the surface of the base plate to be 12 W/m$^2 \cdot$ °C and assuming 85 percent of the heat generated in the resistance wires is transferred to the plate, determine how long it will take for the plate temperature to reach 140°C. Is it realistic to assume the plate temperature to be uniform at all times?



7 Stainless steel ball bearings ($\rho = 8085$ kg/m^3, $k = 15.1$ W/m $\cdot$ °C, $C_p = 0.480$ kJ/kg $\cdot$ °C, and $\alpha = 3.91 \times 10^{-6}$ m^2/s) having a diameter of 1.2 cm are to be quenched in water. The balls leave the oven at a uniform temperature of 900°C and are exposed to air at 30°C for a while before they are dropped into the water. If the temperature of the balls is not to fall below 850°C prior to quenching and the heat transfer coefficient in the air is 125 W/m$^2 \cdot$ °C, determine how long they can stand in the air before being dropped into the water. *Answer:* 3.7 s