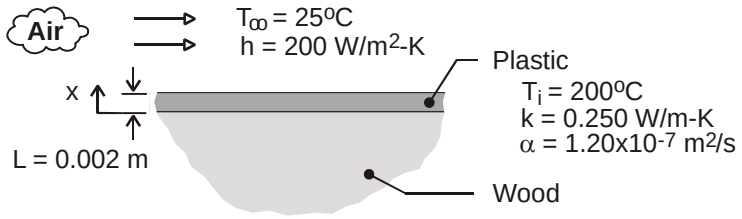
PROBLEM 5.59

KNOWN: Thickness, initial temperature and properties of plastic coating. Safe-to-touch temperature. Convection coefficient and air temperature.

FIND: Time for surface to reach safe-to-touch temperature. Corresponding temperature at plastic/wood interface.

SCHEMATIC:



ASSUMPTIONS: (1) One-dimensional conduction in coating, (2) Negligible radiation, (3) Constant properties, (4) Negligible heat of reaction, (5) Negligible heat transfer across plastic/wood interface.

ANALYSIS: With Bi = hL/k = 200 W/m^2·K × 0.002m/0.25 W/m·K = 1.6 > 0.1, the lumped capacitance method may not be used. Applying the approximate solution of Eq. 5.43a, with C_1 = 1.155 and ζ_1 = 0.990 from Table 5.1,

$$\theta_s^* = \frac{T_s - T_\infty}{T_i - T_\infty} = \frac{(42-25)°C}{(200-25)°C} = 0.0971 = C_1 \exp\left(-\zeta_1^2 Fo\right)\cos\left(\zeta_1 x^*\right) = 1.155\exp\left(-0.980\,Fo\right)\cos\left(0.99\right)$$

Hence, for $x^* = 1$,

$$Fo = -\ln\left(\frac{0.0971}{1.155\cos(0.99)}\right)/(0.99)^2 = 1.914$$

$$t = \frac{Fo\,L^2}{\alpha} = \frac{1.914(0.002m)^2}{1.20\times10^{-7}\,m^2/s} = 63.8s \qquad <$$

From Eq. 5.44, the corresponding interface temperature is

$$T_o = T_\infty + (T_i - T_\infty)\exp\left(-\zeta_1^2 Fo\right) = 25°C + 175°C\exp\left(-0.98\times1.914\right) = 51.8°C \qquad <$$

COMMENTS: By neglecting conduction into the wood and radiation from the surface, the cooling time is overpredicted and is therefore a conservative estimate. However, if energy generation due to solidification of polymer were significant, the cooling time would be longer.