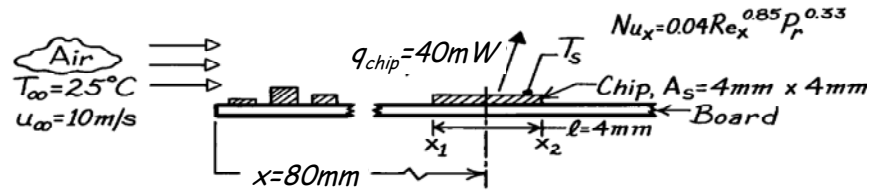


PROBLEM 7.38

KNOWN: Convection correlation for irregular surface due to electronic elements mounted on a circuit board experiencing forced air cooling with prescribed temperature and velocity

FIND: Surface temperature when heat dissipation rate is 40 mW for chip of prescribed area located a specific distance from the leading edge.

SCHEMATIC:



ASSUMPTIONS: (1) Situation approximates parallel flow over a flat plate with prescribed correlation, (2) Heat rate is from top surface of chip.

PROPERTIES: Table A-4, Air (assume $T_s \approx 45^\circ\text{C}$, then $\bar{T} = (45 + 25)^\circ\text{C}/2 \approx 310\text{ K}$, 1 atm): $k = 0.027\text{ W/m}\cdot\text{K}$, $\nu = 16.90 \times 10^{-6}\text{ m}^2/\text{s}$, $\text{Pr} = 0.706$.

ANALYSIS: For the chip upper surface, the heat rate is

$$q_{\text{chip}} = \bar{h}_{\text{chip}} A_s (T_s - T_\infty) \quad \text{or} \quad T_s = T_\infty + q_{\text{chip}} / \bar{h}_{\text{chip}} A_s$$

Assuming the average convection coefficient over the chip length to be equal to the local value at the center of the chip ($x = x_o$), $\bar{h}_{\text{chip}} \approx h_x(x_o)$, where

$$\text{Nu}_x = 0.04 \text{Re}_x^{0.85} \text{Pr}^{0.33}$$

$$\text{Nu}_x = 0.04 \left(10\text{ m/s} \times 0.080\text{ m} / 16.90 \times 10^{-6}\text{ m}^2/\text{s} \right)^{0.85} (0.706)^{0.33} = 335.8$$

$$h_x = \frac{\text{Nu}_x k}{x_o} = \frac{335.8 \times 0.027\text{ W/m}\cdot\text{K}}{0.080\text{ m}} = 113.3\text{ W/m}^2\cdot\text{K}$$

Hence,

$$T_s = 25^\circ\text{C} + 40 \times 10^{-3}\text{ W} / 113.3\text{ W/m}^2\cdot\text{K} \times \left(4 \times 10^{-3}\text{ m} \right)^2 = (25 + 22.1)^\circ\text{C} = 47.1^\circ\text{C}. <$$

COMMENTS: (1) Note that the assumed value of $\bar{T}$ used to evaluate the thermophysical properties was reasonable. (2) We could have evaluated $\bar{h}_{\text{chip}}$ by two other approaches. In one case the average coefficient is approximated as the arithmetic mean of local values at the leading and trailing edges of the chip.

$$\bar{h}_{\text{chip}} \approx [h_{x2}(x_2) + h_{x1}(x_1)] / 2 = [112.9 + 113.8] / 2 = 113.3\text{ W/m}^2\cdot\text{K}.$$

The exact approach is of the form

$$\bar{h}_{\text{chip}} \cdot \ell = \bar{h}_{x2} \cdot x_2 - \bar{h}_{x1} \cdot x_1$$

Recognizing that $h_x \sim x^{-0.15}$, it follows that

$$\bar{h}_x = \frac{1}{x} \int_0^x h_x \cdot dx = 1.1765 h_x$$

and $\bar{h}_{\text{chip}} = 113.3\text{ W/m}^2\cdot\text{K}$. Why do results for the two approximate methods and the exact method compare so favorably?