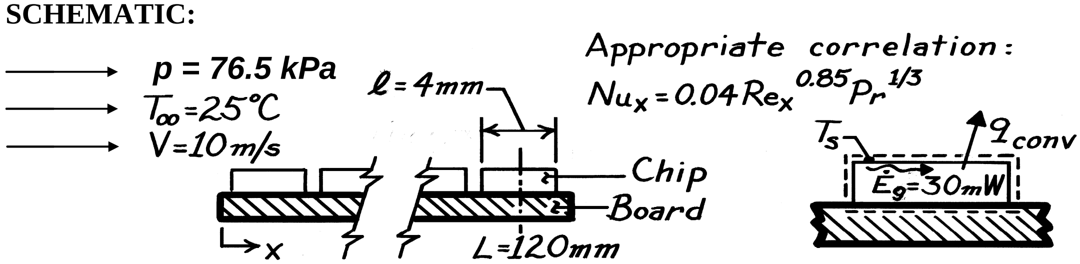
PROBLEM 6.40

KNOWN: Expression for the local heat transfer coefficient of air at prescribed velocity and temperature flowing over electronic elements on a circuit board and heat dissipation rate for a 4 × 4 mm chip located 120 mm from the leading edge. Atmospheric pressure in Mexico City.

FIND: (a) Surface temperature of chip, (b) Air velocity required for chip temperature to be the same at sea level.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Power dissipated in chip is lost bey convection across the upper surface only, (3) Chip surface is isothermal, (4) The average heat transfer coefficient for the chip surface is equivalent to the local value at x = L, (5) Negligible radiation, (6) Ideal gas behavior.

PROPERTIES: Table A.4, air (p = 1 atm, assume T_s = 45 °C, T_f = (45 °C + 25 °C)/2 = 35 °C): k = 0.0269 W/m·K, $\nu = 16.69 \times 10^{-6}\ m^2/s$, Pr = 0.706.

ANALYSIS:

(a) From an energy balance on the chip (see above),

$$q_{conv} = \dot{E}_g = 30\,W. \tag{1}$$

Newton's law of cooling for the upper chip surface can be written as

$$T_s = T_\infty + q_{conv} / \bar{h} A_{chip} \tag{2}$$

where $A_{chip} = \ell^2$. From Assumption 4, $\bar{h}_{chip} \approx h_x(L)$ where the local coefficient can be evaluated from the correlation provided in Problem 6.35.

$$Nu_x = \frac{h_x x}{k} = 0.04\left[\frac{Vx}{\nu}\right]^{0.85} Pr^{1/3} \tag{3}$$

The kinematic viscosity is

$$\nu = \frac{\mu}{\rho} \tag{4}$$

while for an ideal gas,

$$\rho = \frac{p}{RT} \tag{5}$$

Combining Equations 4 and 5 yields

$$\nu \propto p^{-1} \tag{6}$$

Continued…

PROBLEM 6.40 (Cont.)

The Prandtl number is

$$Pr = \frac{\nu}{\alpha} = \frac{\mu\rho c}{\rho k} = \frac{\mu c}{k} \qquad (7)$$

which is independent of pressure.

Therefore, at sea level (p = 1 atm)

$$k = 0.0269\ \text{W/m}\cdot\text{K},\ \ \nu = 16.69 \times 10^{-6}\ \text{m}^2/\text{s},\ \ Pr = 0.706$$

$$h_x = 0.04\ \frac{k}{L}\left[\frac{VL}{\nu}\right]^{0.85} Pr^{1/3}$$

$$h_x = 0.04\left[\frac{0.0269\ \text{W/m}\cdot\text{K}}{0.120\ \text{m}}\right]\left[\frac{10\ \text{m/s} \times 0.120\ \text{m}}{16.69 \times 10^{-6}\ \text{m}^2/\text{s}}\right]^{0.85} (0.706)^{1/3} = 107\ \text{W/m}^2\cdot\text{K}$$

$$T_s = 25°\text{C} + 30 \times 10^{-3}\ \text{W} \Big/ 107\ \text{W/m}^2\cdot\text{K} \times (0.004\ \text{m})^2 = 42.5°\text{C}$$

In Mexico City (p = 76.5 kPa)

$$\nu = 16.69 \times 10^{-6}\ \text{m}^2/\text{s} \times \left[\frac{101.3\text{lPa}}{76.5\text{kPa}}\right] = 22.10 \times 10^{-6}\ \text{m}^2/\text{s}$$

$$k = 0.0269\ \text{W/m}\cdot\text{K},\ \ \ Pr = 0.706$$

$$h_x = 0.04\left[\frac{0.0269\ \text{W/m}\cdot\text{K}}{0.120\ \text{m}}\right]\left[\frac{10\ \text{m/s} \times 0.120\ \text{m}}{22.10 \times 10^{-6}\ \text{m}^2/\text{s}}\right]^{0.85} (0.706)^{1/3} = 84.5\ \text{W/m}^2\cdot\text{K}$$

$$T_s = 25°\text{C} + 30 \times 10^{-3}\ \text{W} \Big/ 84.5\ \text{W/m}^2\cdot\text{K} \times (0.004\ \text{m})^2 = 47.2°\text{C}$$ <

(b) For the same chip temperature, it is required that $h_x = 107\ \text{W/m}^2\cdot\text{K}$. Therefore

$$h_x = 107\ \text{W/m}^2\cdot\text{K} = 0.04\left[\frac{0.0269\ \text{W/m}\times\text{K}}{0.120\ \text{m}}\right]\left[\frac{V \times 0.120\ \text{m}}{22.10 \times 10^{-6}\ \text{m}^2/\text{s}}\right]^{0.85} (0.706)^{1/3}$$

From which we may find V = 13.2 m/s <

COMMENTS: (1) In Part (a), the chip surface temperature increased from 42.4 °C to 47.2 °C. This is considered to be significant and the electronics packaging engineer needs to consider the effect of large changes in atmospheric pressure on the efficacy of the electronics cooling scheme. (2) Careful consideration needs to be given to the effect changes in the atmospheric pressure on the kinematic viscosity and, in turn, on changes in transition lengths which might affect local convective heat transfer coefficients.