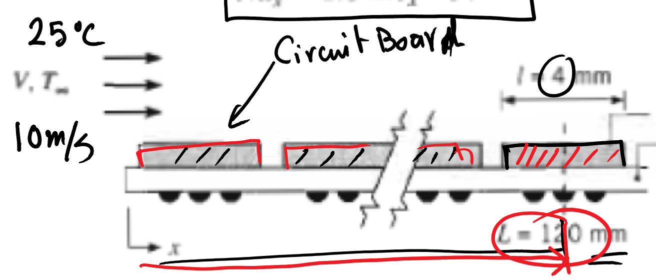
Forced Convection

Monday, March 29, 2021 9:58 AM

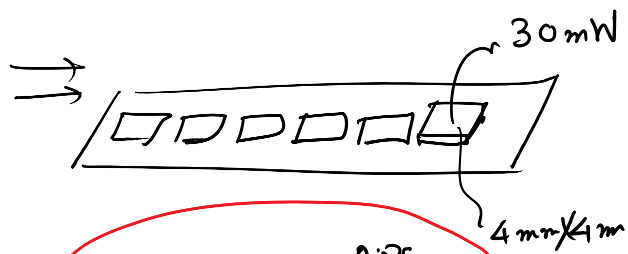
6.26 Forced air at $T_\infty = 25°C$ and $V = 10$ m/s is used to cool electronic elements on a circuit board. One such element is a chip, 4 mm by 4 mm, located 120 mm from the leading edge of the board. Experiments have revealed that flow over the board is disturbed by the elements and that convection heat transfer is correlated by an expression of the form

$$Nu_x = 0.04 Re_x^{0.85} Pr^{1/3}$$



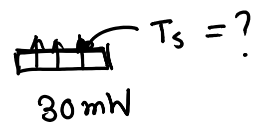
Estimate the surface temperature of the chip if it is dissipating 30 mW.

25°C



$$Nu_x = 0.04 Re_x^{0.85} Pr^{1/3}$$

T_∞



$$q'' = h(T_s - T_\infty)$$

$$\frac{30\times10^{-3}\ W}{4\times4\times10^{-6}\ m^2} = h(T_s - T_\infty)$$

or $\frac{30}{16}\times10^{3} = h(T_s - 25)$ (? ?)

How to find h ?

Let's find Nu_x first.

$$Nu_x = 0.04 Re_x^{0.85} Pr^{1/3}$$

$Re_x = ?$, $Pr = ?$ → ρ_{air}, μ_{air}, k_{air}, C_p

$$Re_x = \frac{\rho U x}{\mu}$$

$$Pr = \frac{\nu}{\alpha} = \frac{\mu C_p}{k}$$

$$\alpha = \frac{k}{\rho C_p}$$

$T_f = \frac{1}{2}(T_s + T_\infty)$? ⇒ Let $T_f = T_s$

$Re = \frac{Ux}{\nu} = \frac{\rho U x}{\mu}$, $x = 120$ mm

Let us assume

$\rho = 1.2\ kg/m^3$

$\nu = 10^{-5}\ m^2/s$

$k = 0.03\ W/mK$

$C_p = 1.004\ kJ/kgK = 1004\ J/kgK$

$$Re_x = \frac{10\times0.12}{10^{-5}} = 1.2\times10^5$$

$$Pr = \frac{1.2\times10^{-5}\times1004}{0.03} = 0.4$$

(1000)

$$Nu = 0.04\times(1.2\times10^5)^{0.85}\times(0.4)^{1/3}$$

$$Nu = 0.04 \times (1.2\times10^5)^{\cdot} \times (0.4)^{1/3}$$

$$= 611.95$$

$$h = \frac{k\,Nu}{x} = \frac{0.03 \times 611.95}{0.12} = \underline{\underline{153}}\ W/m^2$$

$$q'' = h\,(T_s - T_\infty)$$

$$\Rightarrow T_s = \frac{q''}{h} + T_\infty \Rightarrow \frac{30}{16}\times10^3 / 153 + 25$$

$$T_s = 12.25 + 25\ ^\circ C$$

$$= 37.25^\circ C$$

Steps

1) Identify the film temp & the fluid properties or use values from tables

ν, C_p, k, ρ

P_r, ν, k

2) Calculate Re, Pr

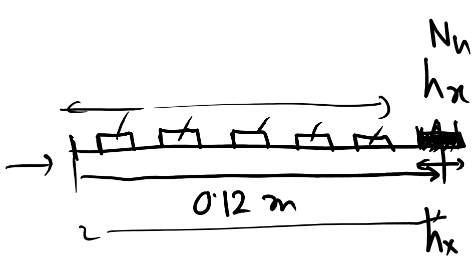
3) Identify the appropriated Nu_x correlation

4) Find out $h_x = \frac{k\,Nu_x}{x}$

(Local Nu and HTC

To find average HTC

$$Nu_x = 0.04\,Re_x^{0.85}\,P_r^{1/3}$$



4m

$$h_x = \frac{k\,Nu_x}{x}$$

$$= \frac{0.04}{k} \times \frac{U^{0.85}}{\nu^{0.85}}\,\frac{x^{0.85}}{x}\,P_r^{1/3}$$

$$= \frac{0.04}{k} \times \frac{u}{\nu^{0.85}} \frac{x}{x} Pr$$

$$= \left(\frac{0.04 \times 10^{0.85} \times (0.4)^{1/3}}{0.03 \times (10^{-5})^{0.85}}\right) \frac{x^{0.85}}{x}$$

$$= (A) x^{-0.15}$$

$$h_x = A x^{-0.15}$$

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

$$h_x = A x^{-n}$$

$$\bar{h}_x = \left(\frac{h_x}{1-n}\right)$$

$$\bar{h}_x = \frac{A x^{-0.15}}{1-n}$$

$x = 0.12$