HEAT TRANSFER (CH21204)

Quiz #4 [Apr. 12, 2023]   Name: Roll:

A 30-cm X 30-cm circuit board that contains 121 square chips on one side is to be cooled by combined natural convection and radiation in a room at 25°C. Each chip dissipates 0.05 W of power, and the emissivity of the chip surfaces is 0.7. Assuming the heat transfer from the back side of the circuit board to be negligible, and the temperature of the surrounding surfaces to be the same as the air temperature of the room, determine the surface temperature of the chips when the circuit board to be positioned horizontally with (a) chips facing up and (b) chips facing down.

[Marks: 10+10 = 20]

Data: The properties of air at 1 atm and anticipated film temperature are:

$$k = 0.02588 \text{ W/m.°C}$$

$$\upsilon = 1.608 \times 10^{-5} \text{ m}^2\text{/s}$$

$$\text{Pr} = 0.7282$$

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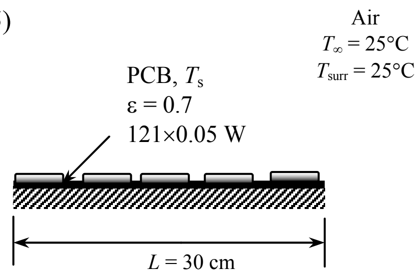
Properties The properties of air at 1 atm and the anticipated film temperature of $(T_s+T_\infty)/2 = (35+25)/2 = 30°C$ are (Table A-15)

$$k = 0.02588 \text{ W/m.°C}$$
$$\upsilon = 1.608\times10^{-5} \text{ m}^2\text{/s}$$
$$\Pr = 0.7282$$
$$\beta = \frac{1}{T_f} = \frac{1}{(30+273)\text{K}} = 0.0033 \text{ K}^{-1}$$



Analysis The solution of this problem requires a trial-and-error approach since the determination of the Rayleigh number and thus the Nusselt number depends on the surface temperature which is unknown. We start the solution process by "guessing" the surface temperature to be 35°C for the evaluation of the properties and h. The characteristic length for both cases is determined from

$$L_c = \frac{A_s}{p} = \frac{(0.3\text{ m})^2}{2[(0.3\text{ m})+(0.3\text{ m})]} = 0.075 \text{ m.}$$

Then,

$$Ra = \frac{g\beta(T_s - T_\infty)L_c^3}{\upsilon^2}\Pr = \frac{(9.81\text{ m/s}^2)(0.00333\text{ K}^{-1})(35-25\text{ K})(0.075\text{ m})^3}{(1.608\times10^{-5}\text{ m}^2\text{/s})^2}(0.7282) = 3.848\times10^5$$

(*a*) Chips (hot surface) facing up:

$$Nu = 0.54Ra^{1/4} = 0.54(3.848\times10^5)^{1/4} = 13.45$$
$$h = \frac{k}{L_c}Nu = \frac{0.02588\text{ W/m.°C}}{0.075\text{ m}}(13.45) = 4.641\text{ W/m}^2\text{.°C}$$
$$A_s = (0.3\text{ m})^2 = 0.09\text{ m}^2$$

Considering both natural convection and radiation, the total rate of heat loss can be expressed as

$$\dot{Q} = hA_s(T_s - T_\infty) + \varepsilon A_s\sigma(T_s^{\ 4} - T_{surr}^{\ 4})$$
$$(121\times0.05)\text{ W} = (4.641\text{ W/m}^2\text{.°C})(0.09\text{ m}^2)(T_s - 25)\text{°C}$$
$$+(0.7)(0.09\text{ m}^2)(5.67\times10^{-8}\text{ W/m}^2\text{.K}^4)[(T_s+273\text{ K})^4 - (25+273\text{ K})^4]$$

Its solution is T_s = **32.5°C**

which is sufficiently close to the assumed value. Therefore, there is no need to repeat calculations.

(*b*) Chips (hot surface) facing up:

$$Nu = 0.27Ra^{1/4} = 0.27(3.848\times10^5)^{1/4} = 6.725$$
$$h = \frac{k}{L_c}Nu = \frac{0.02588\text{ W/m.°C}}{0.075\text{ m}}(6.725) = 2.321\text{ W/m}^2\text{.°C}$$

Considering both natural convection and radiation, the total rate of heat loss can be expressed as

$$\dot{Q} = hA_s(T_s - T_\infty) + \varepsilon A_s\sigma(T_s^{\ 4} - T_{surr}^{\ 4})$$
$$(121\times0.05)\text{ W} = (2.321\text{ W/m}^2\text{.°C})(0.09\text{ m}^2)(T_s - 25)\text{°C}$$
$$+(0.7)(0.09\text{ m}^2)(5.67\times10^{-8}\text{ W/m}^2\text{.K}^4)[(T_s+273\text{ K})^4 - (25+273\text{ K})^4]$$

Its solution is T_s = **35.0°C**

which is identical to the assumed value in the evaluation of properties and h. Therefore, there is no need to repeat calculations.