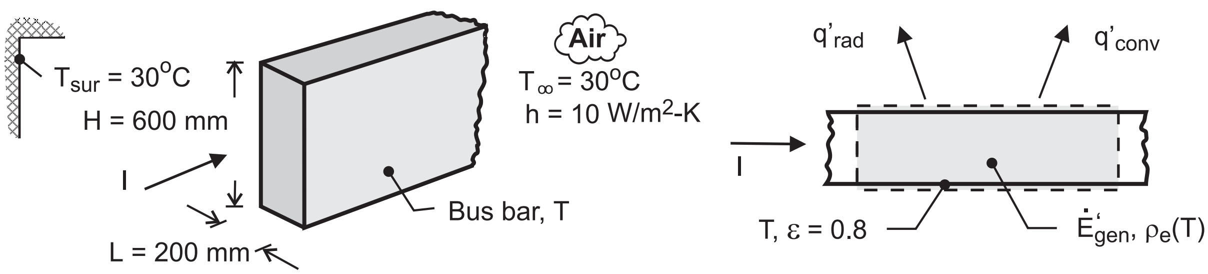
PROBLEM 1.84

KNOWN: Long bus bar of rectangular cross-section and ambient air and surroundings temperatures. Relation for the electrical resistivity as a function of temperature.

FIND: (a) Temperature of the bar with a current of 60,000 A, and (b) Compute and plot the operating temperature of the bus bar as a function of the convection coefficient for the range $10 \le h \le 100$ $W/m^2 \cdot K$. Minimum convection coefficient required to maintain a safe-operating temperature below 120°C. Will increasing the emissivity significantly affect this result?

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Bus bar is long, (3) Uniform bus-bar temperature, (3) Radiation exchange between the outer surface of the bus bar and its surroundings is between a small surface and a large enclosure.

PROPERTIES: Bus-bar material, $\rho_e = \rho_{e,o}\left[1+\alpha\left(T-T_o\right)\right]$, $\rho_{e,o} = 0.0828\,\mu\Omega\cdot m$, $T_o = 25°C$,

$\alpha = 0.0040\,K^{-1}$.

ANALYSIS: (a) An energy balance on the bus-bar for a unit length as shown in the schematic above has the form

$$\dot{E}'_{in} - \dot{E}'_{out} + \dot{E}'_{gen} = 0 \qquad -q'_{rad} - q'_{conv} + I^2 R'_e = 0$$

$$-\varepsilon P\sigma\left(T^4 - T_{sur}^4\right) - hP\left(T - T_\infty\right) + I^2\rho_e / A_c = 0$$

where $P = 2(H+W)$, $R'_e = \rho_e / A_c$ and $A_c = H \times W$. Substituting numerical values,

$$-0.8\times 2(0.600+0.200)\,m\times 5.67\times 10^{-8}\,W/m^2\cdot K^4\left(T^4 - [30+273]^4\right)K^4$$

$$-10\,W/m^2\cdot K\times 2(0.600+0.200)\,m\left(T-[30+273]\right)K$$

$$+(60,000\,A)^2\left\{0.0828\times 10^{-6}\,\Omega\cdot m\left[1+0.0040\,K^{-1}\left(T-[25+273]\right)K\right]\right\}/(0.600\times 0.200)\,m^2 = 0$$

Solving for the bus-bar temperature, find $\qquad T = 426\ K = 153°C.$ $\qquad$ <

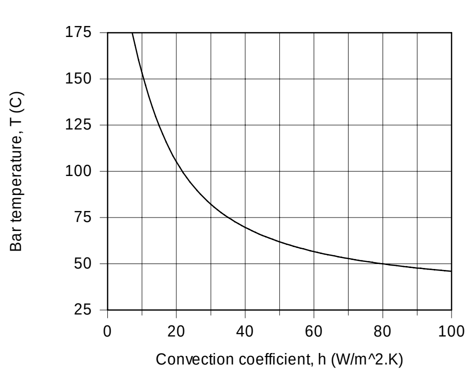
(b) Using the energy balance relation in the Workspace of IHT, the bus-bar operating temperature is calculated as a function of the convection coefficient for the range $10 \le h \le 100$ $W/m^2\cdot K$. From this graph we can determine that to maintain a safe operating temperature below 120°C, the minimum convection coefficient required is

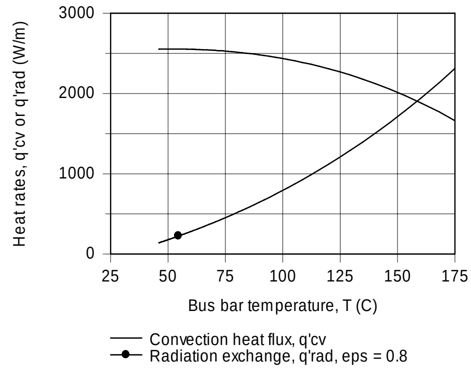
$$h_{min} = 16\ W/m^2\cdot K.$$ <

Continued …

PROBLEM 1.84 (Cont.)

Using the same equations, we can calculate and plot the heat transfer rates by convection and radiation as a function of the bus-bar temperature.





Note that convection is the dominant mode for low bus-bar temperatures; that is, for low current flow. As the bus-bar temperature increases toward the safe-operating limit (120°C), convection and radiation exchange heat transfer rates become comparable. Notice that the relative importance of the radiation exchange rate increases with increasing bus-bar temperature.

COMMENTS: (1) It follows from the second graph that increasing the surface emissivity will be only significant at higher temperatures, especially beyond the safe-operating limit.

(2) The Workspace for the IHT program to perform the parametric analysis and generate the graphs is shown below. It is good practice to provide commentary with the code making your solution logic clear, and to summarize the results.

```
/* Results for base case conditions:
Ts_C   q'cv   q'rad   rhoe        H     I     Tinf_C   Tsur_C   W     alpha
       eps    h
153.3  1973   1786    1.253E-7    0.6   6E4   30       30       0.2   0.004
       0.8    10   */

// Surface energy balance on a per unit length basis
-q'cv - q'rad + Edot'gen = 0
q'cv = h * P * (Ts - Tinf)
P = 2 * (W + H)          // perimeter of the bar experiencing surface heat transfer
q'rad = eps * sigma * (Ts^4 - Tsur^4) * P
sigma = 5.67e-8
Edot'gen = I^2 * Re'
Re' = rhoe / Ac
rhoe = rhoeo * ( 1 + alpha * (Ts - Teo))
Ac = W * H

// Input parameters
I = 60000
alpha = 0.0040           // temperature coefficient, K^-1; typical value for cast aluminum
rhoeo = 0.0828e-6        // electrical resistivity at the reference temperature, Teo; microohm-m
Teo = 25 + 273           // reference temperature, K
W = 0.200
H = 0.600
Tinf_C = 30
Tinf = Tinf_C + 273
h = 10
eps = 0.8
Tsur_C = 30
Tsur = Tsur_C + 273
Ts_C = Ts - 273
```