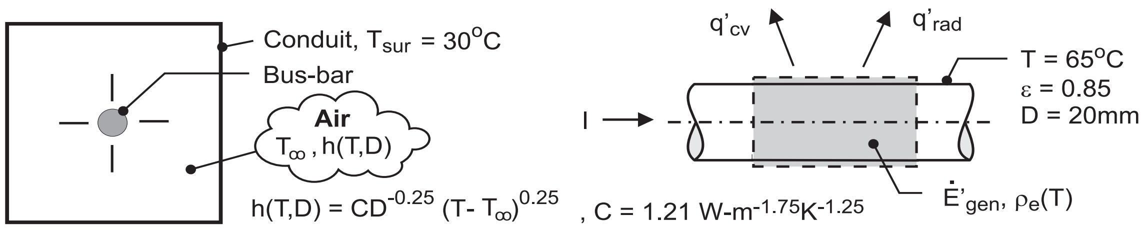
# PROBLEM 1.61

**KNOWN:** Long bus bar of prescribed diameter and ambient air and surroundings temperatures. Relations for the electrical resistivity and free convection coefficient as a function of temperature.

**FIND:** (a) Current carrying capacity of the bus bar if its surface temperature is not to exceed 65°C; compare relative importance of convection and radiation exchange heat rates, and (b) Show graphically the operating temperature of the bus bar as a function of current for the range $100 \le I \le 5000$ A for bus-bar diameters of 10, 20 and 40 mm. Plot the ratio of the heat transfer by convection to the total heat transfer for these conditions.

**SCHEMATIC:**




**ASSUMPTIONS:** (1) Steady-state conditions, (2) Bus bar and conduit are very long, (3) Uniform bus-bar temperature, (4) Radiation exchange between the outer surface of the bus bar and the conduit is between a small surface and a large enclosure.

**PROPERTIES:** Bus-bar material, $\rho_e = \rho_{e,o}\left[1+\alpha\left(T-T_o\right)\right]$, $\rho_{e,o} = 0.0171\mu\Omega\cdot m$, $T_o = 25°C$, $\alpha = 0.00396\,K^{-1}$.

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

$$\dot{E}'_{in} - \dot{E}'_{out} + \dot{E}'_{gen} = 0$$

$$-q'_{rad} - q'_{conv} + I^2 R'_e = 0$$

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

where $R'_e = \rho_e / A_c$ and $A_c = \pi D^2/4$. Using the relations for $\rho_e(T)$ and $h(T,D)$, and substituting numerical values with T = 65°C, find

$$q'_{rad} = 0.85\pi\left(0.020m\right)\times 5.67\times10^{-8}\,W/m^2\cdot K^4\left(\left[65+273\right]^4 - \left[30+273\right]^4\right)K^4 = 14.0\,W/m \qquad <$$

$$q'_{conv} = 7.83\,W/m^2\cdot K\;\pi\left(0.020m\right)\left(65-30\right)K = 17.2\,W/m \qquad <$$

where $h = 1.21\,W\cdot m^{-1.75}\cdot K^{-1.25}\left(0.020m\right)^{-0.25}\left(65-30\right)^{0.25} = 7.83\,W/m^2\cdot K$

$$I^2 R'_e = I^2\left(198.2\times10^{-6}\,\Omega\cdot m\right)/\pi\left(0.020\right)^2 m^2/4 = 6.31\times10^{-5} I^2\;W/m$$

where $\rho_e = 0.0171\times10^{-6}\,\Omega\cdot m\left[1 + 0.00396\,K^{-1}\left(65-25\right)K\right] = 198.2\,\mu\Omega\cdot m$

The maximum allowable current capacity and the ratio of the convection to total heat transfer rate are

$$I = 700\,A \qquad q'_{cv}/\left(q'_{cv} + q'_{rad}\right) = q'_{cv}/q'_{tot} = 0.55 \qquad <$$

For this operating condition, convection heat transfer is 55% of the total heat transfer.

(b) Using these equations in the Workspace of IHT, the bus-bar operating temperature is calculated and plotted as a function of the current for the range $100 \le I \le 5000$ A for diameters of 10, 20 and 40 mm. Also shown below is the corresponding graph of the ratio (expressed in percentage units) of the heat transfer by convection to the total heat transfer, $q'_{cv}/q'_{tot}$.

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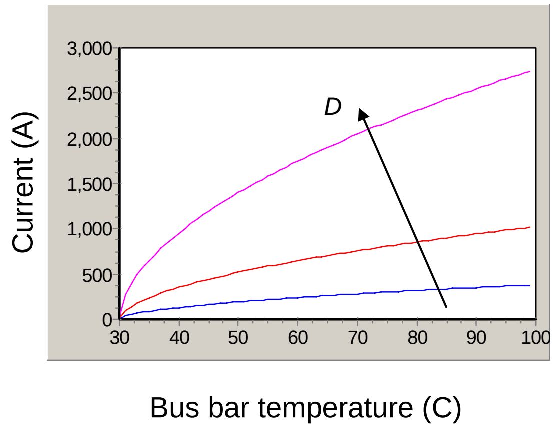


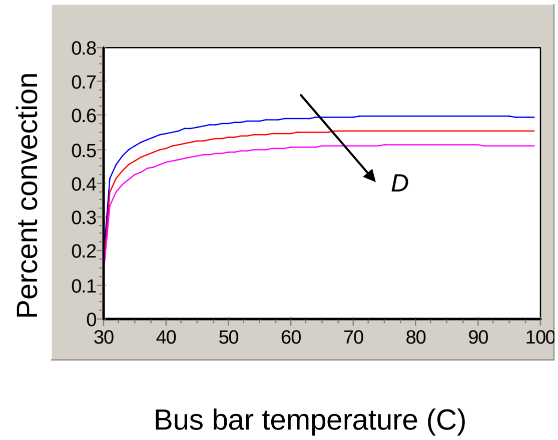


**COMMENTS:** (1) The trade-off between current-carrying capacity, operating temperature and bar diameter is shown in the first graph. If the surface temperature is not to exceed 65°C, the maximum current capacities for the 10, 20 and 40-mm diameter bus bars are 260, 700, and 1900 A, respectively.

(2) From the second graph with $q'_{cv} / q'_{tot}$ vs. T, note that the convection heat transfer rate is typically comparable to the radiation heat transfer rate. Since the convection heat transfer increases with decreasing diameter, the convection transfer rate is relatively smaller for the larger diameter bus bars.

(3) 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.

```
//Temperature Information (Celsius unless otherwise indicated)
Ts = 65
TsK = Ts + 273
Tsur = 30
TsurK = Tsur + 273
Tinf = 30

//Radiation (Stefan-Boltzmann constant and emissivity)
sigma = 5.67*10^-8
eps = 0.85

//Three bus bar diameters (m)
D1 = 10/1000
D2 = 20/1000
D3 = 40/1000

//Electrical resistivity (Ohm-m)
rhoe = (0.0171*10^-6) *(1 + 0.00396*(Ts - 25))

//Radiation per unit length (W/m)
qradp1 = eps*sigma*pi*D1*(TsK^4 - TsurK^4)
qradp2 = eps*sigma*pi*D2*(TsK^4 - TsurK^4)
qradp3 = eps*sigma*pi*D3*(TsK^4 - TsurK^4)

//Free convection coefficients (W/m^2K)
h1 = 1.21*(D1^-0.25)*(Ts - Tinf)^0.25
h2 = 1.21*(D2^-0.25)*(Ts - Tinf)^0.25
h3 = 1.21*(D3^-0.25)*(Ts - Tinf)^0.25
```

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```
//Free convection per unit length (W/m)
qconvp1 = h1*D1*pi*(Ts - Tinf)
qconvp2 = h2*D2*pi*(Ts - Tinf)
qconvp3 = h3*D3*pi*(Ts - Tinf)

//Electrical resistance per unit length (Ohm/m)
Rep1 = rhoe/Ac1
Rep2 = rhoe/Ac2
Rep3 = rhoe/Ac3

//Cross sectional areas (m^2)
Ac1 = pi*D1*D1/4
Ac2 = pi*D2*D2/4
Ac3 = pi*D3*D3/4

//Energy balances (W/m)
-qradp1-qconvp1+I1*I1*Rep1 = 0
-qradp2-qconvp2+I2*I2*Rep2 = 0
-qradp3-qconvp3+I3*I3*Rep3 = 0

//Ratios of convection to total heat transfer
rat1 = qconvp1/(qconvp1 + qradp1)
rat2 = qconvp2/(qconvp2 + qradp2)
rat3 = qconvp3/(qconvp3 + qradp3)
```