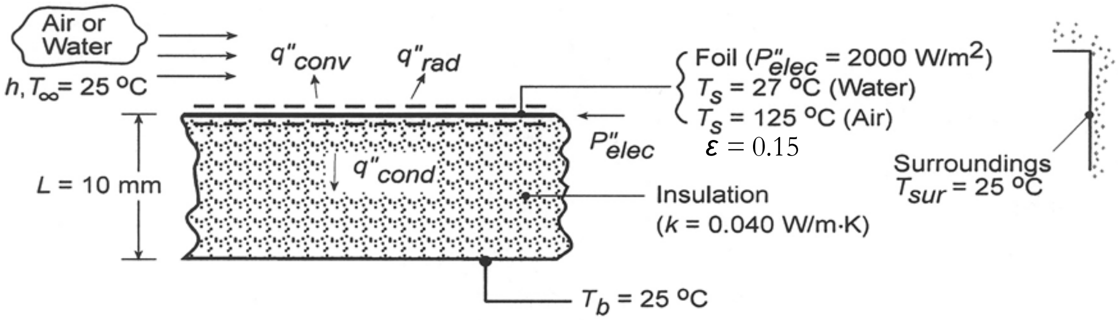
## PROBLEM 02

**KNOWN:** Design and operating conditions of a heat flux gage.

**FIND:** (a) Convection coefficient for water flow ($T_s$ = 27°C) and error associated with neglecting conduction in the insulation, (b) Convection coefficient for air flow ($T_s$ = 125°C) and error associated with neglecting conduction and radiation, (c) Effect of convection coefficient on error associated with neglecting conduction for $T_s$ = 27°C.

**SCHEMATIC:**




**ASSUMPTIONS:** (1) Steady-state, (2) One-dimensional conduction, (3) Constant k.

**ANALYSIS:** (a) The electric power dissipation is balanced by convection to the water and conduction through the insulation. An energy balance applied to a control surface about the foil therefore yields

$$P''_{elec} = q''_{conv} + q''_{cond} = h\left(T_s - T_\infty\right) + k\left(T_s - T_b\right)/L$$

Hence,

$$h = \frac{P''_{elec} - k\left(T_s - T_b\right)/L}{T_s - T_\infty} = \frac{2000\,\mathrm{W/m^2} - 0.04\,\mathrm{W/m\cdot K}\left(2\,\mathrm{K}\right)/0.01\,\mathrm{m}}{2\,\mathrm{K}}$$

$$h = \frac{\left(2000 - 8\right)\mathrm{W/m^2}}{2\,\mathrm{K}} = 996\,\mathrm{W/m^2\cdot K} \qquad <$$

If conduction is neglected, a value of h = 1000 W/m$^2$·K is obtained, with an attendant error of (1000 - 996)/996 = 0.40%

(b) In air, energy may also be transferred from the foil surface by radiation, and the energy balance yields

$$P''_{elec} = q''_{conv} + q''_{rad} + q''_{cond} = h\left(T_s - T_\infty\right) + \varepsilon\sigma\left(T_s^4 - T_{sur}^4\right) + k\left(T_s - T_b\right)/L$$

Hence,

$$h = \frac{P''_{elec} - \varepsilon\sigma\left(T_s^4 - T_{sur}^4\right) - k\left(T_s - T_\infty\right)/L}{T_s - T_\infty}$$

$$= \frac{2000\,\mathrm{W/m^2} - 0.15\times 5.67\times10^{-8}\,\mathrm{W/m^2\cdot K^4}\left(398^4 - 298^4\right)\mathrm{K^4} - 0.04\,\mathrm{W/m\cdot K}\,(100\,\mathrm{K})/0.01\,\mathrm{m}}{100\,\mathrm{K}}$$

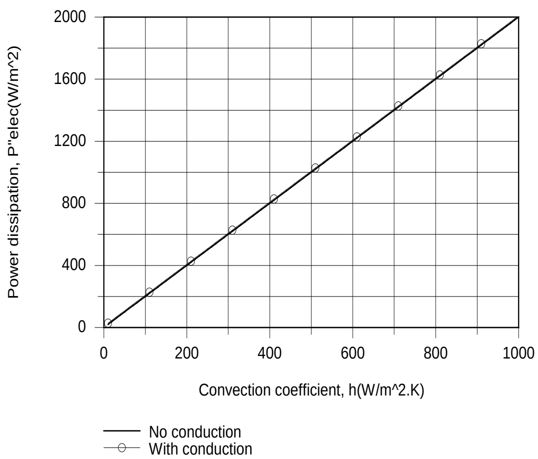
$$= \frac{\left(2000 - 146 - 400\right)\mathrm{W/m^2}}{100\,\mathrm{K}} = 14.5\,\mathrm{W/m^2\cdot K} \qquad <$$

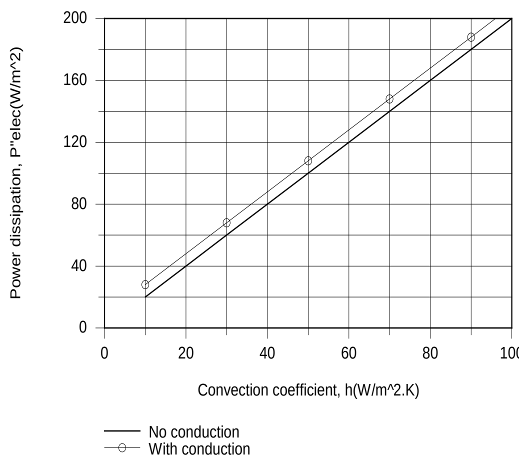
Continued...

## PROBLEM 02 (Cont.)

If conduction, radiation, or conduction and radiation are neglected, the corresponding values of h and the percentage errors are 18.5 $W/m^2 \cdot K$ (27.6%), 16 $W/m^2 \cdot K$ (10.3%), and 20 $W/m^2 \cdot K$ (37.9%).

(c) For a fixed value of $T_s$ = 27°C, the conduction loss remains at $q''_{cond}$ = 8 $W/m^2$, which is also the fixed difference between $P''_{elec}$ and $q''_{conv}$. Although this difference is not clearly shown in the plot for $10 \leq h \leq 1000$ $W/m^2 \cdot K$, it is revealed in the subplot for $10 \leq 100$ $W/m^2 \cdot K$.




Errors associated with neglecting conduction decrease with increasing h from values which are significant for small h ($h < 100$ $W/m^2 \cdot K$) to values which are negligible for large h.

**COMMENTS:** In liquids (large h), it is an excellent approximation to neglect conduction and assume that all of the dissipated power is transferred to the fluid.