

CHG 2314

Heat Transfer Operations

Winter 2016

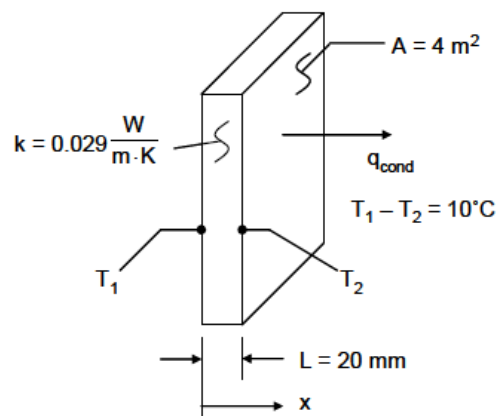
Solutions to Problem Set 1

PROBLEM 1.1

KNOWN: Thermal conductivity, thickness and temperature difference across a sheet of rigid extruded insulation.

FIND: (a) The heat flux through a $2\text{ m} \times 2\text{ m}$ sheet of the insulation, and (b) The heat rate through the sheet.

SCHEMATIC:



ASSUMPTIONS: (1) One-dimensional conduction in the x-direction, (2) Steady-state conditions, (3) Constant properties.

ANALYSIS: From Equation 1.2 the heat flux is

$$q_x'' = -k \frac{dT}{dx} = k \frac{T_1 - T_2}{L}$$

Solving,

$$q_x'' = 0.029 \frac{\text{W}}{\text{m} \cdot \text{K}} \times \frac{10 \text{ K}}{0.02 \text{ m}}$$

$$q_x'' = 14.5 \frac{\text{W}}{\text{m}^2} \quad <$$

The heat rate is

$$q_x = q_x'' \cdot A = 14.5 \frac{\text{W}}{\text{m}^2} \times 4 \text{ m}^2 = 58 \text{ W} \quad <$$

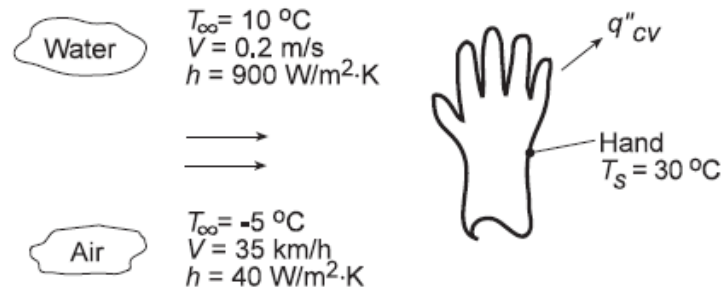
COMMENTS: (1) Be sure to keep in mind the important distinction between the heat flux (W/m^2) and the heat rate (W). (2) The direction of heat flow is from hot to cold. (3) Note that a temperature *difference* may be expressed in kelvins or degrees Celsius.

PROBLEM 1.18

KNOWN: Hand experiencing convection heat transfer with moving air and water.

FIND: Determine which condition feels colder. Contrast these results with a heat loss of 30 W/m^2 under normal room conditions.

SCHEMATIC:



ASSUMPTIONS: (1) Temperature is uniform over the hand's surface, (2) Convection coefficient is uniform over the hand, and (3) Negligible radiation exchange between hand and surroundings in the case of air flow.

ANALYSIS: The hand will feel colder for the condition which results in the larger heat loss. The heat loss can be determined from Newton's law of cooling, Eq. 1.3a, written as

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

For the air stream:

$$q''_{\text{air}} = 40 \text{ W/m}^2 \cdot \text{K} [30 - (-5)] \text{ K} = 1,400 \text{ W/m}^2 \quad <$$

For the water stream:

$$q''_{\text{water}} = 900 \text{ W/m}^2 \cdot \text{K} (30 - 10) \text{ K} = 18,000 \text{ W/m}^2 \quad <$$

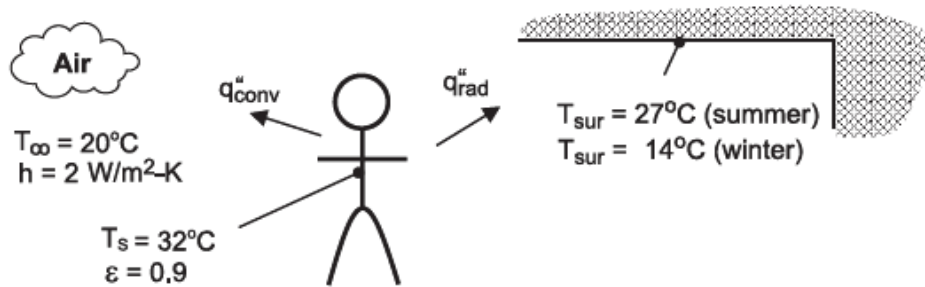
COMMENTS: The heat loss for the hand in the water stream is an order of magnitude larger than when in the air stream for the given temperature and convection coefficient conditions. In contrast, the heat loss in a normal room environment is only 30 W/m^2 which is a factor of 400 times less than the loss in the air stream. In the room environment, the hand would feel comfortable; in the air and water streams, as you probably know from experience, the hand would feel uncomfortably cold since the heat loss is excessively high.

PROBLEM 1.29

KNOWN: Air and wall temperatures of a room. Surface temperature, convection coefficient and emissivity of a person in the room.

FIND: Basis for difference in comfort level between summer and winter.

SCHEMATIC:



ASSUMPTIONS: (1) Person may be approximated as a small object in a large enclosure.

ANALYSIS: Thermal comfort is linked to heat loss from the human body, and a *chilled* feeling is associated with excessive heat loss. Because the temperature of the room air is fixed, the different summer and winter comfort levels cannot be attributed to convection heat transfer from the body. In both cases, the heat flux is

$$\text{Summer and Winter: } q''_{\text{conv}} = h(T_s - T_\infty) = 2 \text{ W/m}^2 \cdot \text{K} \times 12 \text{ }^\circ\text{C} = 24 \text{ W/m}^2$$

However, the heat flux due to radiation will differ, with values of

$$\text{Summer: } q''_{\text{rad}} = \varepsilon\sigma(T_s^4 - T_{\text{sur}}^4) = 0.9 \times 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 (305^4 - 300^4) \text{ K}^4 = 28.3 \text{ W/m}^2$$

$$\text{Winter: } q''_{\text{rad}} = \varepsilon\sigma(T_s^4 - T_{\text{sur}}^4) = 0.9 \times 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 (305^4 - 287^4) \text{ K}^4 = 95.4 \text{ W/m}^2$$

There is a significant difference between winter and summer radiation fluxes, and the chilled condition is attributable to the effect of the colder walls on radiation.

COMMENTS: For a representative surface area of $A = 1.5 \text{ m}^2$, the heat losses are $q_{\text{conv}} = 36 \text{ W}$, $q_{\text{rad(summer)}} = 42.5 \text{ W}$ and $q_{\text{rad(winter)}} = 143.1 \text{ W}$. The winter time radiation loss is significant and if maintained over a 24 h period would amount to 2,950 kcal.