3.6 A technique for measuring convection heat transfer coefficients involves bonding one surface of a thin metallic foil to an insulating material and exposing the other surface to the fluid flow conditions of interest.

By passing an electric current through the foil, heat is dissipated uniformly within the foil and the corresponding flux, \( P_{\text{elec}} \), may be inferred from related voltage and current measurements. If the insulation thickness \( L \) and thermal conductivity \( k \) are known and the fluid, foil, and insulation temperatures \( T_{\text{fl}}, T_{\text{f}}, T_{\text{i}} \) are measured, the convection coefficient may be determined. Consider conditions for which \( T_{\text{fl}} = T_{\text{f}} = 25^\circ\text{C}, \ P_{\text{elec}} = 2000 \text{ W/m}^2, \ L = 10 \text{ mm}, \) and \( k = 0.040 \text{ W/m} \cdot \text{K}. \)

(a) With water flow over the surface, the foil temperature measurement yields \( T_{\text{f}} = 77^\circ\text{C} \). Determine the convection coefficient. What error would be incurred by assuming all of the dissipated power to be transferred to the water by convection?

(b) If, instead, air flows over the surface and the temperature measurement yields \( T_{\text{f}} = 125^\circ\text{C} \), what is the convection coefficient? The foil has an emissivity of 0.15 and is exposed to large surroundings at 25°C. What error would be incurred by assuming all of the dissipated power to be transferred to the air by convection?

Typically, heat flux gauges are operated at a fixed temperature \( T_{\text{f}} \), in which case the power dissipation provides a direct measure of the convection coefficient. For \( T_{\text{f}} = 27^\circ\text{C} \), plot \( P_{\text{elec}} \) as a function of \( h \) for \( 10 \leq h \leq 1000 \text{ W/m}^2 \cdot \text{K} \). What effect does \( h \) have on the error associated with neglecting conduction through the insulation?

25 W/m²·K, but with 30 km/h winds it reaches 65 W/m²·K. In both cases the ambient air temperature is -15°C.

(a) What is the ratio of the heat loss per unit area from the skin for the calm day to that for the windy day?

(b) What will be the skin outer surface temperature for the calm day? For the windy day?

(c) What temperature would the air have to assume on the calm day to produce the same heat loss occurring with the air temperature at -15°C on the windy day?

3.8 A thermostane window consists of two pieces of glass 7 mm thick that enclose an air space 7 mm thick. The window separates room air at 20°C from outside ambient air at -10°C. The convection coefficient associated with the inner (room-side) surface is 10 W/m²·K.

(a) If the convection coefficient associated with the outer (ambient) air is \( h_b = 80 \text{ W/m}^2 \cdot \text{K} \), what is the heat loss through a window that is 0.8 m long by 0.5 m wide? Neglect radiation, and assume the air enclosed between the panes to be stagnant.

(b) Compute and plot the effect of \( h_b \) on the heat loss for \( 10 \leq h_b \leq 100 \text{ W/m}^2 \cdot \text{K} \). Repeat this calculation for a triple-pane construction in which a third pane and a second air space of equivalent thickness are added.

3.9 The composite wall of an oven consists of three materials, two of which are of known thermal conductivity, \( k_A = 30 \text{ W/m} \cdot \text{K} \) and \( k_B = 50 \text{ W/m} \cdot \text{K} \), and known thickness, \( L_A = 0.30 \text{ m} \) and \( L_B = 0.15 \text{ m} \). The third material, B, which is sandwiched between materials A and C, is of unknown thickness, \( L_B = 0.15 \text{ m} \), but unknown thermal conductivity \( k_B \).

Under steady-state operating conditions, measurements reveal an outer surface temperature of \( T_{\text{f, o}} = 20^\circ\text{C} \), an inner surface temperature of \( T_{\text{f, i}} = 600^\circ\text{C} \), and an oven air temperature of \( T_{\text{f, a}} = 800^\circ\text{C} \). The inside convection coefficient \( h_b \) is known to be 25 W/m²·K. What is the value of \( k_B \)?

3.10 A testing lab is contracted to measure the thermal conductivity of various liquids as a function of the liquid temperature. Typically, the lab would measure the thermal conductivity and its temperature dependence of a material conductivity material sandwiched between two \( t_1 = 1\text{-mm-thick stainless steel plates with } k_1 = 15 \text{ W/m} \cdot \text{K} \). The resulting stainless steel-low thermal conductivity-stainless steel sandwiches then separate \( N = 5 \), \( t_2 = 2\text{-mm-thick layers of the liquid. The entire structure is heated from above to eliminate natural convection within the liquid, and cooled from below with a flowing liquid. The temperature of each stainless steel sheet is measured with a thermocouple, and the device is encased in insulation. The temperature range over which the thermal conductivity of a particular liquid is to be measured is 300 K \( \leq T \leq 400 \text{ K} \). To resolve the temperature dependence of the liquid's thermal conductivity, the temperature difference across each liquid layer is set to be held within \( \Delta T = 2^\circ\text{C} \). The nominal thermal conductivity of the liquid is \( h_b = 0.8 \text{ W/m} \cdot \text{K} \).

1.4 A cylindrical insulated tank, \( d = 0.1 \text{ m}, h = 0.2 \text{ m}, \) contains water at \( t_0 = 0.1 \text{ m}, \) with damped engine operating at 3000 W. Determine \( k_{\text{eff,a}}, \) of the water, with respect to \( \Delta T \), and compare the 

(a) Consider the low thermal conductivity material to be Bakelite. Determine the overall height, \( H \), of the experimental apparatus.

(b) Consider replacing the Bakelite with an aerogel characterized by \( k_a = 0.0065 \text{ W/m} \cdot \text{K} \). What is the overall height of the apparatus?

(c) To minimize heat losses through the sides of the device, the area of the heater (\( A_H \)) is made 10 times larger than the area of the sides (\( A_S \)) of the device. Compare the required heater area and required electrical power for devices constructed using Bakelite and aerogel low thermal conductivity materials.

3.11 The wall of a drying oven is constructed by sandwiching an insulation material of thermal conductivity \( k = 0.05 \text{ W/m} \cdot \text{K} \) between thin metal sheets. The oven air is at \( T_{\text{a, o}} = 30^\circ\text{C} \), and the corresponding convection coefficient is \( h_a = 30 \text{ W/m}^2 \cdot \text{K} \). The inner wall surface absorbs a radiant flux of \( q_{\text{rad}} = 100 \text{ W/m}^2 \) from hotter objects.