جامعة تكريت كلية الهندسة قسم الهندسة الميكانيكية

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المرحلة: الثالثة

Tikrit university

Collage of engineering

Mechanical department

Subject: Heat Transfer

Class: 3ed Year

Lecturer: Dr. Tadahmun Ahmed Yassen

References:

1. Principle of heat transfer by Krieth.
2. Heat transfer by Holman.
3. Heat Transfer a practical approach by Yunus Single.
4. Fundamentals of heat and mass transfer by Incropera.

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CHAPTER ONE

Introduction

1.1 Heat Transfer Definition

The science of thermodynamics deals with the amount of heat transfer as a system undergoes a process from one equilibrium state to another, and makes no reference to how long the process will take. But in engineering, we are often interested in the rate of heat transfer, which is the topic of the science of heat transfer.

Heat transfer or (heat) is thermal energy in transmit due to a spacial temperature difference.

Whenever there exist a temperature difference in a medium or between media, heat transfer must occur.

As shown in Figure 1.1, we refer to different types of heat transfer processes as modes. When a temperature gradient exists in a stationary medium, which may be a solid or a fluid, we use the term conduction to refer to the heat transfer that will occur across the medium. In contrast, the term convection refers to heat transfer that will occur between a surface and a moving fluid when they are at different

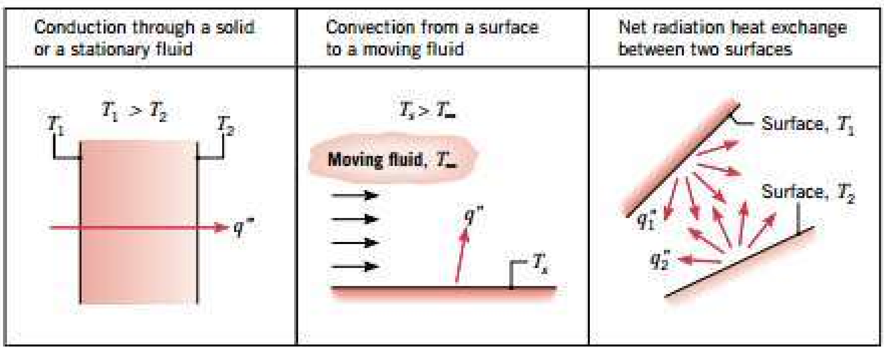


FIGURE 1.1 Conduction, convection, and radiation heat transfer modes.

temperatures. The third mode of heat transfer is termed thermal radiation. All surfaces of finite temperature emit energy in the form of electromagnetic waves. Hence, in the absence of an intervening medium, there is net heat transfer by radiation between two surfaces at different temperatures.

1.2 Physical Origins and Rate Equations

As engineers it is important that we understand the physical mechanisms which underlie the heat transfer modes and that we be able to use the rate equations that quantify the amount of energy being transferred per unit time.

1.2.1 Conduction

At mention of the word conduction, we should immediately conjure up concepts of atomic and molecular activity, for it is processes at these levels that sustain this mode of heat transfer. Conduction may be viewed as the transfer of energy from the more energetic to the less energetic particles of a substance due to interactions between the particles. The physical mechanism of conduction is most easily explained by considering a gas and using ideas familiar from your thermodynamics background. Consider a gas in which there exists a temperature gradient and assume that there is no bulk, or macroscopic, motion. The gas may occupy the space between two surfaces that are maintained at different temperatures, as shown in Figure 1.2. We associate the temperature at any point with the energy of gas molecules in proximity to the point. This energy is related to the random translational motion, as well as to the internal rotational and vibrational motions, of the molecules.

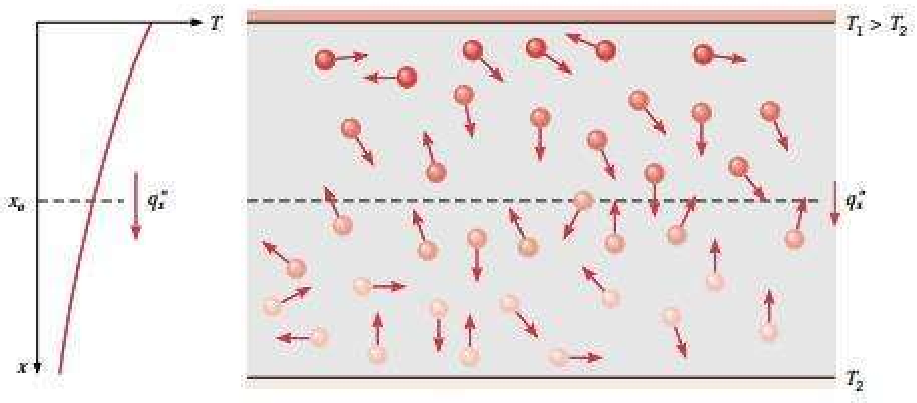


FIGURE 1.2 Association of conduction heat transfer with diffusion of energy due to molecular activity.

Conduction can take place in solids, liquids, or gases. In gases and liquids, conduction is due to the *collisions* and *diffusion* of the molecules during their random motion. In solids, it is due to the combination of *vibrations* of the molecules in a lattice and the energy transport by *free electrons*.

It is possible to quantify heat transfer processes in terms of appropriate rate equations. These equations may be used to compute the amount of energy being transferred per unit time. For heat conduction, the rate equation is known as Fourier's law. For the one-dimensional plane wall shown in Figure 1.3, having a temperature distribution T(x), the rate equation is

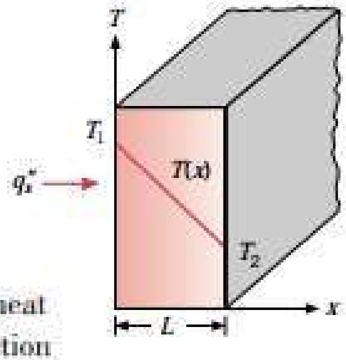


FIGURE 1.3 One-dimensional heat transfer by conduction (diffusion of energy).

expressed as:

$$\frac{q_x}{A}\alpha-\frac{dT}{dx}$$

Where:

q_x: is the heat flow in x-direction, w.

A: is the area normal to the flow direction, m^2.

$\frac{dT}{dx}$: temperature gradiant (slope of the temperature curve), ˚C/m.

$$\ddot{q_x}=\frac{q_x}{A}=-k\frac{dT}{dx} \qquad 1.1$$

Where:

k : the proportional costant (thermal conductivity of the material), W/m.˚C.

$\ddot{q_x}$: heat flux, W/m^2.

Simplifying above equation we get:

$$\frac{q_x}{A}dx = -kdT$$

$$\int_0^L \frac{q_x}{A}dx = \int_{T_1}^{T_2} -kdT$$

Where the temperature is T_1 at x=0 and T_2 at x=L

For constant heat flux and thermal conductivity integrating the above equation we get:

$$\frac{q_x}{A}L = -k(T_2 - T_1)$$

$$\frac{q_x}{A} = -K\frac{(T_2-T_1)}{L} \qquad 1.2$$

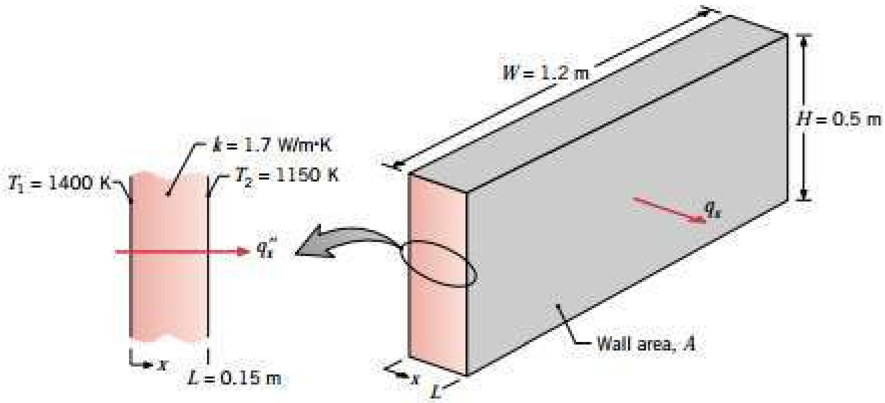
Example 1.1

The wall of an industrial furnace is constructed from 0.15-m-thick fireclay brick having a thermal conductivity of 1.7 W/m.K. Measurements made during steady state operation reveal temperatures of 1400 and 1150 K at the inner and outer surfaces, respectively. What is the rate of heat loss through a wall that is 0.5 m by 1.2 m on a side?

Known: Steady-state conditions with prescribed wall thickness, area, thermal conductivity, and surface temperatures.

Find: Wall heat loss.

Schematic:



Assumptions:

1. Steady-state conditions.

2. One-dimensional conduction through the wall.

3. Constant thermal conductivity.

Analysis: Since heat transfer through the wall is by conduction, the heat flux may be determined from Fourier's law. Using Equation 1.2, we have.

$\ddot{q}_x = -K\frac{(T_2-T_1)}{L}$ = 1.7 W/m.K $*\frac{250\ K}{0.15\ m}$ = 2833 W/m^2

The heat flux represents the rate of heat transfer through a section of unit area, and it is uniform (invariant) across the surface of the wall. The heat loss through the wall of area is then

$q_x = \ddot{q}_x A = (HW)\ddot{q}_x = (0.5m * \ 1.2m) * 2833$ W/m^2=1700 W.

Thermal Conductivity

It is a property of the material. The value of k, is an indicator of how fast heat is conduct through material. For most substances; thermal conductivity varies with temperature.

$$k(T) = k_\circ(1 + \beta_k T) \qquad 1.3$$

Where:

β_k : imperical constant.

$k_\circ$: thermal conductivity at datum temperature.

$$\int_0^L \frac{q_x}{A} dx = \int_{T_1}^{T_2} -k_\circ (1 + \beta_k T) dT$$

$$\frac{q_x}{A} L = -k_\circ \left[(T_2 - T_1) + \frac{\beta_k}{2} (T_2^2 - T_1^2) \right]$$

1.2.2 Convection Heat Transfer

Convection is a mode of heat transfer associated with fluid motion and it is of two types:

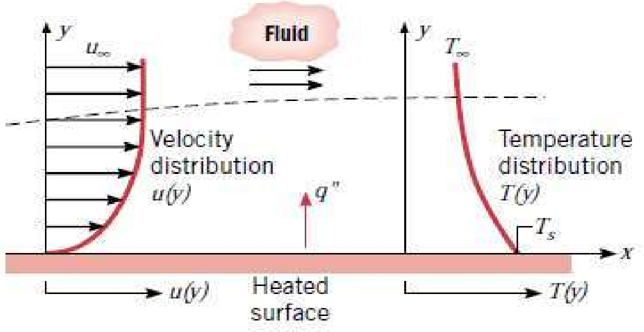


FIGURE 1.4
Boundary layer development in convection heat transfer.

1. Forced convection: when the flow is caused by external means, such as by a fan, a pump, or atmospheric winds. As an example, consider the use of a fan to provide forced convection air cooling of hot electrical components on a stack of printed circuit boards (Figure 1.5a).
2. Free (or natural) convection: the flow is induced by buoyancy forces, which are due to density differences caused by temperature variations in the fluid. An example is the free convection heat transfer that occurs from hot components on a vertical array of circuit boards in air (Figure 1.5b). Air that makes contact with the components experiences an increase in temperature and hence a reduction in density. Since it is now lighter than the surrounding air, buoyancy forces induce a vertical motion for which warm air ascending from the boards is replaced by an inflow of cooler ambient air.

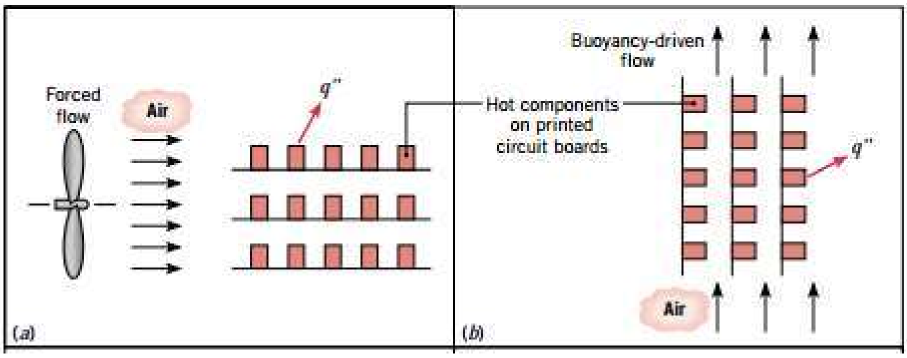


Figure 1.5: a. Forced convection, b. Free convection.

The heat transfer by convection is found to be proportional to the temperature difference.

$$\frac{q_c}{A}\alpha(T_s - T_\infty) \qquad 1.4$$

$$q_c = \overline{h_c}A(T_s - T_\infty)$$

Where:

T_s : wall surface temperature, ˚C.

T_∞ : surrounding temperature, ˚C.

$\overline{h_c}$: proportionality constant (convection heat transfer coefficient, W/m^2. ˚C.

Example 1.2:

Air at 20 ˚C blows over a hot plate 50 by 75 cm maintained at 250 ˚C. The convection heat-transfer

coefficient is 25 W/m^2 · ˚C. Calculate the heat transfer.

Solution

From Newton's law of cooling

$$\mathrm{q_c} = \overline{\mathrm{h_c}}\mathrm{A}(\mathrm{T_s} - \mathrm{T_\infty})$$

= (25)(0.50*0.75)(250−20)

= 2.156 Kw

Example 1.3:

A plane wall of thermal conductivity (k=2.4 W/m^2. ˚C) has its side temperature of 100 ˚C and 40 ˚C, the wall thickness is 10 cm and exposed to environment at right side where convection heat transfer coefficient is 10 W/m^2. ˚C, calculate:

1. The heat flow per unit area.
2. The temperature of the air at right side.

Assume steady state.

Solution:

T_1=100 ˚C, T_2=40 ˚C, k=2.4 W/m. ˚C, h_c=10 W/m^2. ˚C.

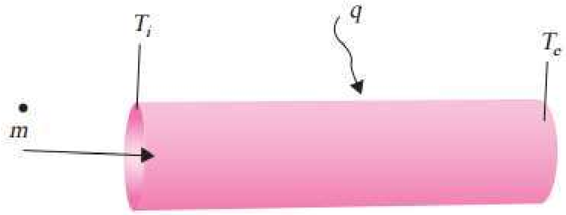
$$\ddot{q} = \frac{q}{A} = -K\frac{\Delta T}{\Delta x} = -2.4\frac{(40-100)}{0.1} = 1440 \ \text{W/m}^2$$

$$\frac{q}{A} = h_c(T_w - T_\infty) = 10(40 - T_\infty)$$

$T_\infty = 104°\mathrm{C}$

Find T_∞ when h_c=100 W/m^2. °C.

Convection Energy Balance on a Flow Channel



from inlet conditions at T_i to exit conditions at T_e. Using the symbol i to designate enthalpy (to avoid confusion with h, the convection coefficient), the energy balance on the fluid is

$$q = \dot{m}(i_e - i_i)$$

where $\dot{m}$ is the fluid mass flow rate. For many single-phase liquids and gases operating over reasonable temperature ranges $\Delta i = c_p \Delta T$ and we have

$$q = \dot{m} c_p (T_e - T_i)$$

$$q = \dot{m} c_p (T_e - T_i) = hA(T_{w,\text{avg}} - T_{\text{fluid, avg}})$$

1.2.3 Radiation

Thermal radiation is energy emitted by matter that is at a nonzero temperature. Although we will focus on radiation from solid surfaces, emission may also occur from liquids and gases. Regardless of the form of matter, the emission may be attributed to changes in the electron configurations of the constituent atoms or molecules. The energy of the radiation field is transported by electromagnetic waves (or alternatively, photons). While the transfer of energy by conduction or convection requires the presence of a material medium, radiation does not. In fact, radiation transfer occurs most efficiently in a vacuum.

There is an upper limit to the emissive power, which is prescribed by the Stefan–Boltzmann law

$$E_b = \sigma T_s^{\,4} \qquad 1.5$$

σ*:* is the proportional constant *Stefan–Boltzmann constant* and have a value of 5.67*10^{-8} W/m^2.K^4.

Most real materials surfaces do not emit radiation ideally. These are called gray surfaces, emit ε value of black body which called emissivity, and for gray body:

$$E = \varepsilon\sigma T^4 \qquad 1.6$$

ε :is a radiative property of the surface termed the emissivity. With values in the range , the range $0 \le \varepsilon \le 1$.

Radiation in an Enclosure

A simple radiation problem is encountered when we have a heat-transfer surface at temperature T_1 completely enclosed by a much larger surface maintained at T_2. We will show that the net radiant exchange in this case can be calculated with

$$\frac{q_r}{A} = \sigma\varepsilon({T_1}^4 - {T_2}^4) \qquad 1.7$$

In addition, we must take into account the fact that not all the radiation leaving one surface will reach the other surface since electromagnetic radiation travels in straight lines and some will be lost to the surroundings. We therefore introduce two new factors in Equation (1-6) to take into account both situations, so that

$$\frac{q_r}{A} = F_\varepsilon F_G \sigma({T_1}^4 - {T_2}^4)$$

where F_ε is the emissivity function, and F_G is the geometric "view factor" function.

Example 1.4:

Two infinite black plates at 800 ˚C and 300 ˚C exchange heat by radiation. Calculate the heat transfer per unit area.

$$\frac{q_r}{A} = \sigma({T_1}^4 - {T_2}^4)$$

$=5.67*10^{-8} (1073^4-573^4)$

$=69.03$ Kw/m^2.

Air at 20°C blows over a hot plate 50 by 75 cm maintained at 250°C. The convection heat-transfer coefficient is 25 W/m^2 · °C. Calculate the heat transfer.

■ Solution

From Newton's law of cooling

$$q = hA(T_w - T_\infty)$$
$$= (25)(0.50)(0.75)(250 - 20)$$
$$= 2.156 \text{ kW} \quad [7356 \text{ Btu/h}]$$

Example 1.5:

Assuming that the plate in Example 1-2 is made of carbon steel (1%) 2 cm thick and that 300 W is lost from the plate surface by radiation, calculate the inside plate temperature.

Solution

The heat conducted through the plate must be equal to the sum of convection and radiation heat losses:

$$q_{\text{cond}} = q_{\text{conv}} + q_{\text{rad}}$$

$$-kA\frac{\Delta T}{\Delta x} = 2.156 + 0.3 = 2.456 \text{ kW}$$

$$\Delta T = \frac{(-2456)(0.02)}{(0.5)(0.75)(43)} = -3.05°\text{C} \quad [-5.49°\text{F}]$$

where the value of k is taken from Table 1-1. The inside plate temperature is therefore

$$T_i = 250 + 3.05 = 253.05°\text{C}$$

Example 1.6:

A horizontal steel pipe having a diameter of 5 cm is maintained at a temperature of 50◦C in a large room where the air and wall temperature are at 20◦C. The heat-transfer coefficient for free convection with this geometry and air is h = 6.5 W/m^2 · ◦C. The surface emissivity of the steel may be taken as 0.8. Calculate the total heat lost by the pipe per unit length.

Solution:

T1 = 50◦C = 323◦K and T2 = 20◦C = 293◦K,

The total heat loss is the sum of convection and radiation. The surface area is πdL, so the convection loss per unit length is

$$q/L]_{\text{conv}} = h(\pi d)(T_w - T_\infty)$$
$$= (6.5)(\pi)(0.05)(50 - 20) = 30.63 \text{ W/m}$$

The pipe is a body surrounded by a large enclosure so the radiation heat transfer can be calculated from Equation

$$q/L]_{\text{rad}} = \epsilon_1(\pi d_1)\sigma(T_1^4 - T_2^4)$$
$$= (0.8)(\pi)(0.05)(5.669 \times 10^{-8})(323^4 - 293^4)$$
$$= 25.04 \text{ W/m}$$

The total heat loss is therefore

$$q/L]_{\text{tot}} = q/L]_{\text{conv}} + q/L]_{\text{rad}}$$
$$= 30.63 + 25.04 = 55.67 \text{ W/m}$$

H.W chapter one

1-1 If 3 kW is conducted through a section of insulating material 0.6 m^2 in cross section and 2.5 cm thick and the thermal conductivity may be taken as 0.2W/m · ◦C, compute the temperature difference across the material.

1-2 A temperature difference of 85◦C is impressed across a fiberglass layer of 13 cm thickness. The thermal conductivity of the fiberglass is 0.035W/m · ◦C. Compute the heat transferred through the material per hour per unit area.

1-4 The temperatures on the faces of a plane wall 15 cm thick are 375 and 85◦C. The wall is constructed of a special glass with the following properties: k =0.78 W/m · ◦C, ρ=2700 kg/m^3, c_P =0.84 kJ/kg · ◦C. What is the heat flow through the wall at steady-state conditions?

1-9 A 5-cm layer of loosely packed asbestos is placed between two plates at 100 and 200◦C. Calculate the heat transfer across the layer.

1-10 A certain insulation has a thermal conductivity of 10 W/m · ◦C. What thickness is necessary to effect a temperature drop of 500◦C for a heat flow of 400 W/m^2?

1-12 Two perfectly black surfaces are constructed so that all the radiant energy leaving a surface at 800◦C reaches the other surface. The temperature of the other surface is maintained at 250◦C. Calculate the heat transfer between the surfaces per hour and per unit area of the surface maintained at 800◦C.

1-13 Two very large parallel planes having surface conditions that very nearly approximate those of a blackbody are maintained at 1100 and 425◦C, respectively. Calculate the heat transfer by radiation between the planes per unit time and per unit surface area.

1-14 Calculate the radiation heat exchange in 1 day between two black planes having the area of the surface of a 0.7-m-diameter sphere when the planes are maintained at 70 K and 300 K.

1-15 Two infinite black plates at 500 and 100◦C exchange heat by radiation. Calculate the heat-transfer rate per unit area. If another perfectly black plate is placed between the 500 and 100◦C plates, by how much is the heat transfer reduced? What is the temperature of the center plate?

a. $q = (5.669\times10^{-8})[(773)^4 - (373)^4] = 1.914\times10^4 \text{ W/m}^2$

b. $q = (5.669\times10^{-8})[(773)^4 - (T_p)^4]$

$= (5.669\times10^{-8})[(T_p)^4 - (373)^4]$

$T_p = 641 \text{ K}$

$q = 8474\cdot3 \text{ W/m}^2$

Reduced by 44.3%

1-16 Water flows at the rate of 0.5 kg/s in a 2.5-cm-diameter tube having a length of 3 m. A constant heat flux is imposed at the tube wall so that the tube wall temperature is 40◦C higher than the water temperature. Calculate the heat transfer and estimate the temperature rise in the water. The water is pressurized so that boiling cannot occur.

$$q = hA(T_w - T_{fluid})$$

From Table 1–2 $h = 3500 \dfrac{\text{W}}{\text{m}^2 \cdot {}^\circ\text{C}}$

$$q = (3500)\pi dL(40) = (3500)\pi(0.025)(3)(40) = 32987 \text{ W}$$

$$q = mc_p\Delta T_{fluid}$$

$$32{,}987 \text{ W} = (0.5 \text{ kg/s})(4180 \text{ J/kg}\cdot{}^\circ\text{C})\Delta T$$

$$\Delta T = 15.78^\circ\text{C}$$

1-19 A small radiant heater has metal strips 6 mm wide with a total length of 3 m. The surface emissivity of the strips is 0.85. To what temperature must the strips be heated if they are to dissipate 2000Wof heat to a room at 25◦C?

$$q = \sigma\varepsilon A[(T_1)^4 - (T_2)^4]$$

$$2000 \text{ W} = (5.669\times10^{-8})(0.85)(0.006)(3)[(T_1)^4 - (298)^4]$$

$$T_1 = 1233 \text{ K}$$

1-20 Calculate the energy emitted by a blackbody at 1000◦C.

1-21 If the radiant flux from the sun is 1350W/m2, what would be its equivalent blackbody temperature?

1-22 A 4.0-cm-diameter sphere is heated to a temperature of 200◦C and is enclosed in a large room at 20◦C. Calculate the radiant heat loss if the surface emissivity is 0.6.

1-23 A flat wall is exposed to an environmental temperature of 38◦C. The wall is covered with a layer of insulation 2.5 cm thick whose thermal conductivity is 1.4 W/m · ◦C, and the temperature of the wall on the inside of the insulation is 315◦C. The wall loses heat to the environment by convection. Compute the value of the convection heat-transfer coefficient that must be maintained on the outer surface of the insulation to ensure that the outer-surface temperature does not exceed 41◦C.

1-25 One side of a plane wall is maintained at 100◦C, while the other side is exposed to a convection environment having T =10◦C and h=10 W/m2 · ◦C. The wall has k =1.6W/m· ◦C and is 40 cm thick. Calculate the heat-transfer rate through the wall.

1-28 A solar radiant heat flux of 700 W/m2 is absorbed in a metal plate that is perfectly insulated on the back side. The convection heat-transfer coefficient on the plate is 11 W/m2 · ◦C, and the ambient air temperature is 30◦C. Calculate the temperature of the plate under equilibrium conditions.