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Chapter One

INTRODUCTION

Heat transfer is the science that seeks to predict the energy transfer which may take Place between material bodies a result of a temperature difference.

Method of Heat Transfer

1. Conduction heat transfer.

2. Convection heat transfer.

3. Radiation heat transfer.

Conduction Heat Transfer:

Represent energy transfer from high temperature region to low temperature region. The energy is transferred by Conduction and that heat transfer rate per unit is proportional to the normal temperature gradient. The area

Heat transfer rate equation (Q):

$$Q_{cond} = -kA\frac{\Delta T}{\Delta x} \quad (W) \qquad (1.1)$$

where

k: is the thermal conductivity (W/m. k)

A: is the cross sectional area (m^2)

ΔT: is the temperature gradient (k, c)

Δx: is the heat flow path (m)

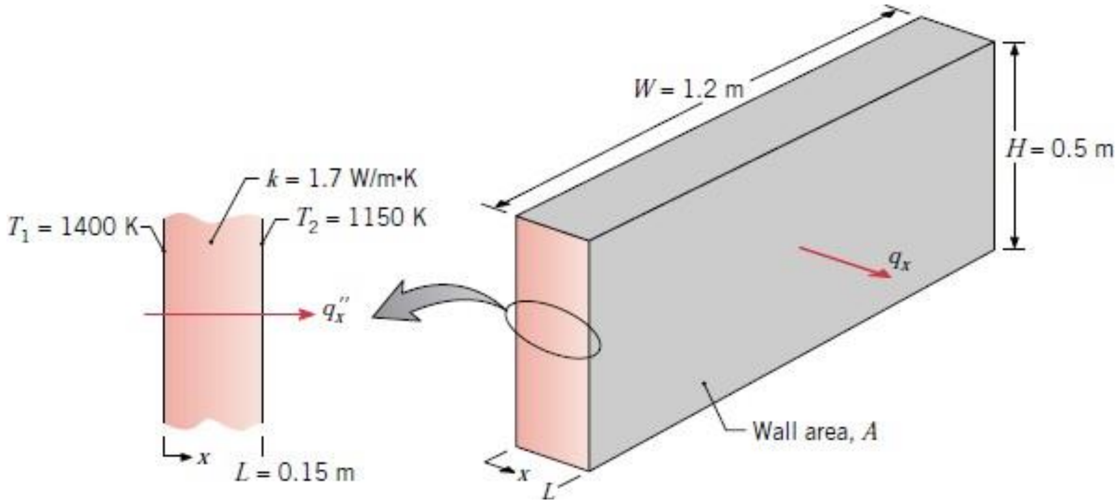
Heat flux (q)

$$q = \frac{Q}{A} = -k\frac{\Delta T}{\Delta x} \quad (W/m^2) \qquad (1.2)$$

NOTE: Negative Sign denotes heat transfer in the direction of decreasing temperature.

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 5511 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) a side?

Solution:



$$Q_{cond} = -kA\frac{\Delta T}{\Delta x} = -k(H * W)\frac{(T_2 - T_1)}{(x_2 - x_1)}$$

$$Q_{cond} = -1.7 * (0.5 * 1.2)\frac{(1150 - 1400)}{(0.015 - 0)}$$

$$Q_{cond} = 1700\ W$$

Example (1.2): The concrete slab of a basement is (11 m) long (8m) wide and (0.2 m) thick. During the winter temperatures are normally (17 ºC) and (10 ºC) at the top and the bottom surfaces respectively. If the concrete has a thermal conductivity of (1.4 w/m. k). What is the rate of heat loss through the slab?

Solution:

$$Q_{cond} = -kA\,\frac{\Delta T}{\Delta x} = -k(L * W)\,\frac{(T_2 - T_1)}{(x_2 - x_1)}$$

$$Q_{cond} = -1.4 * (11 * 8)\frac{(10 - 17)}{0.2}$$

$Q_{cond} = 4312\ W$

Convection Heat Transfer:

Is either free or forced also may be laminar or turbulent. The rate of convection heat transfer is observed to be proportional to the temperature difference and is conveniently expressed by newton's law of cooling as

$$Q_{conv} = h\, A_s (T_s - T_\infty) \qquad (1.3)$$

where

h: is the convection heat transfer coefficient in (W/m². ºC).

A_s: is the surface area through which convection heat transfer takes place (m²).

T_s:is the surface area temperature (ºC).

T_∞: is the temperature of fluid sufficiently far from the surface (ºC).

The force Convection heat transfer is heat transfer between a Solid Surface and the adjacent moving fluid.

Typical Values of the Convection Heat Transfer Coefficient

Process	***h*** **(W/m². ºC)**
Free Convection	
Gases	2-25
Liquids	50-1000
Forced Convection	
Gases	25-250
Liquids	100-20000
Convection with Phase Change	
Boiling or Condensation	2500-100000

Example (1.3): A cartridge electrical heater is shaped as a cylinder of length (L = 200 mm) and outer diameter (D = 20 mm) under normal operating conditions the heater dissipates (2 KW) while submerged in a water flow that is at (20 ºC) and provides a convection heat transfer coefficient of (h = 5000 W/m^2. K). Neglecting heat transfer from the ends of heater, determine its surface temperature (T_s). If the water flow is inadvertently terminated while the heater continues to operate the heater surface is exposed to air that is also at (20 ºC) but for which (h = 50W/m^2. ºC), what is the corresponding surface temperature?

Solution:

T_s in water =?

T_s in air =?

In water:

$$Q_{conv} = hA_s(T_s - T_\infty)$$

$$2000 = 5000 * (\pi * 0.02 * 0.2)(T_s - 20)$$

$$T_s = 20 + \frac{2000}{5000 * \pi * 0.02 * 0.2}$$

$$T_s = 51.8\,℃$$

In air:

$$Q_{conv} = hA_s(T_s - T_\infty)$$

$$2000 = 50 * (\pi * 0.02 * 0.2)(T_s - 20)$$

$$T_s = 20 + \frac{2000}{50 * \pi * 0.02 * 0.2}$$

$$T_s = 3203\,℃$$

Radiation Heat Transfer:

Heat may also be transfer in the regions where a perfect vacuum exists. The mechanism in this case is electromagnetic radiation. The net heat exchange is proportional to the difference in T^4.

$$Q_{rad} = \varepsilon\sigma A(T_s^4 - T_{sur}^4) \qquad (1.4)$$

Where

σ: Stefan-Boltzman Constant = 5.67×10^{-8} W/m^2. K^4

T_s and T_{sur} in k (ºC+ 273=K).

T_s: absolute temperature of surface (K).

T_{sur}: absolute temperature of surroundings (k).

ε: Surface emissivity with values in range $(0 \le \varepsilon \le 1)$

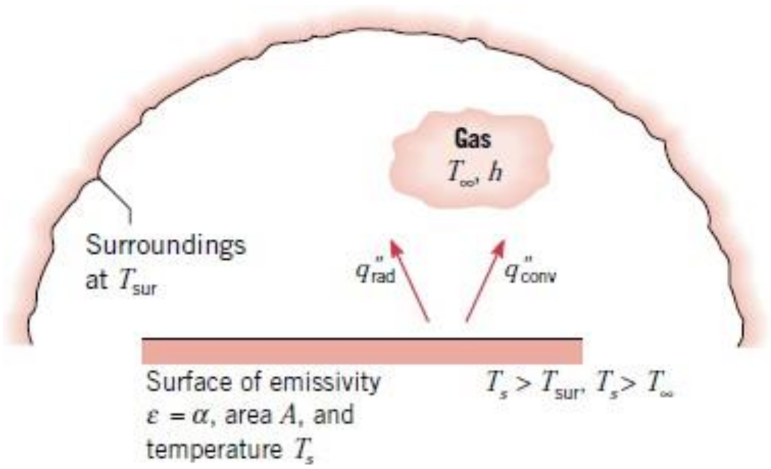


Figure (1) Radiation Exchange between a Large Surface and Surrounding

For the conditions of Figure (1) the total rate of heat transfer from the surface is

$$Q = Q_{conv} + Q_{rad} \qquad (1.5)$$

$$Q = hA(T_s - T_\infty) + \varepsilon\sigma A(T_s^4 - T_{sur}^4) \qquad (1.6)$$

Example (1.4): Two infinite black plates at (800 ºC) and (300 ºC) exchange heat by radiation. Calculate the heat transfer per unit area.

Solution:

T_1= 800 + 273 = 1073 K

T_2 = 300 +27=573 K

Black body ⇒ ε = 1

$$Q_{rad} = \varepsilon\sigma A(T_1^4 - T_2^4)$$

$$Q_{rad}/A = \varepsilon\sigma(T_1^4 - T_2^4)$$

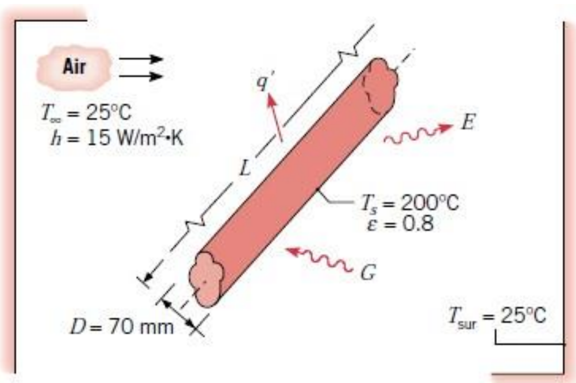
$$\frac{Q_{rad}}{A} = 1 * 5.67 * 10^{-8}(1073^4 - 573^4)$$

$$\frac{Q_{rad}}{A} = 69030\ W/m^2$$

$$\frac{Q_{rad}}{A} = 69.03\ kw/m^2$$

Example (1.5): An uninsulated steam pipe pass through a room and walls are at (25 ºC). The outside diameter of the pipe is (70 mm) and its surface temperature and emissivity are (200 ºC)) and (0.8) respectively, what is the rate of heat loss from the surface per unit length of pipe? If the coefficient associated with free convection heat transfer from the surface to the air is (15 W/m^2. K).

Solution:



$$A = \pi DL$$

$$Q = Q_{conv} + Q_{rad}$$

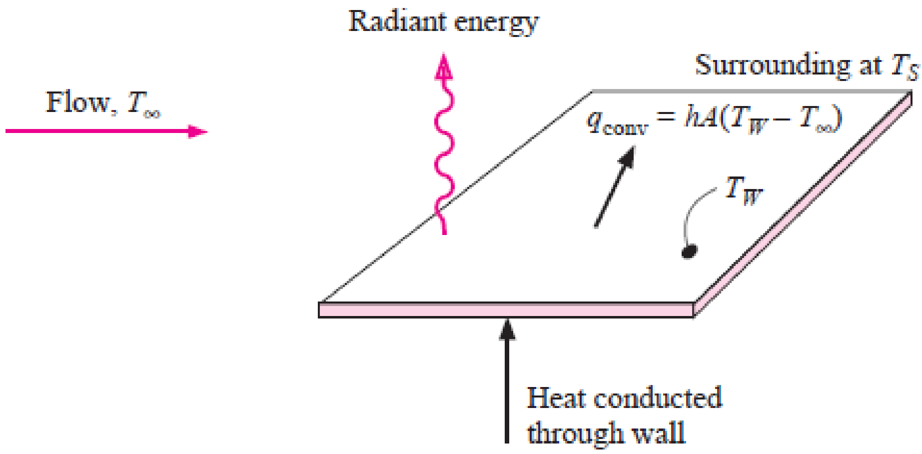
$$Q = hA(T_s - T_\infty) + \varepsilon\sigma A(T_s^4 - T_{sur}^4)$$

$$Q = h(\pi DL)(T_s - T_\infty) + \varepsilon\sigma(\pi DL)(T_s^4 - T_{sur}^4)$$

$$Q/L = h(\pi D)(T_s - T_\infty) + \varepsilon\sigma(\pi D)(T_s^4 - T_{sur}^4)$$

$$\frac{Q}{L} = 15 * \pi * 0.07(200 - 25) + 0.8 * 5.67 * 10^{-8}(473^4 - 293^4) = 998\ W/m$$

Combination of Conduction, Convection and Radiation Heat Transfer



Example (1.6): Air at 20 ºC blows over a hot plate (50 by 75 cm) through wall is made of carbon steel (2 cm) thick maintained at (250 ºC) and that (300 W) is lost from the plate surface by radiation. Calculate the inside plate temperature The Convection heat transfer coefficient is (25 W/m^2. K) and (k = 43 W/m. ºC)

Solution:

$$Q = Q_{conv} + Q_{rad}$$

$$-KA\frac{\Delta T}{\Delta x} = hA(T_s - T_\infty) + Q_{rad}$$

$$\frac{\Delta T}{\Delta x} = \frac{hA(T_s - T_\infty) + Q_{rad}}{-KA}$$

$$\frac{\Delta T}{\Delta x} = \frac{25 * 0.5 * 0.75\ (250 - 20)\ + 300}{-43 * 0.5 * 0.75}$$

$$\frac{\Delta T}{0.2} = -152.5 \Rightarrow \Delta T = -3.05$$

$$\Delta T = T_s - T_i \Rightarrow -3.05 = 250 - T_i$$

$$T_i = 253.05\ ℃$$

Home Work (1):

1- The thermal conductivity of a sheet of rigid, extruded insulation is reported to be (0.029 W/m. K). The measured temperature difference across a (20 mm) thick sheet of the material is ($T_1 - T_2 = 10$ ºC).

(a) What is the heat flux through a (2 m x 2 m) sheet of the insulation?

(b) What is the rate of heat transfer through the sheet of insulation?

2- One face of a copper plate 3 cm thick is maintained at (400 °C), and the other face is maintained at (100 ºC) and the thermal conductivity for copper is (370 W/m·°C). How much heat is transferred through the plate?

3- 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.

4- 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 ºC). The surface emissivity of the steel may be taken as (0.8). If the heat transfer coefficient for free convection with this geometry and air is (6.5 W/m^2.°C), calculate the total heat lost by the pipe per unit length.

5- 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 (0.2 W/m.°C), compute the temperature difference across the material.

6- A certain insulation has a thermal conductivity of (0.01 W/m.°C). What thickness is necessary to effect a temperature drop of 500 °C for a heat flow of (400 W/m^2. K).

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

8- Boiling water at 1 atm may require a surface heat flux of (170340 W/m^2) for a surface temperature of (120 °C). What is the value of the heattransfer coefficient?

9- 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).

10- 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/m^2.°C). The wall has (k = 1.6 W/m.°C) and is (40 cm) thick. Calculate the heat-transfer rate through the wall.

11- A vertical square plate, (30 cm) on a side, is maintained at (50 °C) and exposed to room air at (20 °C). The surface emissivity is (0.8) and the convection heat transfear coefficient is (4.5 W/m^2.°C). Calculate the total heat lost by both sides of the plate.

12- A glass window of width (W=1 m) and height (H =2 m) is (5 mm) thick and has a thermal conductivity of (k_g= 1.4 W/m.K). If the inner and outer surface temperatures of the glass are (15 °C) and (-20 °C), respectively, on a cold winter day, what is the rate of heat loss through the glass? To reduce heat loss through windows, it is customary to use a double pane construction in which adjoining panes are separated by an air space. If the spacing is (10 mm) and the glass surfaces in contact with the air have temperatures of (10 °C) and (-15 °C), what is the rate of heat loss from a (1 m × 2 m) window? The thermal conductivity of air is (k_a= 0.024 W/m.K).