Thermal Conductivity

Thermal conductivity, (k), is the property of a material's ability to conduct heat. It appears primarily in Fourier's Law for heat conduction.

- Experimental measurements may be made to determine the thermal conductivity of different materials.
- In general, the thermal conductivity is strongly temperature-dependent.
- The numerical value of the thermal conductivity indicates how fast heat will flow in a given material.

Some values of thermal conductivity of various materials are shown below:

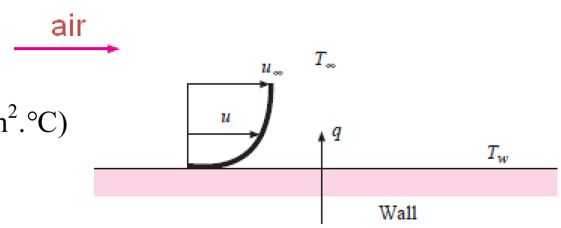
Gases	Liquids	Solids
H_2 = 0.175 W/m.°C	H_2O = 0.556 W/m.°C	Ag = 410 W/m.°C
He = 0.141 W/m.°C	Hg = 8.21 W/m.°C	Cu = 385 W/m.°C
Air = 0.024 W/m.°C	NH_3 = 0.540 W/m.°C	AL = 202 W/m.°C
CO_2 = 0.0146 W/m.°C	Freon = 0.073 W/m.°C	Ni = 93 W/m.°C

Convection Heat Transfer

- Convection was considered as it related to the boundary conditions of a conduction problem.
- The hot metal will cool faster when placed in front of a fan (forced convection) than when exposed to still air (natural convection).

$$q = hA\,(T_w - T_\infty)$$

h = convection heat transfer coeff. (W/m^2.°C)



- If a heated plate were exposed to ambient room air without an external source of motion, a movement of the air would be experienced as a result of the density gradients near the plate. We call this natural, or free, convection as opposed to forced convection, which is experienced in the case of the fan blowing air over a plate.

Radiation Heat Transfer

- In conduction and convection, the energy transfer through a material medium.
- Radiation: the energy can be transferred through vacuum by propagation of electromagnetic radiation.

- Black boby (ideal radiation): it's a body emit energy at a rate proportional to the fourth power of the absolute temperature (in Kelvin) of the body and directly proportional to its surface area. Thus

$$\frac{q}{A}\alpha\, T^4 \Rightarrow \frac{q}{A} = \sigma\, T^4$$

σ = Stefan-Boltzmann constant with the value of 5.669×10^{-8} W/m^{2}K^4.

- Stefan-Boltzmann law of thermal radiation is $q = \sigma\, A(T_1^4 - T_2^4)$ for **black infinite bodies**. T_1 is the temperature of radiative body (K), and T_2 is the temperature of receiving body (K).
- For non black body and take into account 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, the emissivity factor (Є) is used for this purpose as a correction factor for non black bodies. Therefore:

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

F_{ϵ} is the emissivity function
F_G is the geometric function.

EXAMPLE 1-1 Conduction Through Copper Plate

One face of a copper plate 3 cm thick is maintained at 400°C, and the other face is maintained at 100°C. How much heat is transferred through the plate?

Solution

From Appendix A, the thermal conductivity for copper is 370 W/m · °C at 250°C. From Fourier's law

$$\frac{q}{A} = -k\frac{dT}{dx}$$

Integrating gives

$$\frac{q}{A} = -k\frac{\Delta T}{\Delta x} = \frac{-(370)(100-400)}{3\times10^{-2}} = 3.7\ \text{MW/m}^2 \quad [1.173\times10^6\ \text{Btu/h}\cdot\text{ft}^2]$$

Convection Calculation 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

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

Multimode Heat Transfer — EXAMPLE 1-3

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:

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

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

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

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

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

Heat Source and Convection — EXAMPLE 1-4

An electric current is passed through a wire 1 mm in diameter and 10 cm long. The wire is submerged in liquid water at atmospheric pressure, and the current is increased until the water boils. For this situation $h = 5000 \text{ W/m}^2 \cdot {}^\circ\text{C}$, and the water temperature will be 100°C. How much electric power must be supplied to the wire to maintain the wire surface at 114°C?

Solution

The total convection loss is given by Equation (1-8):

$$q = hA\,(T_w - T_\infty)$$

For this problem the surface area of the wire is

$$A = \pi d L = \pi(1 \times 10^{-3})(10 \times 10^{-2}) = 3.142 \times 10^{-4} \text{ m}^2$$

The heat transfer is therefore

$$q = (5000 \text{ W/m}^2 \cdot {}^\circ\text{C})(3.142 \times 10^{-4} \text{ m}^2)(114 - 100) = 21.99 \text{ W} \quad [75.03 \text{ Btu/h}]$$

and this is equal to the electric power that must be applied.

EXAMPLE 1-5 Radiation Heat Transfer

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

Solution

Equation (1-10) may be employed for this problem, so we find immediately

$$
\begin{aligned}
q/A &= \sigma(T_1^4 - T_2^4) \\
&= (5.669 \times 10^{-8})(1073^4 - 573^4) \\
&= 69.03\ \text{kW/m}^2 \quad [21{,}884\ \text{Btu/h}\cdot\text{ft}^2]
\end{aligned}
$$