Technical Language for mechanical engineering

Heat transfer

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Heat transfer

Heat transfer (or heat) is thermal energy in transit due to a spatial temperature difference. Whenever a temperature difference exists in a medium or between media, heat transfer must occur. As shown in Figure, 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 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.

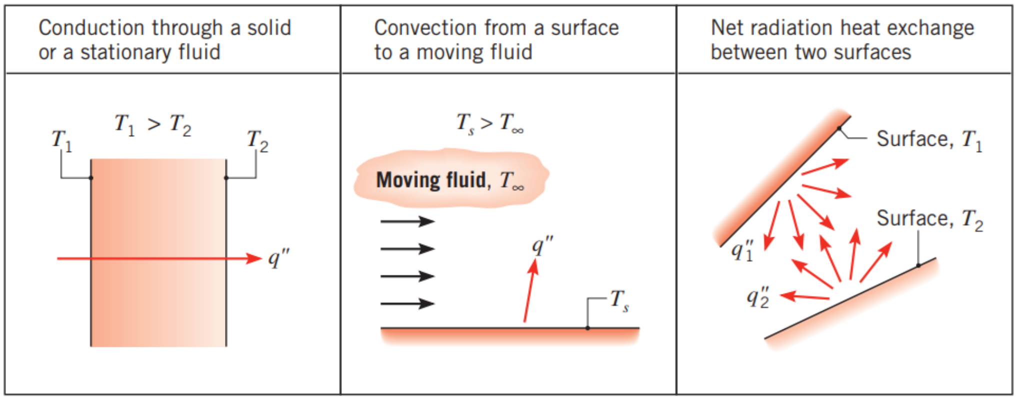

FIGURE 1 Conduction, convection, and radiation heat transfer modes.

At mention of the word conduction, we should immediately conjure up concepts of atomic and molecular activity because processes at these levels 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 a temperature gradient exists, 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 2.

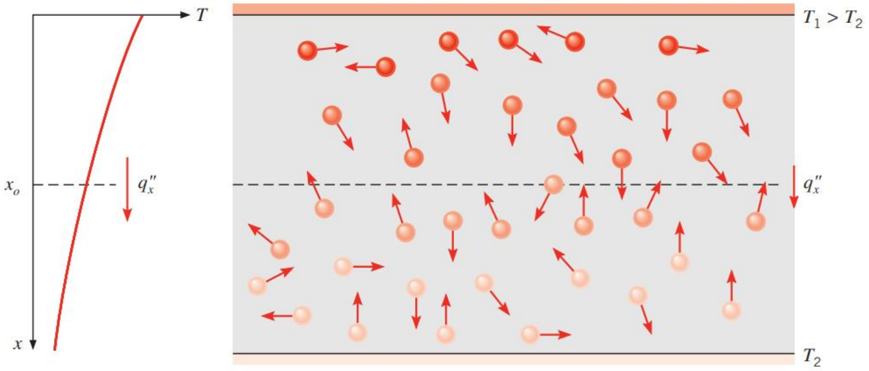

FIGURE 2 Association of conduction heat transfer with diffusion of energy due to molecular activity.

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.

Examples of conduction heat transfer

The exposed end of a metal spoon suddenly immersed in a cup of hot coffee is eventually warmed due to the conduction of energy through the spoon.

On a winter day, there is significant energy loss from a heated room to the outside air. This loss is principally due to conduction heat transfer through the wall that separates the room air from the outside air. Heat transfer processes can be quantified 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’ Law. For the one-dimensional plane wall shown in Figure 3, having a temperature distribution T(x), the rate equation is expressed as:

$$q''_x = -k\frac{dT}{dx}$$

The heat flux (Watt/m2) is the heat transfer rate in the x-direction per unit area perpendicular to the direction of transfer, and it is proportional to the temperature gradient, dT/dx, in this direction. The parameter k is a transport property known as the thermal conductivity (W/m K) and is a characteristic of the wall material. The minus sign is a consequence of the fact that heat is transferred in the direction of decreasing temperature.

Convection

The convection heat transfer mode is comprised of two mechanisms. In addition to energy transfer due to random molecular motion (diffusion), energy is also transferred by the bulk, or macroscopic, motion of the fluid. This fluid motion is associated with the fact that, at any instant, large numbers of molecules are moving collectively. Such motion, in the presence of a temperature gradient, contributes to heat transfer. The convection heat transfer mode is sustained both by random molecular motion and by the bulk motion of the fluid within the boundary layer. The contribution due to random molecular motion (diffusion) dominates near the surface where the fluid velocity is low. In fact, at the interface between the surface and the fluid the fluid velocity is zero, and heat is transferred by this mechanism only. The contribution due to bulk fluid motion originates from the fact that the boundary layer grows as the flow progresses in the x-direction.

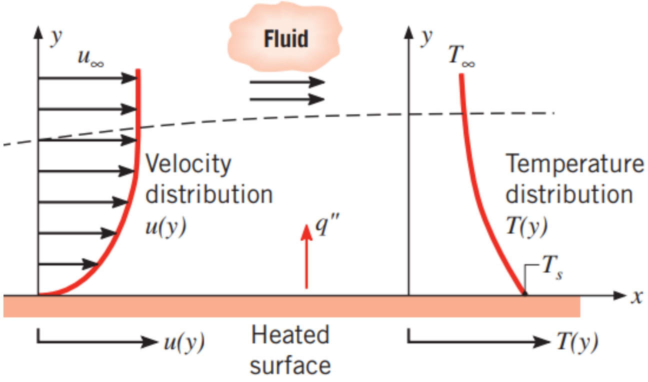

FIGURE 4 Boundary layer development in convection heat transfer.

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In contrast, for free (or natural) convection, the flow is induced by buoyancy forces, which are due to density differences caused by temperature variations in the fluid. For some convection processes, there is latent heat exchange. This latent heat exchange is generally associated with a phase change between the liquid and vapor states of the fluid. Two special cases of interest in this text are boiling and condensation.

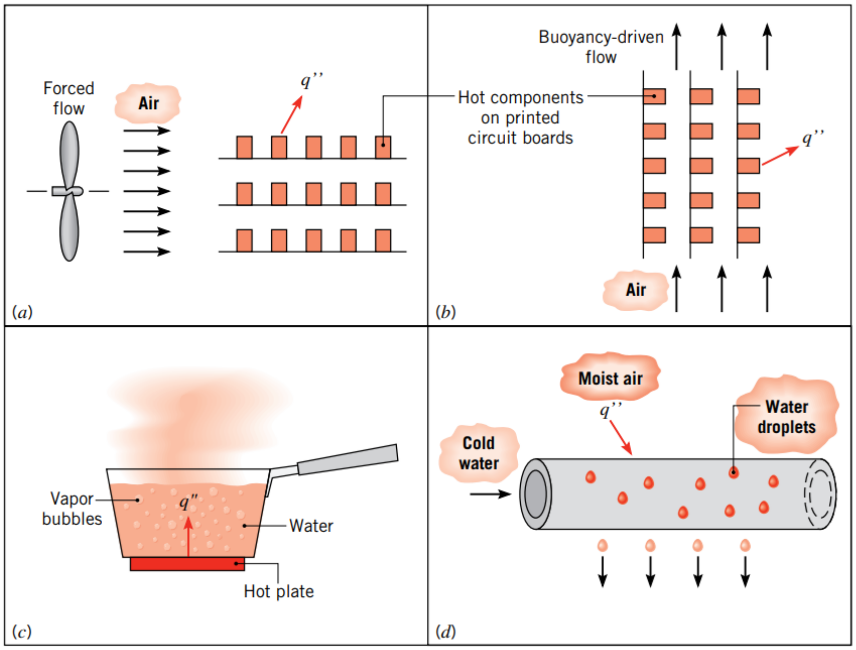

FIGURE 5 Convection heat transfer processes. (*a*) Forced convection. (*b*) Natural convection. (*c*) Boiling. (*d*) Condensation.

Regardless of the nature of the convection heat transfer process, the appropriate rate equation is of the form

$$q" = h\ (T_s - T_{inf})$$

where ,q" the convective heat flux (W/m2), is proportional to the difference between the surface and fluid temperatures, Ts and Tinf, respectively. This expression is known as Newton's law of cooling, and the parameter h is termed the convection heat transfer coefficient.

This coefficient depends on conditions in the boundary layer , which are influenced by surface geometry (flat plate, cylinder, sphere,..), the nature of the fluid motion (laminar flow, turbulent flow, mixed flow, cavitation), and an assortment of fluid thermodynamic and transport properties

By the way, h is in Watts per meter squared K. For gases, h is 25 to 250 W/m2K. If it is liquid, h is much larger. So if you want good heat transfer, you want to use a liquid, compared a gas. If you want to cool your engine block, you are going to apply water. Because water takes lots of heat out not air.

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:

$$q" = \sigma {T_s}^4$$

where Ts is the absolute temperature (K) of the surface and σ is the Stefan-Boltzmann constant.

$\sigma = 5.67 \times 10^{-8} \quad \frac{W}{m^2 K^4}$

Such a surface is called an ideal radiator or blackbody. The heat flux emitted by a real surface is less than that of a blackbody at the same temperature and is given by:

$$q" = \varepsilon \sigma {T_s}^4$$

where ε is a radiative property of the surface termed the emissivity. With values in the range $0 \leq \varepsilon \leq 1$, this property provides a measure of how efficiently a surface emits energy relative to a blackbody. It depends strongly on the surface material and finish.

Radiation may also be incident on a surface from its surroundings. The radiation may originate from a special source, such as the sun, or from other surfaces to which the surface of interest is exposed. Irrespective of the source(s), we designate the rate at which all such radiation is incident on a unit area of the surface as the irradiation G.

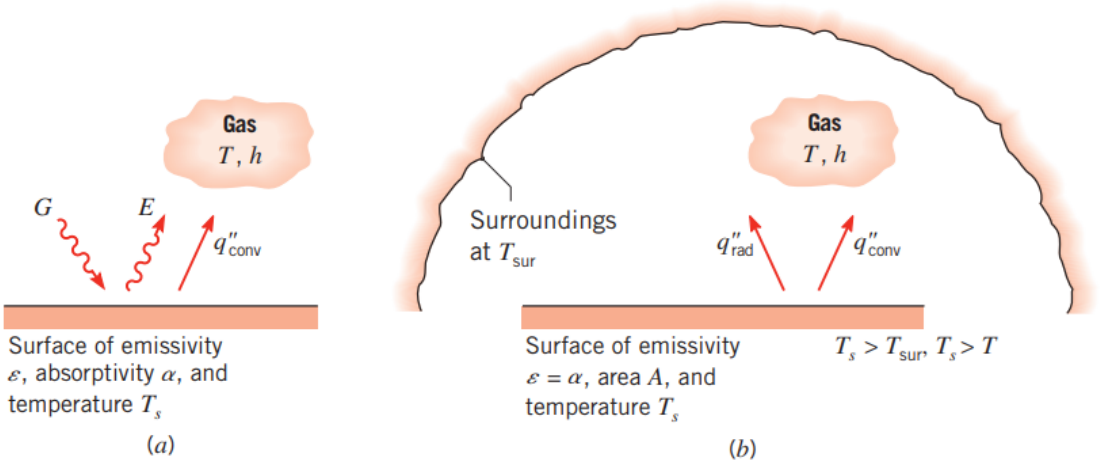

FIGURE 6 Radiation exchange: (*a*) at a surface and (*b*) between a surface and large surroundings.

A portion, or all, of the irradiation may be absorbed by the surface, thereby increasing the thermal energy of the material. The rate at which radiant energy is absorbed per unit surface area may be evaluated from knowledge of a surface radiative property termed the absorptivity α. That is:

$$G_{abs} = \alpha G$$

where $0 \leq \alpha \leq 1$. If $\alpha < 1$ and the surface is opaque, portions of the irradiation are reflected. If the surface is semitransparent, portions of the irradiation may also be transmitted. However, whereas absorbed and emitted radiation increase and reduce, respectively, the thermal energy of matter, reflected and transmitted radiation have no effect on this energy. Note that the value of α depends on the nature of the irradiation, as well as on the surface itself. For example, the absorptivity of a surface to solar radiation may differ from its absorptivity to radiation emitted by the walls of a furnace.

Reference

Fundamentals-of-Heat-and-Mass-Transfer-7th-Edition