$V_m$ = velocity in feet per minute.
$v$ = specific volume, cubic feet per pound.
$W$ = weight of gas flowing, pounds per hour.
$Y$ = expansion factor—correcting for expansion of gas under reduced downstream pressure.
$z$ = elevation above some arbitrary datum, in feet.

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CHAPTER 5

# Fundamentals of Heat Transfer

*Conduction, Convection, Radiation, Combined Convection and Radiation, Heat-Flow Resistance, Electrical Analogies, Practical Heat Transfer Problems, Unit Conductances for Convection Flow Systems, Radiation Factors or Emissivities, Solutions for Steady-State Conduction Problems*

HEAT is that form of energy which is transferred from place to place by virtue of an existing temperature difference. The temperature difference is the potential which causes the transfer, the latter in turn being resisted by the thermal properties of the material combined in a simple term and known as the resistance. Energy exchange associated with mass transfer from place to place (evaporation, condensation, etc.) due to concentration differences is treated elsewhere such as in the section on *cooling tower design* in Chapter 37. The objectives of this chapter are to:

1. Describe the mechanisms and present the rate equations for the different modes of heat transfer.

2. Illustrate the application of the basic concepts to steady-state problems (temperature independent of time or a cyclic variable thereof) by means of several typical solutions of heat transfer systems.

Further applications to specific systems will be found throughout THE GUIDE.

## CONDUCTION, CONVECTION AND RADIATION

*Thermal conduction* in fluids is the term applied to the mechanism of heat transfer whereby the molecules of higher random kinetic energies transmit by direct molecular collision part of their energy to adjacent molecules of lower random kinetic energy. Since the temperature is proportional to the random kinetic energy of the molecules, thermal transfer will occur in the direction of decreasing temperature. The molecules oscillate about a mean position at fairly high velocities and frequencies, but there is no net material flow associated with the conduction mechanism. In the case of fluids, thermal conduction is significant in the region very close to a solid boundary or wall, for in this region the flow is laminar, parallel with the wall surface, and there are practically no cross currents in the direction of the heat transfer across the solid fluid boundary. In solid bodies the significant mechanism of heat transport is always thermal conduction and is ascribed to an energy transfer mechanism associated with the free electrons [1].

Contrasted to the thermal conduction mechanism, *thermal convection* involves energy transfer by eddy mixing and diffusion [2] in addition to conduction. This condition is pictured schematically in Fig. 1 which exhibits transfer from a pipe wall at surface temperature $t_s$ to a colder fluid at a bulk temperature $t_f$. (Bulk temperature is that which would be attained if the fluid stream were drawn off at a certain section and mixed. It is therefore slightly higher than the lowest temperature in the stream). In the *laminar* sublayer, immediately adjacent to the wall, the heat transfer occurs by thermal conduction; in the *transition* region, which is called the buffer layer, eddy mixing as well as conduction effects are significant; in the *eddy* or *turbulent* region the major fraction of the transfer occurs by eddy mixing.