type of atmospheric water cooling apparatus to be used. This effectiveness is expressed as the percentage ratio of the actual cooling effect to the maximum possible cooling effect. Since the wet-bulb temperature of the entering air is the equilibrium temperature to which the water could be cooled, the effectiveness of water cooling apparatus can be indicated thus:

$$E_1 = \frac{(\text{hot water temperature} - \text{cold water temperature}) \times 100}{\text{hot water temperature} - \text{wet-bulb temperature of entering air}} \qquad (2)$$

where

E_1 = water cooling effectiveness, per cent.

Magnitudes of this effectiveness ratio will vary through wide limits in accordance with construction and conditions of operation. Values indicative of the commercial range of the effectiveness ratio are given in Table 3, although unusual designs may operate outside these ranges.

Example 1. A mechanical refrigeration installation of 100-ton capacity requires 3 gpm of cooling water with the hot-water temperature at 95 F and the cold-water at 84 F with a design wet-bulb temperature of 78 F. Find the water-cooling effectiveness of a mechanical draft tower for the above conditions.

Solution. Substituting known conditions in Equation 2,

$$\text{Water-cooling effectiveness} = \frac{95 - 84}{95 - 78} \times 100 = 64.7 \text{ per cent (typical)}$$

From a consideration of the factors which include the water-cooling range and the design wet-bulb temperature of the ambient air, the quantity of water required can be calculated from the amount of heat to be rejected. The average quantities of heat to be removed from various types of mechanical equipment that require cooling are listed in Table 4.

WATER-COOLING TOWER DESIGN

Because of the many variables[3] in water-cooling tower calculations and performance, it is difficult to provide simple handbook equations and tables whereby an engineer can readily select the type and size of unit for a definite requirement. Each manufacturer has a semi-confidential method of sizing a tower, based largely upon research and actual performance correlated with definite requirements; selection of water-cooling equipment for any specified service must ultimately depend upon overall considerations established from reliable design and performance data.

Table 4. Heat Absorbed by Cooling Water

Mechanical Equipment	Btu per Min per Ton	Btu per Lb of Steam	Btu per bhp-hr
Refrigeration Compressor	250	—	—
Refrigeration, Absorption System	550	—	—
Steam Turbine Condenser	—	1000	—
Steam Jet Refrigerating Condenser	550	1100	—
Diesel Engine Jacket & Lube Oil:			
Four-cycle, Supercharged	—	—	2600
Four-cycle, Non-supercharged	—	—	3000
Two-cycle, Crank-case Compressor	—	—	2000
Two-cycle, Pump Scavenging, Large Unit	—	—	2500
Two-cycle, Pump Scavenging, High Speed	—	—	2200
Natural Gas Engine:			
Four-cycle	—	—	4500
Two-cycle	—	—	4000

Some of the variables encountered in water-cooling tower work are: continuously changing air and water temperatures throughout the structure; varying moisture content, pressure, and volume of the moving air; caprice of the weather, ambient air changes in temperature, humidity, wind velocity and direction, and the amount of sunshine. Other less important physical properties of the air and water affecting tower performance are: density, specific heat, conductivity, viscosity, vapor pressure, surface tension, latent heat, coefficient of expansion, vapor diffusivity, emissivity, and molecular weight. The air velocity, overall and in different parts of the tower, is an important heat transfer factor; also the type of air movement provided, whether natural draft, forced draft, induced draft, counterflow, or crossflow design. Different details of construction will produce dissimilar velocities of water, its distribution and diffusion, size of the drops, jets, sprays, and sheets as affected by the pressure and elevation of the water supply system, as well as the adsorption and interfacial surface tension of the wetted tower areas.

Dissolved gases and other impurities in the water influence the water-cooling process. Additional cooling tower variables affecting its performance include: location (ground, roof, nearby obstructions, wind orientation), dimensions, relative proportions (contour) of tower structure, materials, type and arrangement of interior surfaces; the louver and drift-eliminator designs as they facilitate the air flow to and from the tower; temperature of the structure at different points as influenced by the external and internal conditions. Other cooling tower factors to be considered are: loss of water by entrainment (drift loss), design and location of water-collecting basin, and surface evaporation therefrom, also the noise generated by the air, water, fan, and structure vibration.

Basically, a water-cooling tower is a heat exchanger in which heat flows from the water to the air: (1) by a flow of sensible heat from the warm water to the cooler air, and (2) by an exchange of latent heat resulting from the evaporation of a small part of the circulating water to increase the humidity ratio of the air by a corresponding amount. The general principles involved are similar to those encountered in the processes of diffusion in absorption and extraction equipment.[5,6]

Details of the application of the process to water-cooling tower performance have been published by various authorities,[7,8,9,10,11,12] and those interested in the derivation of the various equations should refer to these references, as listed at the end of this chapter. The approach in each case is based on a heat balance in which the total heat given up by the water equals the total heat absorbed by the air. These derivations are also based on certain assumptions, viz: that the specific heat of water is unity at the temperatures encountered; that there is no loss in weight of the circulating water as a result of evaporation; that the water suspended in the tower is surrounded by a film of air which is saturated with water vapor and at the temperature of the water surrounded; and that the basic theory of cooling tower operation proposed by Lewis[13] and developed by Merkel[14] is applicable. This theory refers to the fact that the numerical value of the coefficient of sensible heat transfer when divided by the numerical value of the coefficient of diffusion equals the specific heat (at constant pressure) of air. The reader should observe that this relationship refers to the numerical values of three distinct constants, the units for each being different. The above relationship makes it possible to simplify the heat