no case for a wind velocity of more than 5 mph. It is obvious that natural draft towers and other natural draft equipment must be so located that they are not obstructed by trees, buildings, or other wind deflectors.

Mechanical Draft Towers

Mechanical draft towers usually consist of vertical shells, constructed of wood, metal, or masonry, in which water is distributed uniformly at the top and falls to a collecting basin at the bottom. The inside of the tower may be filled with wood checker-work over which the water drips, or the water surface may be presented to the air by filling the entire inside of the structure with spray from nozzles. Air is circulated through the tower from bottom to top by forced or induced draft fans. Since the air flows counter to the water, the air is in contact with the hottest of the water just before leaving the top of the tower, and each unit of air picks up more heat than a similar unit would on natural draft equipment, so the mechanical draft tower cools water by using less air than the other types of equipment need. As movement of the air through the towers is obtained by power-consuming fans, it is essential that the air used be reduced to a minimum so as to secure the lowest possible operating cost.

The efficiency of a mechanical draft tower is increased by increasing height, area, or air quantity. Increasing the height increases the length of time the air is in contact with the water without affecting seriously the fan power required, but it increases the pumping power needed. Increasing the area while maintaining constant fan power increases the air quantity somewhat and because of lowered velocities it increases the time this air is in contact with the water. The surface area of water in contact with the air is increased in both cases. Increasing the air quantity decreases the time the air is in contact with the water, but, since a greater quantity is passing through, the average differential between the water temperature and the wet-bulb temperature of the air is increased, and this speeds up the heat transfer rate. Increased air quantities are obtained only at the expense of increased fan power, which increases approximately as the cube of the air quantity. Air velocities through mechanical draft towers vary from 250 to 600 fpm over the gross area of the structure.

Mechanical draft water cooling equipment may be set up inside buildings, where it usually draws its air supply from the general space in which it is installed, and discharges its exhaust air through a duct to the outside. Indoor cooling towers may be either of the wood-filled or the spray-filled type. In many cases where little height but considerable area is available, water is cooled in a spray-filled structure similar to an air washer, with the air passing horizontally through the apparatus and being discharged through a duct to the outside. Such apparatus does not have the counter-flow advantage of the vertical mechanical draft water cooling equipment, and therefore requires a much larger excess of air for proper operation. Air velocities and operating powers are considerably above those required by vertical mechanical draft water cooling equipment.

Cooling Tower Design

The method of design of equipment for energy transfer from water to an air-water vapor mixture is similar to that used for absorption equip-

ment. Details of this procedure are available[3, 4, 5] and its application to the problem of the cooling tower operating at atmospheric pressure is illustrated by the following development. The nomenclature used is as follows:

a = overall average wetted area, square feet per cubic foot of tower volume.
c = specific heat of liquid water, Btu per (pound) (degree Fahrenheit).
e = effectiveness.
ε = natural base.
G = weight rate of flow of air, pounds of dry air per hour.
h = enthalpy, Btu per pound of dry air.
h_a = enthalpy of air-vapor mixture, Btu per pound of dry air.
h^n = enthalpy of saturated air-vapor mixture at water temperature, Btu per pound of dry air.
K = overall energy unit conductance, Btu per (hour) (square feet) (Btu per pound).
Ka = overall rate coefficient, Btu per (hour) (cubic feet) (Btu per pound).
L = water rate, pounds per hour.
lm = logarithmic mean.
S = average cross-sectional area of cooling tower for air flow, square feet.
t = water-main body temperature, degrees Fahrenheit.
t_{wb} = wet-bulb temperature, degrees Fahrenheit.
V = tower volume, cubic foot.

Subscripts 1 and 2 refer to water entrance and exit sections respectively, for the counter-flow tower.

A section of a typical counter-flow tower is shown in Fig. 4. If the reduction in water rate due to evaporation within the volume is neglected, the energy balance for this differential section of the exchanger volume may be written as:

$$L\,c\,dt = G\,dh \tag{2}$$

The potential for net energy transfer due to heat and mass transfer from the water to the mixture in contact with it may be expressed with reasonable accuracy as the difference between the enthalpy of saturated air at the water temperature, h^n, and the enthalpy of the main stream air vapor mixture[6], h_a. The rate of energy transfer is given by the expression:

$$Ka\,(h^n - h_a)\,dV \tag{3}$$

which equation defines the overall rate coefficient, Ka; the latter being the product of the overall energy unit conductance, K, and the ratio of the transfer surface to the exchanger volume, a.

Equations 2 and 3 are conveniently illustrated by means of the temperature-enthalpy diagram of Fig. 5. Equation 2 indicates that the succession of air and water states existing in the exchanger sections must combine to form a straight line (for L = constant) on the temperature enthalpy diagram. The slope of this operating line is $\frac{dh}{dt} = \frac{Lc}{G}$. Since

[3] Principles of Chemical Engineering, by W. H. Walker, W. K. Lewis, W. H. McAdams and E. R. Gilliland (McGraw-Hill Co., New York City, 1937, p. 480).

[4] Absorption and Extraction, by T. K. Sherwood (McGraw-Hill Co., New York City, 1937, p. 91).

[5] Performance Characteristics of a Mechanically Induced Draft, Counterflow, Packed Cooling Tower, by A. L. London, W. E. Mason and L. M. K. Boelter (*A.S.M.E. Transactions*, January, 1940, Vol. 62, p. 41).

[6] Determination of Unit Conductances for Heat and Mass Transfer by the Transient Method, by A. L. London, H. B. Nottage and L. M. K. Boelter (*Industrial and Engineering Chemistry*, April, 1941, Vol. 33, p. 467).