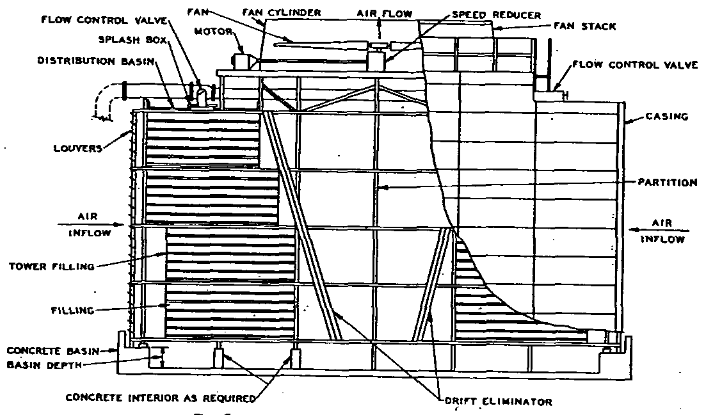

Fig. 5 . . . . Crossflow Mechanical Draft Tower

tower creates a low-pressure area on the leeward side. The exhaust vapors may then move downward and flow back into the tower. This increases the entering wet-bulb temperature and affects the performance accordingly. Recirculation is worse with forced-draft towers because of their low exit velocities. As a result, most towers built since 1940 are of induced-draft type. The forced-draft towers, however, have the advantage of locating the mechanical equipment away from the humid exhaust-air stream.

Air velocities usually vary from 300 to 400 fpm in counter-flow towers. The lower friction losses in cross-flow towers make it practicable to operate them at velocities up to 600 fpm. The water loading of counter-flow towers varies from 1.2 to 8 gpm per sq ft of plan area. The upper limit is largely determined by the blanketing effect of the distribution system. Since this blanketing is less pronounced in cross-flow towers, the loadings, based on plan area of the filling, can go up to 14 gpm per sq ft or higher.

Mechanical-draft towers require less plan area than ponds or atmospheric towers because of the higher water loadings. This is quite important in roof installations where the available space may be limited. This feature can be of great importance also in large industrial applications where space may be at a premium. Reduction in plan area will usually result in a saving in piping costs also.

Most manufacturers guarantee a drift loss that will not exceed 0.2 percent of the circulating rate, and the usual losses are probably less than that figure. The nuisance from drift is therefore much less with mechanical-draft towers.

COOLING TOWER THEORY

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.[4, 5]

The generally accepted concept of cooling tower performance is based on enthalpy potential as the driving force. This is based on the relationship in an air-water mixture proposed by Lewis[6] showing that the numerical value of the coefficient of sensible heat transfer when divided by the coefficient of diffusion, approximately equals the specific heat of air at constant temperature. The relationship, involving three numerical values, each having different units, also explains why the wet-bulb temperature of a mixture of air and water

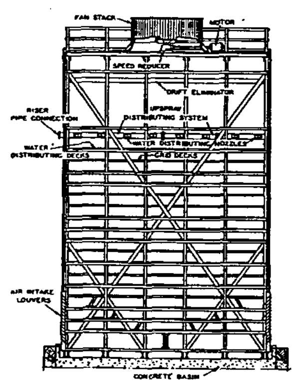

Fig. 6 . . . . Counterflow Induced Draft Cooling Tower

vapor approximates the temperature of adiabatic saturation. The relationship was applied by Merkel[7, 8] to combine the two coefficients into one overall coefficient based on enthalpy potential.

Details of the theoretical analysis have been published by various authors[9, 10, 11, 12] and those interested in the derivation of the equations should refer to these references. The derivations are based on the following assumptions:

1. Each particle of water is surrounded by a film of air that is at the temperature of the water and saturated with moisture.
2. The specific heat of water is unity at the temperatures encountered.
3. A constant wet-bulb temperature at varying humidity ratios represents constant enthalpy.
4. There is no weight loss of water due to evaporation during the cooling process.
5. The Lewis relationship applies.

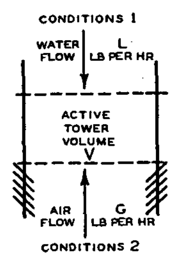

Fig. 7 . . . . Operations in a Typical Water Cooling Tower

Considering the cooling tower shown in Fig. 7 on the basis of these assumptions, the heat transfer per square foot of plan area in an incremental volume dV is

$$(G)(dh) = Ka(h'' - h_a)dV \tag{1}$$

Integration gives the familiar equation

$$\frac{KaV}{G} = \int_2^1 \frac{dh}{h'' - h_a} \tag{2}$$

It is more convenient to analyse cooling tower performance on the basis of water temperature, so

$$dh = \frac{L}{G}\, dt \tag{3}$$

and

$$\frac{KaV}{L} = \int_2^1 \frac{d\theta}{h'' - h_a} \tag{4}$$

where

a = overall average wetted area (surface of water drops plus wetted tower surface), square feet per cubic foot of active tower volume.
G = weight rate of flow of air, pounds of dry air per hour.
h_a = enthalpy of air-vapor mixture, Btu per pound of dry air.
h'' = enthalpy of saturated air-vapor mixture at water temperature, Btu per pound of dry air.
K = overall energy unit conductance, Btu per (hour) (square foot overall average wetted area) (Btu enthalpy difference per pound of dry air).
L = water rate, pounds per hour.
θ = temperature of water in tower, Fahrenheit.
θ_1 = temperature of inlet water, Fahrenheit.
θ_2 = temperature of outlet water, Fahrenheit.
V = active tower volume, cubic feet.
Z = height of filled volume, feet.

Either Equation 2 or 4 applies, but Equation 4 is more commonly used to reduce performance conditions to a numerical value called the *Number of Transfer Units* (NTU). A *transfer unit* is related to a set of performance conditions which are such as to make the right-hand side of the equation equal unity. This is a condition in which the temperature change equals the mean driving force. The (NTU) evaluates the degree-of-difficulty by expressing the rate of temperature change per square foot of plan area per Btu of mean driving force.

The (NTU) applies to a vertical column of tower having one sq ft of plan area, a height Z and a volume V. Since V and Z are numerically equal

$$\frac{Ka}{L} = \frac{1}{Z} \int \frac{d\theta}{h'' - h_a} \tag{5}$$

This is the Unit-Volume Coefficient, obtained by dividing (NTU) by height. It evaluates the rate of temperature change per cubic foot of tower per square foot of plan area per Btu of mean driving force. This refers to temperature change without regard to the amount of water being cooled. Transposing L

$$Ka = \frac{L}{Z} \int \frac{d\theta}{h'' - h_a} \tag{6}$$

This is the overall coefficient and evaluates the Btu transferred per cubic foot of tower per square foot of plan area per Btu of mean driving force.

Equation 4 may be evaluated by a process of mechanical or graphical integration with the aid of a temperature-enthalpy diagram such as is shown in Fig. 8. The water enters the tower at temperature θ_1, having enthalpy h_1''. As it is cooled, the enthalpy of the air film surrounding it follows the saturation curve to temperature θ_2 where the enthalpy is

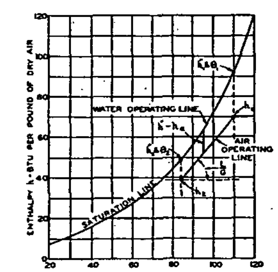

Fig. 8 . . . . Temperature-Enthalpy Diagram for Air-Water Vapor Mixture Showing Operating Lines for Example 2