

transfer equation by combining the two driving forces into one potential represented as the difference between the enthalpy of the air film (at water temperature) surrounding the water and the enthalpy of the main air stream.

Tower Performance Factor

The operations taking place in a typical water-cooling tower are shown in Fig. 10. If the reduction in water flow rate due to evaporation within the volume is neglected, and the usual concepts of heat flow and mass heat transfer are applied the equations typifying cooling tower operation are:

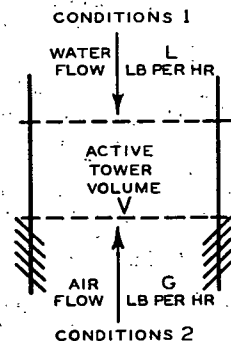


FIG. 10. OPERATIONS IN A TYPICAL WATER COOLING TOWER

$$\frac{KaV}{G} = \int_2^1 \frac{dh}{h'' - h_a} \quad (3)$$

and

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

where

- a = over-all 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 = enthalpy, Btu per pound of dry air.
- 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 = over-all energy unit conductance, Btu per (hour) (square foot over-all 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.

Either term $\frac{KaV}{G}$ or $\frac{KaV}{L}$ may be called the *Tower Performance Factor* or *Number of Tower Units (NTU)*.

These equations indicate that the rate of heat transfer from the water to the air depends primarily upon the enthalpy of the air, the latter being dependent only on the wet-bulb temperature of the air; this explains the common observation that cooling tower performance is independent of inlet dry-bulb air temperature and that adiabatic conditions exist.

The integration of Equations 3 and 4 must be performed by mechanical or graphical means, because direct mathematical integration would be

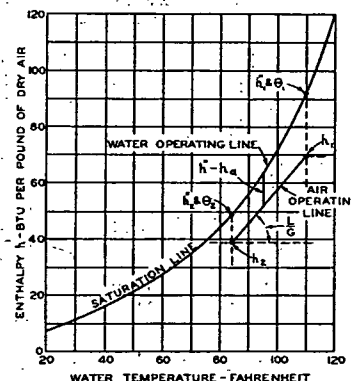


FIG. 11. TEMPERATURE-ENTHALPY DIAGRAM FOR AIR-WATER VAPOR MIXTURE SHOWING OPERATING LINES FOR EXAMPLE 2

accurate only within narrow temperature limits. The temperature enthalpy diagram in Fig. 11 represents the conditions for either of the above equations. The water is cooled from the temperature θ_1 to θ_2 , and the enthalpy of the air film surrounding it follows the saturation line h'' . Air enters the tower at a wet-bulb temperature of t'_2 and an enthalpy of h_a ; it is heated to an outlet wet-bulb temperature of t'_1 , having an enthalpy of h_g . Since the heat rejected by the water equals the heat absorbed by the air, the heat absorbed per pound of air is a function of the pounds of water per pound of air going through the tower, and the slope of the air operating line is the $\frac{L}{G}$ ratio.

Example 2. It is desired to cool 150,000 lb of water per hour (about 100 tons of mechanical refrigeration) from 110 to 84 F with 125,000 lb of dry air per hour with a design wet-bulb air temperature of 75 F. These conditions could prevail with a steam-turbine driven centrifugal refrigeration compressor. Determine the *Tower Performance Factor*, show in tabular form the successive steps for this mechanical integration by selecting two-degree intervals of the water-temperature range.

Solution. The accompanying Table 5 shows the sequence of mechanical integration for the given water and air temperatures. The first column shows the water temperature θ in increments of two degrees ($\Delta\theta = 2$ F deg). Column 2 gives the enthalpies