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 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.

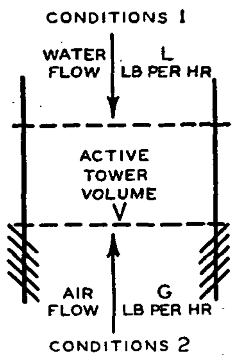

FIG. 10. OPERATIONS IN A TYPICAL WATER COOLING TOWER

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:

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

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 = 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 = 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.

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

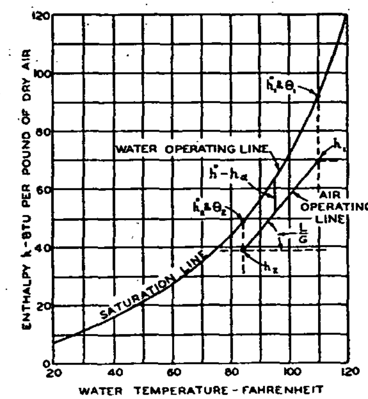

FIG. 11. TEMPERATURE-ENTHALPY DIAGRAM FOR AIR-WATER VAPOR MIXTURE SHOWING OPERATING LINES FOR EXAMPLE 2

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 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_2. It is heated to an outlet wet-bulb temperature of t_1', with an enthalpy of h_1. 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 L/G ratio.