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'', and the enthalpy of the main stream air vapor mixture[7], h_a. The rate of energy transfer is given by the expression:

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

which equation defines the over-all rate coefficient, Ka; the latter being

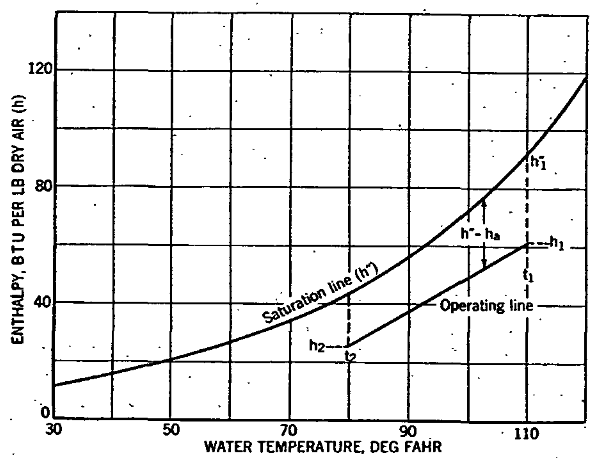

FIG. 5 TEMPERATURE ENTHALPY DIAGRAM FOR AIR WATER VAPOR MIXTURE SHOWING THE OPERATING LINE FOR EXAMPLE 1

the product of the over-all 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 the heat capacity of water is approximately unity, this slope is the ratio of the water to the air rate. Equation 3 indicates that the potential for energy transfer at any section is the difference between the enthalpy of saturated air at the main-body water temperature at that section and the enthalpy of the air stream in contact with that water. This potential is the difference in the ordinates of the saturation and operating lines for the water temperature at the plane in the tower which is under consideration.

[7]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).

Combination of Equations 2 and 3 results in the expression:

$$G\,dh = Ka\,(h'' - h_a)\,dV \tag{4}$$

Integrating this equation over the length of the exchanger:

$$\int_2^1 \frac{G}{Ka}\,\frac{dh}{h'' - h_a} = V \tag{5}$$

The integration of the left side of Equation 5 determines the tower volume required to achieve the desired energy exchange. This summation is readily accomplished for counter and parallel flow arrangements. G and Ka are usually independent of the tower volume and Equation 5 then becomes:

$$NTU = \int_2^1 \frac{dh}{h'' - h_a} = \frac{Ka\,V}{G} \tag{6}$$

Where NTU is defined as the *Number of Transfer Units* and is a measure of the difficulty of the cooling process.

The integration is made numerically or graphically. In the graphical integration $\frac{1}{h'' - h_a}$ is evaluated as a function of h_a. This determination involves the use of the energy balance equation integrated from one section to the section in question. The area under the curve between any two abscissae is the number of transfer units required to change the air state from h_2 to h_1.

An approximate value for the number of transfer units can also be determined by a simple graphical method of direct construction on the temperature enthalpy diagram[8]. This method cannot be applied very satisfactorily to cooling towers as the operating range is small and the value of the NTU is near unity.

When the relationship between the enthalpy of the saturated air and the temperature is linear over the range of water temperatures involved, it can be shown[9] that the logarithmic mean of the terminal potentials, h_{lm}, is the correct driving force. This is true to a good approximation when the water cooling does not exceed 15 F. The approximation to linearity may be determined by inspection of Table 6, Chapter 1, or the temperature enthalpy diagram of Fig. 5. If the logarithmic mean is a valid potential, Equation 6 may be written:

$$\frac{h_1 - h_2}{\Delta h_{lm}} = \frac{Ka\,V}{G} \tag{7}$$

and the need for the numerical integration for the determination of the tower volume is eliminated.

The over-all rate coefficient, Ka, must be known if the tower volume is to be determined. Experiments conducted on towers containing different packing construction have yielded some magnitudes of this coefficient, evaluated on an over-all basis. These data are presented in Fig. 6 as a function of the gas mass velocity through the packing, and apply only to the particular packing structure for which they were obtained. The over-all rate coefficient (Ka) may also be a function of the water rate,

[8]Graphical Method of Determining Number Transfer Units, by T. Baker (*Industrial and Engineering Chemistry*, August, 1935, Vol. 27, p. 977).

[9]Loc. Cit. Note 4, p. 79.