energy transfer at any section is the difference between the enthalpy of saturated air at the water temperature of that point and the enthalpy of the air in contact with that water. This potential is the difference in ordinates between the saturation and operating lines for the water temperature at the point considered.

Combination of equations 2 and 3 results in the expression:

$$G dh = Ka\,(h'' - h_a)\,dV \qquad (4)$$

Integrating this equation over the length of the exchanger:

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

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

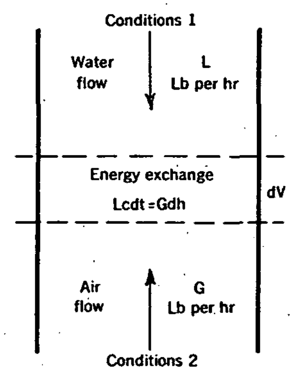

FIG. 4. SECTION OF TYPICAL COUNTER-FLOW TOWER

Ka are usually independent of the tower volume and Equation 5 then becomes:

$$\int_2^1 \frac{dh}{h'' - h_a} = \frac{KaV}{G} \qquad (6)$$

$\frac{KaV}{G}$ is defined as the *Number of Transfer Units* (*NTU*).

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.

The overall rate coefficient, Ka, must be known if the tower volume is to be determined.[4] Experiments conducted on towers containing different packing construction have yielded some magnitudes of this coefficient,

evaluated on an overall 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. Ka may also be a function of the water rate, since a reduction of the water rate may reduce the wetted area within the exchanger[5]. The results included in Fig. 6 probably represent values of Ka obtained with complete wetting.

A typical design procedure is illustrated in the example following;

Example 1. The rate of air flow, arbitrarily assumed in the data given, is related to the tower volume by economic considerations. A balance between air rate and tower volume rests on consideration of the costs of producing air flow and of the tower construction[6]. A counter-flow forced draft cooling tower is to cool 36,000 lb of water per

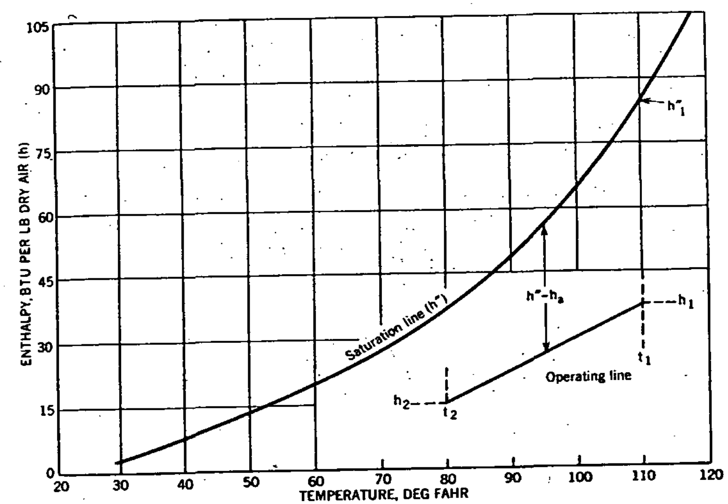

FIG. 5. TEMPERATURE ENTHALPY DIAGRAM FOR AIR, WATER, VAPOR MIXTURE SHOWING AN OPERATING LINE FOR A COUNTER-FLOW COOLING TOWER

hour from an initial temperature of 144 F to a final temperature of 100 F. Air having an initial condition of 65 F dry-bulb and 58 F wet-bulb temperature will be forced through the tower counter to the direction of water flow at the rate of 30,000 lb of dry air per hour.

The cross-section of the tower is to be 6 ft x 6 ft and the packing is to be of the type producing a rate coefficient as indicated in curve No. 2 of Fig. 6.

Solution:

Initial air enthalpy = 25 Btu per pound.

Final air enthalpy:

$$(h_1 - h_2) = \frac{Lc}{G}\,(t_1 - t_2)$$

$$(h_1 - 25) = \frac{36{,}000 \times 1}{30{,}000}\,(144 - 100)$$

$$h_1 = 77.8 \text{ Btu per pound dry air.}$$

[5]Loc. Cit. Note 4.

[6]Loc. Cit. Note 2, p. 142.