by comparison of area A_1, A_2, and A_3 of Fig. 7. Each represents the Number of Transfer Units required to achieve a water temperature reduction of about 10 F.

$$A_1 = 0.471\ NTU\ (110 \text{ to } 100 \text{ F})$$
$$A_2 = 0.595\ NTU\ (100 \text{ to } 90 \text{ F})$$
$$A_3 = 0.657\ NTU\ (90 \text{ to } 80 \text{ F})$$

The use of the logarithmic mean driving potential is illustrated by applying Equation 7 to example 1:

$$NTU = \frac{(Ka)\ V}{G} = \frac{h_1 - h_2}{\Delta h_{lm}}$$

$$\Delta h_{lm} = \frac{(h_1'' - h_1) - (h_2'' - h_2)}{ln_{\epsilon} \dfrac{h_1'' - h_1}{h_2'' - h_2}} = \frac{30.7 - 18.4}{ln_{\epsilon} \dfrac{30.7}{18.4}} = 24$$

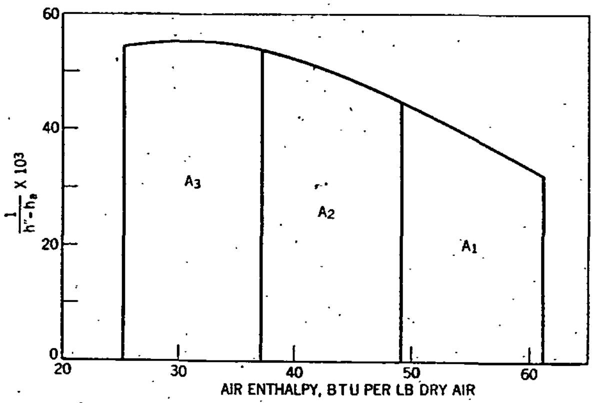

Fig. 7. Graphical Integration to Determine Number of Transfer Units Required for Desired Operating Conditions of Example 1

$$NTU = \frac{61.1 - 25.1}{24} = 1.5$$

The Number of Transfer Units required as determined by use of the logarithmic mean driving potential equals 1.5 which compares favorably with the correct magnitude, 1.72.

The application of the foregoing design method to atmospheric towers is difficult because rate coefficients and flow conditions are not yet well defined for such equipment. If these are known, application of Equation 7 to sections of the tower small enough to justify use of the logarithmic mean potential will yield the tower volume required for each section. The sections must be taken perpendicular to the path of water flow. A correction to adjust the logarithmic mean potential, evaluated as for counter-flow, to the reduced effectiveness of cross-flow, has been derived for heat transfer and may be applied to this case[11].

[11]Heat Transmission, by W. H. McAdams (McGraw-Hill Co., New York City, 1933, p. 157).

Atmospheric towers operate with natural draft, produced in a vertical direction by the stack action of the tower structure, at zero velocity of the approach wind. Approach wind of sufficient magnitude (the magnitude depending on the baffle arrangement which is designed to reduce drift) will cause cross-flow augmenting the natural draft. An adequate design requires the consideration of both flow conditions.

Expression for Cooling Tower Performance

The performance of a cooling tower is described in terms of its effectiveness as an energy exchanger. The effectiveness is defined as the ratio of the energy actually exchanged to the energy available for exchange.

Effectiveness expressions:

Case 1. The slope of the operating line on the $t - h$ diagram exceeds the slope of the saturation line in the region of water temperatures considered.

$$e = \frac{h_1 - h_2}{h_1'' - h_2} \tag{8}$$

Case 2. The slope of the saturation line exceeds that of the operating line.

$$e = \frac{h_1 - h_2}{\dfrac{Lc}{G}(t_1 - t_{wb})} = \frac{t_1 - t_2}{t_1 - t_{wb}} \tag{9}$$

This equation represents the *approach to wet-bulb.*

Usual tower operating conditions conform to Case 1. Because of the curvature of the saturation line, operating conditions may present themselves to which neither Case 1 nor 2 applies. Since a simple expression for the intermediate case is not available, the expression of Case 1 may be utilized for the small number of operating conditions falling into the intermediate classification.

Make-Up Water

Since the atmospheric water cooling equipment performs its functions chiefly by evaporating a portion of the water in order to cool the re-

Table 5. Comparison of Various Types of Atmospheric Water Cooling Equipment

Figures indicate order of desirability

	Cooling Pond	Spray Pond	Spray Tower	Deck Tower	Mechanical Draft	Indoor Tower
Cost	x	2	1	3	4	5
Area	5	4	3	2	1	x
Height	1	2	3	4–5	4–5	x
Weight per square foot	x	x	1	3	4	2
Independence of wind velocity	6	3	4	5	1–2	1–2
Drift nuisance	1	6	5	4	2–3	2–3
Make-up water required	1	6	5	4	2–3	2–3
Pumping head	1	2	4	5	3	6
Maintenance	2	1	3	4	5	6
Suitability for congested districts	x	5	4	3	1	2
Water quantity required for definite result	6	5	4	1–2	1–2	3

xNot comparable.