where

f_i = internal film coefficient of heat transfer, Btu per (hour) (square foot of internal tube surface) (Fahrenheit degree).

t_r = average refrigerant temperature, Fahrenheit degrees.

To evaluate f_i by this method the same tests that were required to determine f_o may be used.

When water is the cooling medium in tubes, the rate of heat transfer is a function of its velocity, which influences the number of contacts of the water molecules with the tube surface, per unit of time. Increased water velocity and reduced tube diameter cause increased heat transfer. Heat transfer is also greater at higher temperatures of the water. The basic formula for the film coefficient of heat transfer for flow of water in smooth tubes is as follows:

$$f_i = 1.5(t + 100)\,\frac{V^{0.8}}{D^{0.2}} \qquad (10)$$

where

V = water velocity, feet per second.

D = internal diameter of tube, inches.

t = average water temperature, Fahrenheit degrees.

Equation 10 should not be used when Reynolds number is less than 2000.

Since, in the case of finned tubes using water as a refrigerant, test values of f_i based on the calculated surface temperature for the entire coil may be lower than those obtained by use of Equation 10, actual test results are preferred if available.

When saturated steam is condensed in the tubes of coils, the film coefficient f_i varies from 1000 to 2000, depending on freedom from air in the steam, and upon good drainage of the tubes. The coefficient is fairly constant for a particular coil, giving values of $(t_s - t_r)$ that are directly proportional to q_t. However, if water coil test results are analyzed on a row-by-row basis good agreement with Equation 10 will result.[4]

The use of turbulence promoters increases the value of f_i for liquids in tubes at the expense of pressure drop. The increase obtained depends upon the type of turbulence promoter and the rate of flow. No general statement can be made regarding their use, and it is best to refer to detailed papers on this subject for further information.[4, 5]

Determining Size of Cooling Coil

To illustrate the use of individual film coefficients in coil calculations, the procedure for selecting the proper size cooling coil and for determining exit air condition, coil surface temperature, total coil load and refrigerant temperature, is outlined in Example 1.

Example 1: An industrial application requires the cooling of a certain quantity of air from a condition of 102 F dry-bulb and 85 F wet-bulb to a final condition of 80.5 F dry-bulb and 73 F wet-bulb. The air velocity across the coil is to be 400 fpm and coil data are as follows: f_o = 10.7 at 400 fpm, f_i = 325, external surface area = 15 sq ft per (square foot of face) (row of coil depth), ratio of external surface area to internal surface area = 15.

Solution: (1) Lay out the problem psychrometry as indicated in Fig. 13 and note that the minimum horizontal distance between the load ratio line and the saturation curve is 1.8 F dry-bulb at point A Fig. 13. This means that $t_2 - t_{dp2}$ in Equation 7 must not be less than 1.8. Therefore, Equation 7 should be solved for N to determine the proper number of rows to be used for the coil.

$$\frac{f_o A N}{0.243 G} = \log_e \frac{t_1 - t_{dp1}}{t_2 - t_{dp2}} = \log_e \frac{102 - 80}{1.8} = \log_e 12.22 = 2.5$$

Then substituting values for f_o, A and G, N may be found as follows:

$$\frac{10.7 \times 15N}{0.243 \times 1740} = 2.5 \text{ from which, } N = 6.58$$

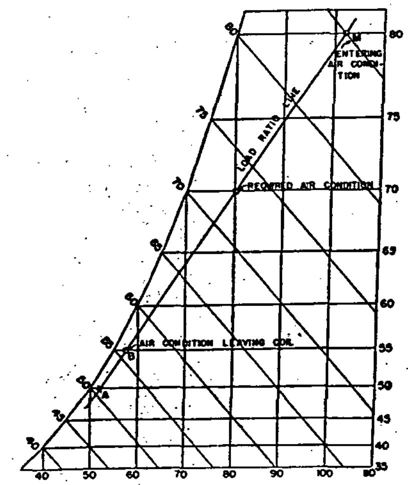

Fig. 13. Psychrometric Layout for Coil Selection

(2) This establishes the maximum whole number of coil rows that can be used as 6, and it is now possible to determine the actual location of the exit air conditions from Equation 7 by solving for the actual value of $t_2 - t_{dp2}$ for a 6 row coil.

$$\frac{10.7 \times 15 \times 6}{0.243 \times 1740} = \log_e \frac{102 - 80}{t_2 - t_{dp2}} = 2.275$$

This establishes values of 9.78 for $\frac{t_1 - t_{dp1}}{t_2 - t_{dp2}}$ = B and 2.25 for $t_2 - t_{dp2}$.

(3) Next, the exit air condition at 57.3 F dry-bulb and 56 F wet-bulb as shown at B, is found by locating a point on the load ratio line at a horizontal distance of 2.25 dry-bulb degrees from the saturation curve.

(4) The surface temperature may now be found from Equation 7 which may also be written as

$$t_s = \frac{Bt_2 - t_1}{B - 1}$$

where

$$B = \frac{t_1 - t_{dp1}}{t_2 - t_{dp2}}$$