

for fins on tubes because of air turbulence and because of the temperature gradient prevalent from the edge of a fin to its center. It is therefore necessary to make tests to evaluate the combined term ηh_a . The term, ηh_a , will be written merely h_a in this discussion as there is no necessity for separately evaluating η and because values of h_a are usually applied only to the particular coils for which tests are made.

The air side coefficient, h_a , of a coil of particular dimensions is an exponential function of the mass velocity of the air:

$$h_a = Z G^n \quad (8)$$

where

h_a = film coefficient of heat transfer, Btu per (hour) (square foot external surface) (Fahrenheit degree mean temperature difference between air and average surface temperature).

G = air mass velocity, pounds per (hour) (square foot of coil face area).

Z and n = constants which depend upon both air turbulence and surface arrangement.

Evaluation of constants Z and n may be accomplished through the use of test data in Equation 7 which gives values of h_a directly from the results of any *wet coil test*. If h_a , calculated in this manner, is plotted against values of G which prevailed during the tests a straight line should result on logarithmic coordinates. The slope of this line is the value of n . The value of Z may then be determined by direct substitution in Equation 8.

For finned coils of different designs, values of Z and n are extremely variable, depending on the particular design and arrangement of the coil surface. Therefore, it is desirable that these constants be determined directly from test data for each type of coil surface.

Internal Film Coefficient

The internal film coefficient, h_r which appears in Equation 3, is evaluated in various ways, depending upon the nature of the fluid, and whether the fluid is changing state.

When evaporating refrigerants are used in tubes, the temperature of the fluid is fairly constant, being affected principally by pressure drop through the tubes, by superheat of the evaporated refrigerant, and by the presence of oil in solution. To obtain maximum coil capacity it is necessary to keep the pressure drop through the tubes at a minimum, to keep the superheat as low as possible without carrying liquid back to the compressor, and to arrange for good separation and return of oil to the compressor. Another important factor is the removal of gas to keep the tube surface flooded with liquids as much as possible. The internal film coefficient is markedly increased by heavy heat loads, because the increased turbulence and gas velocity cause good contact of the liquid with the tubes. Values of h_r usually lie between 150 and 450. For rating of dehumidifying coils, satisfactory results are obtainable by first determining the average external surface temperature from Equation 7, and then using the difference between the external film temperature and the refrigerant for evaluating h_r in Equation 9.

$$h_r = \frac{q_t}{\frac{A N}{R} (t_a - t_r)} \quad (9)$$

where

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

t_r = average refrigerant temperature, Fahrenheit degrees.

The term $(t_a - t_r)$ is commonly written Δt . To evaluate h_r by this method the same tests that were required to determine h_a 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:

$$h_r = 1.5 (t + 100) \frac{V^{0.8}}{D^{0.2}} \quad (10)$$

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 h_r 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 h_r 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 Δt 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.³

The use of turbulence promoters increases the value of h_r 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.^{3,4}

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: $h_a = 10.7$ at 400 fpm, $h_r = 325$, 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. 2 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. 2. This means that $t_a - t_{dps}$ 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.

$$\frac{h_a A N}{0.243 G} = \log_e \frac{t_a - t_{dps}}{t_a - t_{dps}} = \log_e \frac{102 - 80}{1.8} = \log_e 12.22 = 2.5$$