U = overall coefficient of heat transfer, Btu per (hour) (square foot of external coil surface) (Fahrenheit degree temperature difference between the fluid within the coil and the air flowing over the coil).

Δt_m = mean temperature difference, Fahrenheit degrees, between the fluid within the coil and the air passing over it. (This is commonly taken as the logarithmic mean temperature difference).

A = external surface area of the given coil, square feet per (square foot of coil face area) (row of coil depth).

N = number of rows of coil depth.

Overall Coefficient of Heat Transfer

While the overall coefficients of heat transfer for plain pipe coils have been defined by numerous tests within close limits, the verification of a plain coil design by a series of tests is an accepted commercial practice. The overall coefficients of heat transfer for finned coils should always be obtained from tests. The data from a series of tests may be used for purposes of extending coil data beyond test range but such data should later be verified by test.

Considering any coil, whether of bare pipe or of finned type, the overall heat transfer coefficient for a given size and design of coil can always be considered as a combined effect of three individual heat transfer coefficients, namely:

1. The film coefficient of heat transfer between air and the external surface of the coil, usually given in Btu per (hour) (square foot external surface) (Fahrenheit, degree mean temperature difference).
2. The conductivity of the coil material—tube wall, fins, ribs, etc., usually given in Btu per (hour) (square foot of surface) (Fahrenheit degree per inch).
3. The film coefficient of heat transfer between the internal surface of the coil and the fluid flowing within the coil, usually given in Btu per (hour) (square foot internal surface) (Fahrenheit degree mean temperature difference).

These three individual coefficients acting in series result in an overall coefficient of heat transfer in accordance with the basic laws given in Chapters 5 and 9. For a *bare pipe* coil the overall coefficient of heat transfer, whether for heating or for cooling (without dehumidification), can be expressed by a simplified basic formula as follows:

$$U = \frac{1}{\frac{R}{f_i} + \frac{L}{k} + \frac{1}{f_o}} \tag{2}$$

where

U = overall coefficient of heat transfer, Btu per (hour) (square foot external surface) (Fahrenheit degree mean temperature difference between air and fluid within the coil).

f_i = film coefficient of heat transfer between the internal surface of the coil and the fluid flowing within the coil, Btu per (hour) (square foot internal surface) (Fahrenheit degree mean temperature difference between that surface and the average fluid temperature).

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

k = conductivity of material from which the bare pipe is constructed, Btu per (hour) (square foot) (Fahrenheit degree per inch thickness).

L = thickness of tube wall inches.

R = ratio between external and internal surface of the bare tube, usually varying from 1.03 to 1.15 for the tube used in typical heating or cooling coils. This ratio R is inserted in the formula in order to place internal fluid coefficient of heat transfer on the basis of external surface.

Frequently, when pipe or tube walls are thin and of material having high conductivity (as is the case in construction of typical heating and cooling coils) the term L/k in Equation 2 becomes negligible and is generally disregarded. (The effect of the term L/k in typical bare pipe heating or cooling coils seldom exceeds 1 to 2 percent of the overall coefficient). Thus, in its simplest form, for bare pipe:

$$U = \frac{1}{\frac{R}{f_i} + \frac{1}{f_o}} \tag{3}$$

For finned coils the formula* for the overall coefficient of heat transfer can be conveniently written:

$$U = \frac{1}{\frac{R}{f_i} + \frac{1}{\eta f_o}} \tag{4}$$

in which the term η, called the *fin efficiency*, is introduced to allow for the resistance to heat flow encountered in the fins.

The term R, in this case, is the ratio of *total* external surface to internal surface. For typical designs of finned coils for heating or cooling, this ratio varies from 10 to 30. Term R is again introduced to place the internal surface coefficient of heat transfer on a basis of external surface.

The performances of all heating and dry cooling coils are influenced by these same factors. But, when cooling coils operate wet or act as dehumidifying coils, the performance cannot be predicted on the basis of overall coefficients.

PERFORMANCE OF DEHUMIDIFYING COILS

When the dew point of the air leaving a cooling coil is lower than the dew point of the air entering the coil, some moisture removal has been accomplished. A coil that normally accomplishes (or is designed to accomplish) moisture removal in addition to sensible heat cooling is termed a dehumidifying coil.

In most air conditioning processes, the air may be considered as a mixture of water vapor and the dry components. Both dry components and the water vapor enter an air conditioning coil at the same dry-bulb temperature; both the dry components and the water vapor lose sensible heat during the contact with the first portion of the cooling coil in the same manner as in a dry cooling coil. As the dry-bulb temperature of the mixture approaches the dew point of the water vapor components, moisture removal starts.

The psychrometric path of air through a cooling coil is generally agreed to follow a path similar to that shown in Fig. 12. When the dry-bulb

* Rational Development and Rating of Extended Air Cooling Surface, by H. B. Pownall (*Refrigerating Engineering*, October, 1935, p. 211).