in which the term $z$, 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. In the discussions which follow, coefficients $f_r$ and $zf_a$ will be considered separately, and also various ways of combining them will be outlined.

**External Film Coefficient**

While formulae have been developed expressing the film coefficient $f_a$ for air passing parallel to a plane surface, they cannot be used directly 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 $zf_a$. The term, $zf_a$, will be written merely $f_a$ in this discussion as there is no necessity for separately evaluating $z$ and because values of $f_a$ are usually applied only to the particular coils for which tests are made.

Transfer of heat from a fluid to a solid is accomplished by the contacting of the molecules of the fluid with the solid. When a molecule strikes a solid, its energy level equalizes with the energy level of the solid. The total amount of heat exchanged between the molecules of a fluid and a solid is determined by the number of contacts per unit of surface per unit of time, and by the energy change of the fluid.[2] The energy change, in the case of air, is measured by the temperature change times the specific heat of the air. The number of contacts is measured by a percentage of the weight of air flowing per unit of time.

In the case where water vapor is mixed with air, and the water vapor is cooled but not condensed, the amount of heat transferred is increased by the energy change of the vapor particles. The additional energy is measured by the temperature change, by the specific heat of the water vapor, and by the weight of vapor contacting the surface per unit of time. In a mixture of air and vapor there is a definite ratio between the weight of the vapor and of the air per cubic foot of the mixture. Therefore, as the temperature of the mixture is lowered, the amount of heat lost by the vapor always bears a definite ratio to the amount of heat lost by the air. The amount of energy involved in the temperature change of the vapor is small, however, and it is usually included with that of the air by using a value of 0.245 for the specific heat of humid air.

Dehumidification of air by a cooling coil occurs whenever the surface temperature of the fins and tubes is below the dew-point temperature of the air. Enough molecules of water vapor are condensed on the coil to create a state of equilibrium between the vapor pressure of the moisture on the coil surface and the vapor pressure of the moisture in that part of the air stream which is in immediate contact with the coil surface. Because of the good contact between the condensed film of water and the coil surface, the water film attains a temperature approaching that of the coil surface. Therefore, those particles of air which actually contact the

[2]Graphical Method of Determining Finned Coil Capacities Described, by E. P. Wells (*Heating, Piping and Air Conditioning*, December, 1936, p. 665).





water film leave the film with a dew-point temperature equal to the outer surface film temperature. However, many air particles, with their attendant water vapor particles, never contact the coil surface, but are by-passed between the fins. These air particles have the same dew-point temperature when they leave the coil as they had when they entered, but after leaving the coil they mix with the air particles which did contact the surface, producing a mixture of air which has a dew-point temperature that lies between the original dew-point temperature and the film surface temperature. This process explains why air seldom leaves a coil in a saturated condition.

The foregoing contact-mixture concept of heat transfer has been found by several independent investigators to be consistent with experimental data. The concept has been used successfully in analyzing the performance of evaporative condensers, cooling towers, condensers and evaporators. A relation has been found between heat transfer and pressure drop of flowing fluids, by assuming that molecules of a fluid lose their momentum upon contact with a solid.[3]

The fact that a coil starts to condense moisture when the surface temperature drops below the dew-point temperature of the entering air makes it possible to measure the surface temperature of a coil, an otherwise practically impossible task. After the surface temperature has been determined, it is possible to analyze completely the surface film coefficient of both the air side and refrigerant side of a coil.

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

$$f_a = C\,w^n \qquad (5)$$

*where*

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

$w$ = air mass velocity, pounds per hour per square foot of coil face area.

$C$ and $n$ = constants which depend upon air turbulence, the number of square feet of external surface per square foot of coil face area, and the depth of the coil.

The difficulty of obtaining sufficient tests to evaluate the constants $C$ and $n$ for all conditions of coil design and operation makes it desirable to use Equation 6 for determining the air side coefficient:

$$f_a = 0.245 \times \frac{w}{a} \times 2.3 \times \log_{10}\left(\frac{1}{1\text{-}E}\right) \qquad (6)$$

*where*

0.245 = specific heat of humid air, Btu per pound per degree Fahrenheit.

2.3 = the constant which converts logarithms from base $e$ to base 10.

$a$ = external surface area, square feet per square foot of coil face area.

$E$ = coil efficiency, a decimal less than 1.0.

This formula gives values of $f_a$ after tests have been made to evaluate the coil efficiency. Equation 6 can be derived[4] by combining the basic

[3]The Contact-Mixture Analogy Applied to Heat Transfer with Mixtures of Air and Water Vapor, by W. H. Carrier (*A.S.M.E. Transactions*, January, 1937, Vol. 59, No. 1, p. 49).

[4]Loc. Cit. Note 2.