quite different from (h_c). Its use is permissible if the temperature difference is small.

The steady-state heat transfer problems encountered in air conditioning applications are not normally of the type involving action of a single mode of heat transfer through a single homogeneous material. Usually more than one of the heat transfer mechanisms is effective, and the thermal current flows through several thermal resistances either in a series or in parallel. This type of problem may best be illustrated by a consideration of a particular system such as the heat transfer from the air to cold water inside an insulated pipe, Fig. 4. Since air is sensibly transparent to radiation, there will be some heat transfer by both radiation and convection to the outer insulation surface. The mechanisms act in parallel on the air side. The total current by radiation and convection then passes through the insulating layer and the pipe wall by thermal conduction, and thence by convection into main cold water streams. Radiation is not

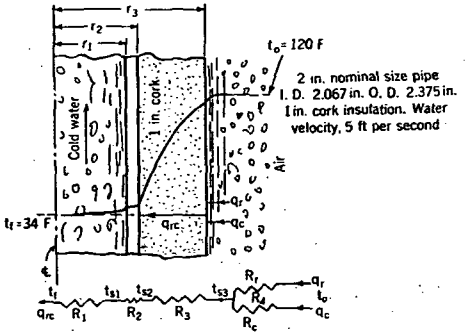

FIG. 4. HEAT TRANSFER CONDITIONS IN THE INSULATED COLD WATER LINE

significant on the water side as liquids are sensibly opaque to radiation, although water transmits energy in the visible region. The contact resistance between the insulation and the pipe wall is presumed to be equal to zero.

Referring to Fig. 4, the thermal current for a given length N of pipe, q_{rc} Btu per hour, may be thought of as flowing through the parallel resistances R_r and R_c, associated with the insulation surface radiation and convection transfer. Then the flow is through the resistance offered to thermal conduction by the insulation, R_3, through the pipe wall resistance, R_2, and into the water stream through the convection resistance, R_1. Note the analogy to the direct current electrical circuit problem. A temperature (potential) drop is required to overcome these resistances to the flow of thermal current. The total resistance to heat transfer, R_T, hour degrees Fahrenheit per Btu, is the summation of the individual resistances:

$$R_T = R_1 + R_2 + R_3 + R_4 \tag{4}$$

where the resultant parallel resistance R_4 is obtained from:

$$\frac{1}{R_4} = \frac{1}{R_r} + \frac{1}{R_c}$$

Provided the individual resistances may be evaluated, the total resistance can be obtained from the above relation. Then the heat transfer current for the length of pipe (N, ft) can be established by the relation:

$$q_{rc}\ (\text{Btu per hour}) = \frac{t_o - t_f}{R_T} \tag{5}$$

For a unit length of the pipe the heat transfer rate is:

$$\frac{q_{rc}}{N}\ (\text{Btu per hour foot}) = \frac{(t_o - t_f)}{R_T N} \tag{5a}$$

The temperature drop, Δt, through an individual resistance may then be calculated from the relation:

$$\Delta t = R\, q_{rc}$$

where R is the resistance in question.

The problem is now reduced to one of evaluating the individual resistances of the system. This entails suitable integration of the rate Equations 1, 2, 3, or 3a to produce expressions of the form:

$$q = \frac{\Delta t}{R} \tag{6}$$

where q is the heat transfer rate, and Δt is the potential drop or temperature difference through the resistance R. Table 6 lists such solutions for six different conduction systems. Table 2 in Chapter 4 and Table 1 of this chapter indicate the magnitudes of the thermal conductivities, k, to be employed in the expressions of Table 6.

The solution applicable to the problem depicted in Fig. 4, for the calculation of R_2 and R_3, is case 2 in Table 6. Thus for a *1 ft length* of 2 in. nominal size pipe (I. D. = 2.067 in., O. D. = 2.375 in.) insulated with 1 in. of cork:

$$R_2 = \frac{\log_e \frac{1.188}{1.033}}{2\pi \times 26 \times 1} = 8.5 \times 10^{-4} \text{ hr degree Fahrenheit per Btu.}$$

$$R_3 = \frac{\log_e \frac{2.188}{1.188}}{2\pi \times 0.025 \times 1} = 3.9 \text{ hr degree Fahrenheit per Btu.}$$

The convection resistances to heat transfer from the pipe wall to the cold water, R_1, and from the air to the surface of the insulating material, R_c, are dependent on the flow conditions prevailing at these surfaces, and on the thermal properties of the fluids. The unit conductances for thermal convection, h, Btu per hour per square foot per degree Fahrenheit, have been determined by test for many flow systems. These data may be employed to predict the conductances for *similar flow systems*. Table 7 summarizes some empirical equations expressing such test results.

For the problem under consideration (Fig. 4) case 3 of Table 7 is applicable for the calculation of the cold water side convection resistance R_1. Corresponding to the water velocity of 5 ft per second, the mass velocity is: