The conductivities of these two materials at mean temperatures of 885 and 352.5 F, interpolated from Table 1, are 0.677 and 0.466 Btu, respectively.

These values are substituted in Equation 2 and a trial calculation made.

The actual thickness of diatomaceous earth covering is 3.095 in. and that of the 85 percent magnesia is 2.125 in. For a nominal 6-in. steel pipe: $r_1 = 3.312$, $r_2 = 6.407$, and $r_3 = 8.532$. Then,

$$q_o = \frac{1200 - 135}{\dfrac{8.532 \log_e \dfrac{6.407}{3.312}}{0.676} + \dfrac{8.532 \log_e \dfrac{8.532}{6.407}}{0.466}} = \frac{1065}{8.33 + 5.24} = 78.5 \text{ Btu.}$$

The temperature drop from the outer surface of the insulation to the surrounding air for a heat loss of 78.5 Btu is found from Fig. 5 to be 49.5 deg for a 17-in. O.D. cylindrical surface, or 49.5 + 80 F room temperature = 129.5 F surface temperature. Since a surface temperature of 135 F was assumed, it is evident that a temperature closer to 129.5 F, or, for instance, 129 F should be used for recalculation:

$$q_o = \frac{1200 - 129}{8.33 + 5.24} = 78.9 \text{ Btu.}$$

Since the temperature drop through each material is equal to the heat flow times the actual resistance of each material, the temperature drop through the diatomaceous earth is 78.9 × 8.33 = 657 F, or the temperature between the two insulating materials is (1200 − 657) = 543 F. Since a temperature of 570 F between the two materials was assumed, it is obvious that a temperature closer to 543, or for instance 545 F may be selected. The mean temperatures of the two insulations corresponding to the new assumptions are (1200 + 545) ÷ 2 = 872.5, and (545 + 129) ÷ 2 = 337, and the interpolated conductivities corresponding to the new mean temperatures are 0.675 and 0.461 for the diatomaceous earth and 85 percent magnesia, respectively. By substituting in Equation 2

$$q_o = \frac{1200 - 129}{\dfrac{5.63}{0.675} + \dfrac{2.44}{0.461}} = \frac{1071}{8.34 + 5.30} = 78.5 \text{ Btu.}$$

Again referring to Fig. 5, it is seen that the temperature drop from the outer surface of the insulation to the surrounding air for a heat loss of 78.5 Btu = 49 deg, which corresponds to the surface temperature of 129 F last assumed. The heat loss is therefore 78.5 × 8.532 ÷ 3.312 = 202 Btu per sq ft of pipe surface. Since the surface area per linear foot of 6-in. pipe is 1.734 sq ft (Table 2), the heat loss per linear foot of pipe will be 202 × 1.734 = 351 Btu per hr.

The rate of heat loss from a surface maintained at constant temperature is greatly increased by air circulation over the surface. In the case of well-insulated surfaces, the increases in losses due to air velocity are very small as compared with increases from bare surfaces, because of the fact that air flowing over the surface of the insulation can increase only the conductance of heat from surface to air, and cannot change the internal conductance of the insulation itself. The maximum increase in heat loss due to air velocity ranges from about 15 percent in the case of 1-in. thick insulation, to about 5 percent in the case of 3-in. thick insulation, provided that the insulation is thoroughly sealed so that air can flow only over the surface. If the conditions are such that the air may circulate through cracks and crevices in the insulation, the increases may be far greater than those given. Therefore, it is essential that insulation be applied in such a manner that air circulation within it, or between it and the pipe, is avoided.

Piping which is covered with a water-mixed product or insulation which will absorb moisture, particularly in damp locations, should be coated with a corrosion-resisting paint. This precaution may prevent early failure due to external pipe corrosion.

The frequent practice of omitting insulation on that portion of a pipe which passes through a masonry wall, or which may be in contact with other metals, should be avoided. Physical contact between the pipe surface and other structural materials of high thermal conductivity will result in heat transfer much greater than that shown in Tables 2 and 3 for transfer from bare pipe to air.

The saving due to use of insulation on piping is illustrated in *Example 4*.

Example 4: If the steam pipe given in *Examples 1* and *2* is covered with nominal 1 in. thick 85 percent magnesia, determine the resulting total annual loss through the insulation. Also compute the monetary value of the annual saving and the percentage of saving over the heat loss from the bare pipe.

Solution: By referring to Fig. 1, the coefficient for 1 in. insulation on a 2-in. pipe is found to be 0.276 Btu per (hr) (linear ft of pipe) (deg temperature difference) at a temperature difference of 159.4 F. The heat insulation factor for 85 percent magnesia insulation, interpolated from Table 6, for a temperature difference of 159.4 F is 1.085. The total hourly loss per linear foot of pipe will then be 0.276 × 159.4 × 1.085 = 47.7 Btu. The total annual loss through the insulation = 47.7 × 165 (linear ft) × (4000 hr) = 31,480 Mb. The annual bare-pipe loss as determined in the solution of *Example 1* was found to be 171,100 Mb. The saving due to insulation is then 171,100 − 31,480 = 139,620 Mb per year.

From the solution of *Example 2*, it was found that the heat supplied to the system cost $0.804 per 1000 Mb. Therefore, the monetary value of the saving = 0.804 (dollars) × 139.6 (thousand Mb) = $112.23 or 8.16 percent of the cost when using uninsulated pipe.

THICKNESS OF INSULATIONS TO BE APPLIED

Thermal insulation is used in a variety of thicknesses for many varied reasons. Refrigerated equipment is normally designed for minimum heat gain, and heated equipment for minimum heat loss, within economical limits. This assures minimum-sized refrigeration or heating equipment, both from the standpoint of original as well as operational cost. Present refrigeration design practice limits the heat gain to 4 to 8 Btu per (hr) (sq ft) of exposed surface. Sometimes the principal object of the insulation is to limit the heat gain or loss to a specified value to control the temperature of a manufacturing or chemical process.

Minor refrigeration and air conditioning equipment and cold-water lines usually utilize only sufficient insulation thickness to prevent condensation on the warm surface so as to prevent dripping. Occasionally the criterion for heated equipment and pipes is the reduction of the outer surface to a temperature (usually a maximum of 175 F to 200 F) low enough to prevent injury to personnel.

ECONOMICAL THICKNESS OF INDUSTRIAL INSULATION

The thicknesses of insulation which ordinarily are used for various temperature conditions are given in Table 7. Where a thorough analysis of economic thickness is desired, the thickness of insulation that will give the lowest sum of annual cost of heat loss and insulation may be found by means of Fig. 6.[2] As the thickness of insulation increases the annual cost of heat loss decreases, but the annual cost of insulation (first cost multiplied by percent fixed charges) increases. The sum of the two costs will first decrease with increasing thickness of insulation, and then, depending on operating conditions, will increase beyond a certain thickness.