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-resistant 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. Refrigerating equipment is normally designed for minimum heat gain, and heating 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

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.[5] 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. Therefore, the thickness at which the sum of the costs is a minimum, is the most economical.

The method of using the chart Fig. 6 is as follows:

From the number of hours of operation per year at the bottom of the chart proceed upward to the line showing value of heat in dollars per million Btu using the appropriate scale *A* or *B*. Proceed right to temperature difference line using either scale *A* or *B*. Move upward to the line representing conductivity of the insulation being considered, then left to discount line, upward to the percent fixed charge line, right to the pipe size or flat surface line and read the economic thickness at top on the scale corresponding to the scales selected for value of heat and temperature difference. For example; with Scale *B* heat value and Scale *A* temperature difference or vice versa, use Scale *A-B* economic thickness. If the intersection with the flat surface is on the *flat surface continued* curve, the economical thickness is read on the prime scales *A'-A'*, *A'-B'*, or *B'-B'*.

Cost of insulation refers to incremental cost in place; i.e., average incremental cost per unit thickness after the first unit. The first inch of insulation will usually cost more than each additional inch. This is due to cost of finish, contractor's setup, and operating costs, which do not increase in proportion to thickness. The first inch of insulation, except in very unusual cases, provides enough saving in heat cost out of bare surface cost to more than cover these extra first costs. To obtain discount from insulation list price, first obtain applied prices for the desired type of insulation in one-inch, two-inch, etc., thickness. Then determine the average incremental cost per inch above one-inch thickness.

Incremental cost in percent discount from list is

$$100\left(1-\frac{X}{Y}\right)$$

where

X = average incremental cost in place per inch above one inch.

Y = list price for one inch.

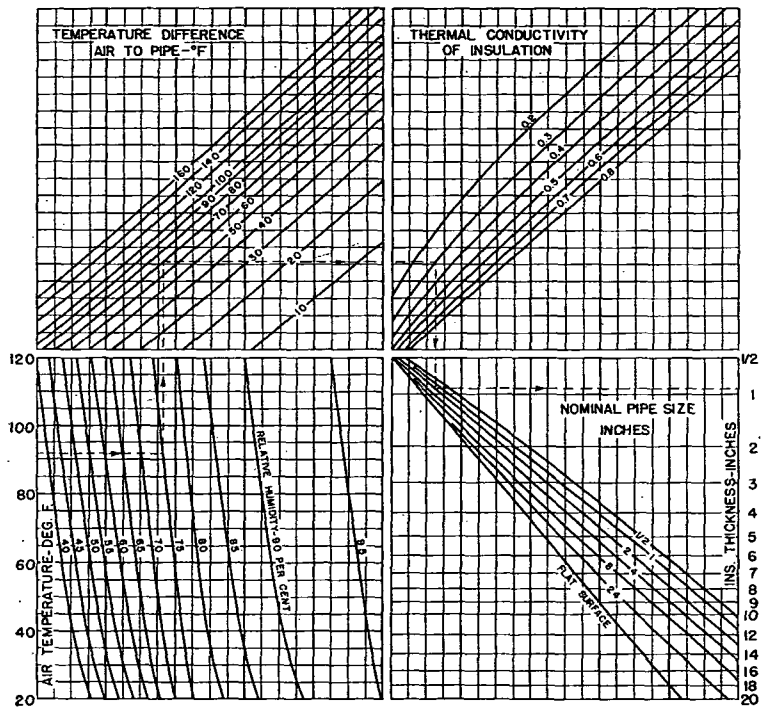
In figuring pipe insulation, use the list price for one-inch thickness for a pipe size consistent with the average incremental cost per inch. For example, if the average incremental cost per inch is based on applied prices for one, two, and three inches, the incremental cost of the second and third inches would be averaged and the pipe size for list price would be that nearest the average pipe size of the second and third inch.

A rapid method for determining the economical thickness of insulation by use of tables has been published.[6]

LOW TEMPERATURE PIPE INSULATION

Surfaces maintained at temperatures lower than the surrounding air are insulated to reduce the flow of heat and to prevent condensation. The insulating material should absorb a minimum amount of moisture, because the absorption of moisture substantially increases the conductivity of the material. This property is particularly important in the insulation of surfaces that are below the dew point of the surrounding air. In such cases, due to vapor-pressure difference, it is necessary to seal the surface of the insulating material against the penetration of water vapor which would condense within the material, causing a serious increase in heat flow, possible breakdown of the material, and corrosion of metal surfaces. An insulating material with a high degree of moisture absorption might pick up moisture before application and then, when the vapor seal is in place and the temperature of the insulated surface reduced, release that moisture to the cold surface. There are a number of methods of producing vapor seals, some of which have been worked out by insulation manufacturers to suit their products, and others by appliers and users. Unless time-proven methods are known, specifications of insulation manufacturers should be obtained and followed carefully.

Equipment must be carefully protected against corrosion caused by condensation of water vapor. All metallic surfaces



[6] Solve problems as indicated by dotted line, entering chart at lower left-hand scale.

Fig. 7 . . . . Thickness of Pipe Insulation to Prevent Condensation on Outer Surface[6]