(2) the necessity of controlling temperature within a structure, cabinet, pipe, vessel, duct, etc., to a specified value, and (3) building structure limitations.

Extensive studies of all factors affecting the true economic thickness are warranted only for large installations. For particular applications, considerations other than thickness alone may be important. Temperature limit, specific heat, moisture absorption, mechanical strength, health, safety, and flame resistance should all be considered when choosing an insulation for installation. The manufacturer should be consulted for information regarding these properties.

The economic thickness of insulation may be determined from Fig. 4 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. Move 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 economic 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 over 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 1 in. thickness.

For pipe insulation, use the list price for 1 in. 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 1, 2, and 3 in., 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.

Reference 16 provides a proven and precise method for determination of economical thickness for heating applications and is especially suitable where large installations are to be considered.

SELECTION OF THICKNESS

Thermal insulation is used in a variety of thicknesses for many reasons. Refrigerating equipment is normally designed for minimum heat gain, and heating equipment for minimum heat loss, within economical limits.

Table 2 lists insulation thicknesses in accord with general practice for refrigeration requirements for average conditions in northern climate zones. Local climatic or unusual conditions of service would determine the insulation thickness to be used.

Table 2 .... Typical Thickness of Insulation for Refrigerating Equipment

(For Flat Surfaces and Average Operating Condition)

Temperature F	Thermal Conductivity k at 70 F					
	0.20	0.25	0.30	0.35	0.40	0.45
−45 to −15	7	8	10	12	13	15
−15 to 0	5	6	8	9	10	12
0 to 15	5	6	7	8	9	10
15 to 25	4	5	6	6	7	8
25 to 35	3	4	4	5	6	7
35 to 50	2	3	3	4	4	5
50 to 60	2	2	2	3	3	3

THICKNESS TO PREVENT SURFACE CONDENSATION

Condensation occurs when the water vapor in air comes in contact with a surface whose temperature is lower than the dew-point of the air. In order to prevent condensation from occurring on the warm side of insulated rooms, pipes, ducts, equipment, etc., a sufficient thickness of insulation should be used to insure that the insulation surface temperature always exceeds the dew-point temperature.

It is impossible to provide insulation of sufficient thickness to prevent condensation at 100 percent relative humidity conditions, because the heat gain would have to be reduced to zero by using an infinite thickness of insulation. Fig. 5 illustrates the steady-state heat transfer for which the following relationship may be used to calculate the data given in Figs. 6 and 7.

$$q = \frac{(D_b - D_p)}{R_s} = \frac{(D_p - t_o)}{R_i}$$

where

q = heat flow rate, Btu per (hour) (square foot).
D_b = ambient still air dry-bulb temperature, Fahrenheit.
D_p = dew point, Fahrenheit.
t_o = operating temperature, Fahrenheit.
R_s = surface thermal resistance = 0.65 F deg per Btu/(hr) (sq ft).
R_i = L/k = insulation thermal resistance = F deg per Btu /(hr) (sq ft).
L = thickness, inches (as read from Fig. 7; flat surface or equivalent thickness).
k = mean thermal conductivity, Btu per (hr) (sq·ft) (F deg /in.).

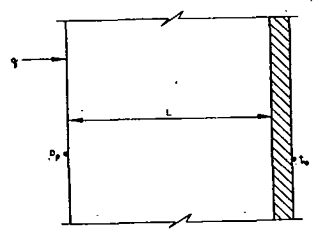

Fig. 5 .... Steady-State Heat Transfer

Equivalent thickness is the thickness of insulation on a flat surface which would be required to give the same rate of heat transmission per square foot of outer surface of insulation as on a cylinder or pipe.

$$L = r_o \log_e r_o/r_i$$

where

r_o = outer radius of insulation, inches.
r_i = inner radius of insulation, inches.

The approximate thickness of insulation required to prevent condensation on pipes and flat metallic surfaces may be obtained from Figs. 6 and 7.

In Fig. 6, t_m is the mean temperature (F deg) for k of a specific insulating material, and is taken as the arithmetic average of D_b and t_o:

$$t_m = D_b + (t_o/2)$$

Actual thickness of pipe insulation is determined from Fig. 7 of actual thickness versus equivalent thickness. Enter Fig. 7 with L as equivalent thickness determined from Fig. 6 for specific conditions. Always select next higher nominal thickness.

Example 1: A nominal 4 in. pipe is operating at 10 F in ambient still air conditions of 90 F and 90 percent relative humidity. Determine the thickness of fibrous glass insulation necessary to prevent condensation.

Solution: Assume a nominal 4 in. pipe operating at 10 F in ambient still air conditions of 90 F and 90 percent relative humidity. In Fig. 6, read up from t_o = 10 (arrow) to 90 percent RH group, intersecting middle line, representing 90 F; then read left to Insulation Resistance (R_i = 14.8. Read down from t_o to the t_m (mean temperature) scale marked (at the right) 90 F. The t_m value at that point is 50. Assume that the insulation specified has a k of 0.28 at t_m of 50 F, according to manufacturer's tables.

Since $R_i = L$, the thickness required for a flat surface or the equivalent thickness in inches (L) for any pipe size is:

$L = R_i k = 14.8 \times 0.28 = 4.144$ (for flat surface, increase to 4½ in.).

To find the actual thickness of a 4 in. pipe, read the Equivalent Thickness scale in Fig. 7, from L of 4.14 to 4 in. pipe size line, and find actual thickness of 2¾ in. on left ordinate. Select next higher standard thickness of 3 in.

PART IV: GENERAL PRACTICE FOR BUILDING INSULATION

Building insulation products should be used for the purpose and in the manner recommended by the manufacturer, who should be consulted for detailed application instructions and also regarding specific problems or unusual conditions involving the use of insulation. It is necessary that all materials be handled carefully and applied correctly in order to assure that the calculated heat loss or heat gain through the insulated sections not be exceeded. Vapor barriers are necessary to re-

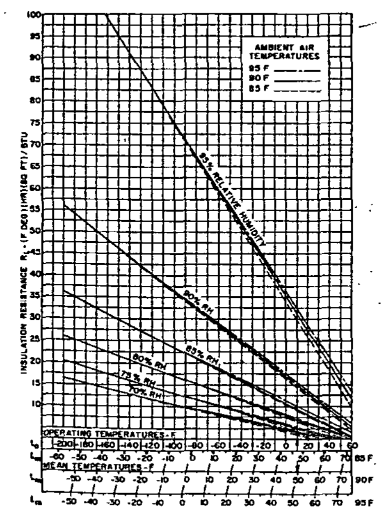

Fig. 6 .... Thermal Resistance of Insulation to Prevent Surface Condensation

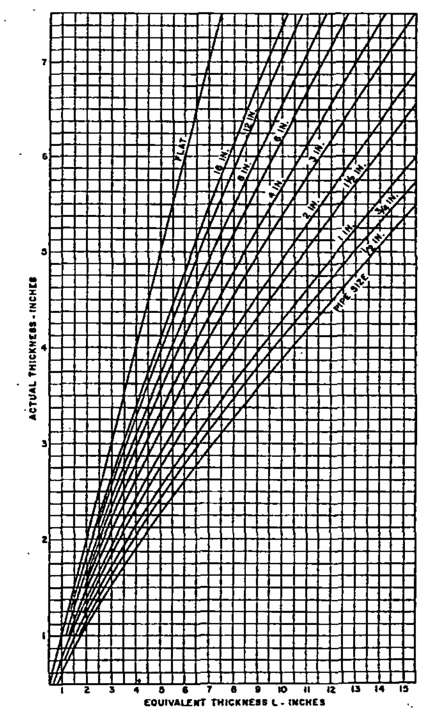

Fig. 7 .... Conversion of Equivalent Thickness to Actual Thickness for Pipe Insulation