Table 7 . . . . Thickness of Pipe Insulation Ordinarily Used Indoors[*]

Steam Pressure Psig or Condition	Steam Temperature Fahrenheit Degrees	Thickness of Insulation		
		Pipes Larger Than 4 In.	Pipes 2 In. to 4 In.	Pipes ½ In. to 1½ In.
0 to 25	212 to 267	1 in.	1 in.	1 in.
25 to 100	267 to 338	1½ in.	1 in.	1 in.
100 to 200	338 to 388	2 in.	1½ in.	1 in.
Low Superheat	388 to 500	2½ in.	2 in.	1½ in.
Medium Superheat	500 to 600	3 in.	2½ in.	2 in.
High Superheat	600 to 700	3½ in.	3 in.	2 in.

[*] All piping located outdoors or exposed to weather is ordinarily insulated to a thickness ½ in. greater than shown in this table, and covered with a waterproof jacket.

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′*.

Table 9 . . . . Data for Estimating Requirements to Prevent Freezing of Water in Pipes with Surrounding Air at −18 F

Nominal Pipe Size (Inches)	Number of Hours to Cool 42 F Water to Freezing Point			Water Flow Required at 42 F to Prevent Freezing, Pounds per Linear Foot of Pipe per Hour		
	Thickness of Insulation in Inches (Conductivity, k = 0.30)					
	2	3	4	2	3	4
½	0.42	0.50	0.57	0.54	0.45	0.40
1	0.83	1.02	1.16	0.68	0.55	0.48
1½	1.40	1.74	2.02	0.84	0.68	0.58
2	1.94	2.48	2.90	0.95	0.75	0.64
3	3.25	4.27	5.08	1.24	0.94	0.79
4	4.55	6.02	7.20	1.47	1.11	0.93
5	5.92	7.96	9.69	1.73	1.29	1.06
6	7.35	9.88	12.20	1.98	1.46	1.19
8	10.05	13.90	17.25	2.46	1.78	1.43
10	13.00	18.10	22.70	2.96	2.12	1.70
12	15.80	22.20	28.10	3.43	2.45	1.93

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.

Table 8 . . . . Heat Gains for Insulated Cold Pipes

Rates of heat transmission given in Btu per (hour) (Fahrenheit degree temperature difference between fluid in pipe and surrounding still air)
Based on materials having conductivity, k = 0.30

Nominal Pipe Size (Inches)	Ice Water Thickness			Brine Thickness			Heavy Brine Thickness		
	Thickness of Insulation (Inches)	Btu Per Linear Foot	Btu Per Sq Ft Pipe Surface	Thickness of Insulation (Inches)	Btu Per Linear Foot	Btu Per Sq Ft Pipe Surface	Thickness of Insulation (Inches)	Btu Per Linear Foot	Btu Per Sq Ft Pipe Surface
½	1.5	0.110	0.502	2.0	0.098	0.446	2.8	0.087	0.394
¾	1.6	0.119	0.431	2.0	0.111	0.405	2.9	0.094	0.340
1	1.6	0.139	0.403	2.0	0.124	0.352	3.0	0.104	0.294
1¼	1.6	0.155	0.357	2.4	0.131	0.300	3.1	0.113	0.260
1½	1.5	0.174	0.351	2.5	0.134	0.270	3.2	0.118	0.238
2	1.5	0.200	0.322	2.5	0.151	0.244	3.3	0.134	0.214
2½	1.5	0.228	0.303	2.6	0.170	0.226	3.3	0.147	0.197
3	1.5	0.269	0.293	2.7	0.186	0.202	3.4	0.162	0.176
3½	1.5	0.295	0.282	2.9	0.191	0.183	3.5	0.176	0.167
4	1.7	0.294	0.248	2.9	0.209	0.176	3.7	0.182	0.154
5	1.7	0.349	0.239	3.0	0.241	0.165	3.9	0.202	0.138
6	1.7	0.404	0.233	3.0	0.259	0.150	4.0	0.228	0.130
8	1.9	0.455	0.201	3.0	0.318	0.140	4.0	0.263	0.116
10	1.9	0.559	0.198	3.0	0.383	0.135	4.0	0.309	0.110
12	1.9	0.648	0.194	3.0	0.438	0.131	4.0	0.364	0.108

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.[a]

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 should be coated with a vapor-impervious barrier (some types of which have an asphaltic or tar base) without any breaks or openings in order to prevent corrosion.

The thickness of insulation required to prevent condensation on the outer surface is that thickness which will raise the temperature of the outer surface of the insulation to a point slightly higher than the dew point of the surrounding vapor. The dew point for various humidities can be readily ascertained from a psychrometric chart. The external vapor barrier must be made as nearly perfect as possible in order to prevent migration of vapor into the insulation.

The approximate required thickness of insulation to prevent condensation on pipes and flat metallic surfaces may be obtained from Fig. 7 in which a surface resistance of 0.606, corresponding to a film conductance of 1.65, was used in calculating the curves. This value provides a slight factor of safety and its use is known to give satisfactory field results. In using the chart it is advisable to specify the next thicker, rather than the next thinner, commercial insulation in cases where an intermediate thickness is indicated.

Heat gains for pipes insulated with a material having an installed conductivity of 0.30 Btu per (sq ft) (hr) (F deg per in.) are given in Table 8. This table may be used for any of the commercial insulations offered for this purpose since they have conductivities very near the 0.3 value used.

INSULATION OF PIPES TO PREVENT FREEZING

If the surrounding air temperature remains sufficiently low for an ample period of time, insulation cannot prevent the freezing of still water, or of water flowing at such a velocity that the quantity of heat carried in the water is not sufficient to take care of the resulting heat losses that will cause the temperature of the water to be lowered to the freezing point. Insulation can materially prolong the time required for the water to give up its heat so that, if the velocity of the water flowing in the pipe is maintained at a sufficiently high rate, freezing may be prevented.

Table 9 may be used for making estimates of the thickness of insulation necessary to take care of still water in pipes at various water and surrounding air temperature conditions. Because damage and service interruptions may result from frozen water in pipes, it is essential that an efficient insulation be utilized. This table is based on the use of a material having a conductivity of 0.30. The initial water temperature is assumed to be 10 deg above, and the surrounding air temperature 50 deg below, the freezing point of water (temperature difference, 60 F).

The last column of Table 9 gives the minimum quantity of water at initial temperature of 42 F that should be supplied every hour for each linear foot of pipe, in order to prevent the temperature of the water from being lowered to the freezing point. The weights given in this column should be multiplied by the total length of the exposed pipe line expressed in feet. As an additional factor of safety, and in order to provide against temporary reductions in flow occasioned by reduced pressure, it is advisable to double the rates of flow listed in the table. It must be emphasized that the flow rates and periods of time designated apply only for the conditions stated. To estimate for other service conditions, the following method of procedure may be used.

If water enters the pipe at any temperature other than 42 F, the time required to cool it to the freezing point will be equal to $(t - 32)/10$ times that given in the table, or the rate of flow of water may be changed to $10/(t - 32)$ times the indicated flow rate in the last columns of Table 9. However, if the water enters the pipe at 34 F, it will be cooled to 32 F in one-fifth of the time given in the table. It will then be necessary to increase the rate of flow so that five times the specified quantity of water will have to be supplied in order to prevent freezing.

If the minimum air temperature is −38 F (temperature difference 80 F) instead of −18 F, the time required to cool the water to the freezing point will be 60/80 of the time given in the table, or the necessary quantity of water to be supplied will be 80/60 of that given.

In making calculations to arrive at the values given in Table 9, the loss of heat stored in the insulation, the effect of a varying temperature difference due to the cooling of pipe and water, and the resistance of the outer surface of the insulation to the transfer of heat to the air, have all been ne-