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 7. 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 8 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 8 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

Table 7....Heat Gains for Insulated Cold Pipes

Rates of heat transmission given in Btu per hour per linear foot with still air conditions of 90 F. Based on materials having a thermal conductivity, k = 0.30 at a mean temperature of the room and the pipe surface

Nominal Pipe Size (Inches)	Pipe Temperature 40 F			Pipe Temperature 15 F			Pipe Temperature −15 F		
	Nominal Thickness of Insulation (Inches)	Actual Thickness of Insulation (Inches)	Btu per Linear Foot	Nominal Thickness of Insulation (Inches)	Actual Thickness of Insulation (Inches)	Btu per Linear Foot	Nominal Thickness of Insulation (Inches)	Actual Thickness of Insulation (Inches)	Btu per Linear Foot
½	¾	0.76	6.6	1½	1.57	7.0	1½	1.57	10
¾	¾	0.66	7.9	1½	1.47	8.0	1½	1.47	12
1	¾	0.77	8.4	1½	1.59	8.8	1½	1.59	13
1¼	¾	0.91	8.8	1½	1.66	9.7	1½	1.66	14
1½	1	1.04	9.0	1½	1.54	11	2	1.82	15
2	1	1.05	11	1½	1.58	13	2	2.11	15
2½	1	1.05	12	1½	1.33	16	2	1.86	19
3	1	1.01	14	1½	1.55	17	2	2.05	20
3½	1½	1.29	14	2	1.79	17	2½	2.79	18
4	1½	1.54	13	2	2.04	17	2½	2.54	21
5	1½	1.50	16	2	2.00	20	2½	2.57	23
6	1½	1.47	19	2	2.03	23	2½	2.53	28
8	1½	1.52	23	2	2.02	28	2½	2.65	33
10	1½	1.57	27	2	2.07	33	2½	2.57	39
12	1½	1.56	31	2½	2.56	32	3	3.06	40
14	1½	1.43	36	2½	2.43	37	3	2.93	44
16	1½	1.43	41	2½	2.43	41	3	2.93	50
18	1½	1.43	46	2½	2.43	45	3	2.93	55
20	1½	1.43	51	2½	2.43	50	3	2.93	60
24	1½	1.43	60	2½	2.43	59	3	2.93	71
30	1½	1.43	74	2½	2.43	73	3	2.93	87

Table 8....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

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 8. 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 8, 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 neglected. When these factors enter into the computations it is necessary to enlarge the factor of safety. Also as stated, the time shown in the table is that required to lower the water to the freezing point. A longer period would be required to freeze the water, but the danger point is reached when freezing starts. The flow of water will stop and the entire line will be in danger as soon as the water freezes across the section of the pipe at any point.

If it is necessary to calculate the time required for the water to cool to 32 F, the following equation may be used

$$H = \frac{C_p(t_1 - 32)}{q_o\left(\frac{\pi}{6} \times r_2\right)} \tag{3}$$

$$C_p = \text{Capacity of pipe, lb water/lin. ft} = \frac{\pi r_p^2}{144} \times 62.4$$

$$q_o = \frac{k\left[\left(\frac{t_1 + 32}{2}\right) - t_a\right]}{r_2 \log_e \frac{r_2}{r_1}} \tag{4}$$

where

H = hours for water to cool to 32 F.
r_p = inside radius of pipe, inches.
t_1 = initial water temperature.
C_p may be obtained from manufacturers' catalogs and handbooks.
See Equation 1 for definitions of other symbols.

When water must remain stationary longer than the times designated in Table 8, the only safe way to insure against freezing is to install a steam or hot water pipe parallel to the cold water pipe or to place an electric resistance heater along the side of the exposed water line. The heating system and the water line are then insulated so that the heat losses from the heating system are not excessive, and the heating effect is concentrated against the water pipe where it is needed. For this form of protection 2 in. of an efficient insulation may be applied.

APPLICATION OF INDUSTRIAL INSULATION

Small pipes are normally insulated with half-sectional insulation split horizontally and furnished with factory applied jackets forming hinge and lap. Large piping is insulated with segmental blocks, wired or banded in place, or with blanket insulations, particularly where removal for frequent servicing of the pipe is necessary. Indoors, sectional insulation is applied with the canvas lap pasted. Outdoors, it is necessary to provide a weatherproof finish. Fittings and bends are insulated with portions of standard preformed insulation, blanket insulations, or insulating cements. Fitting insulation should be carefully specified to be compatible with the pipe insulation. Insulation on lines carrying cold water, brine, or other cold fluids must be protected to prevent the infiltration of water vapor into the insulation.

Flat, curved, and irregular surfaces such as boilers, breechings, tanks, and vessels, are normally insulated with blocks or lagging, or with blanket forms of insulation. The insulation is secured in a variety of ways depending upon the form of insulation and contour of the surface to be insulated. One specification includes wiring the blocks in place, stretching a hexagonal mesh netting tightly over the insulation, and fastening securely with wires. Over the netting a coat of mineral wool or asbestos cement is applied with a second coat of asbestos cement trowelled to a smooth even finish. For outdoor installations weather protection is then applied. For insulation over surfaces at temperatures below ambient, water-vapor protection must be applied for both indoor or outdoor applications.