

uniform width of air space (usually $\frac{1}{4}$ in. in walls and $\frac{1}{2}$ in. or more in ceiling and floors) adjoining the reflective surface. Forms in which the product is available include (1) blankets fabricated to provide a number of air spaces when installed between framing, and (2) large sheets, adhered to insulating batts, blankets, and to other building materials, such as interior finish panels.

In applying reflective type insulations, it is important that the manufacturer's specifications and instructions be followed. If a particular insulation product is provided with a nailing flange, it must be placed and stapled in a manner that will assure a permanent, uniform air space. The ends of the product should also be stapled and sealed to prevent openings. If tears or punctures occur during application, they must be repaired with tape or suitable pieces of vapor barrier material to assure adherence to the reflective surface. The insulation should be trimmed tightly around electric outlet boxes, plumbing, etc., and taped tight.

Since condensation may occur on a single piece of reflective material used alone in the center of a stud space, a separate vapor barrier should be used on the warm side of the wall or two or more single sheets of reflective material or insulation with multiple layers of reflective surfaces may be applied. When irregularities of stud or joist spacing exceed the dimensional tolerances of the reflective blanket involved, other forms of insulation should be used.

FORMED-IN-PLACE INSULATIONS

Formed-in-place insulations include sprayed and plastic foam types. Sprayed insulation is usually inorganic fibrous material which is blown against a clean surface to which has been applied a coat of adhesive to assure a good bond. A special spray gun is used where the adhesive is mixed with the fibers as they are blown against the surface to the desired thickness which may be up to 2 in. The surface is lightly tamped to provide uniformity and obtain a proper density from 1 to $1\frac{1}{2}$ lb per board foot. This type of product is often left exposed to the room to provide acoustical treatment as well as insulation value.

Polystyrene and urethane plastic foams may be molded or foamed-in-place. Urethane insulation may also be applied by spraying. The application of expandable polystyrene requires the use of steam boilers as a source of heat and heavy molds. Thus, it will probably not be used directly as a building insulation but is finding application in panels. Foamed-in-place and spray techniques for urethane require special equipment for correctly metering and mixing the liquid components. These materials, however, can be used in the field and are being applied as roof, wall, and floor insulation.

Since the methods of handling expandable polystyrene and urethane foams are undergoing rapid changes in technology, the recommendations of the manufacturers of these materials should be consulted before attempting to use them as building insulations.

PART V: GENERAL PRACTICE FOR INDUSTRIAL INSULATION

The applications of industrial insulation to be discussed in this section include: (1) pipes; (2) tanks, vessels, and equipment; (3) ducts; (4) refrigerated rooms or buildings; (5) domestic and commercial refrigerators; (6) mobile equipment; and (7) environmental spaces.

PIPES

Small pipes are insulated with sectional insulation which is furnished with factory applied canvas jackets that form a

hinge and lap. Small pipes and tubes are also insulated with closed cell elastomeric tubing that is slipped over the pipe or tubing before joints are made. Large piping is insulated with segmental blocks, wired or braced in place, or with sectional insulation, particularly where removal for frequent servicing of the pipe is necessary. Indoors, sectional insulation is applied with the lap cemented. Outdoors, it is necessary to provide a weatherproof finish. Fittings and bends are insulated with portions of standard preformed insulation, or insulating cements. Fitting insulation should be consistent with the pipe insulation.

Surfaces maintained at temperatures lower than the surrounding air are insulated to reduce heat gain and to prevent condensation. Prevention of moisture accumulation is particularly important in the insulation of surfaces that are below the dew point of the surrounding air, since moisture substantially increases the effective conductivity of the insulating material. In such cases, it is necessary to seal the surface of the insulation against the penetration of water vapor which would condense within the material and cause a serious increase in heat flow, possible breakdown of the material, and corrosion of the metal surfaces. There are a number of systems for accomplishing vapor sealing, some of which have been designed by manufacturers to suit their products, and others by applicators and users. Vapor barrier treatment should be that which is recommended by the insulation or vapor barrier manufacturer and selected on performance rating as a basis. Good practice demands that the insulation should be protected from inclement elements prior to application and applied as dry as possible.

Wherever the pipe is interrupted by fittings, valves or flanges, the pipe insulation should be carefully sealed with a vapor barrier tape, mastic or sealer to prevent the entrance of moisture. Vapor barrier adhesive must be used for fastening laps of sheet vapor barriers. Tapes of adequate width or strips of vapor barrier sheets should be cemented over the joints between sections to completely seal the joint. In some cases for long runs of piping, the ends of permeable insulation sections should be sealed with vapor barrier compounds at intervals of from 15 to 20 feet to limit the extent of water penetration in the event of physical damage. Vapor barrier protective coating may be reinforced with glass fabric or other rot proof strong membranes for additional protection from damage.

Where impermeable or low permeance insulations are used, all butt and longitudinal joints should be filled and sealed with

Table 3 Minimum Insulated Pipe Spacing
(For Proper Application and Sealing of Pipe Insulation)

Insulation Thickness	Space required between parallel pipes, in.	Space required between pipe and adjacent surface, in.
$1\frac{1}{2}$ in. to 2 in.		
Up to 6-in. pipe—screwed fittings	7	5
Larger than 6-in. pipe—screwed fittings	11	6
All pipe sizes—flanged fittings	12	8
2 in. to 3 in.		
Up to 6-in. pipe—screwed fittings	9	7
Larger than 6-in. pipe—screwed fittings	15	9
All pipe sizes—flanged fittings	16	10
3 in. to 4 in.		
Up to 3-in. pipe—screwed fittings	11	9
Larger than 3-in. pipe—screwed fittings	19	13
All pipe sizes flanged fittings	20	14

Thermal Insulation and Water Vapor Barriers

vapor barrier compound. Where multiple layer construction is used, joints in the outer layer must be sealed and the insulation must be applied with staggered joints. Fire resistive vapor barrier material should be used in hazardous areas.

For dual temperature service where the pipe is alternately cold and hot, vapor barrier finish as well as all flashing and sealing compound must be selected to withstand movement of the pipe without permitting water vapor leakage. The barriers and sealers must be able to withstand the highest and lowest temperature to which they are subjected without softening, melting, or otherwise deteriorating.

The piping must be carefully protected against corrosion caused by condensation of water vapor or environmental conditions.

Table 3 shows the minimum spacing that must be allowed to permit proper application and sealing of pipe insulation.

Heat gains for pipes insulated with a material having a conductivity of 0.30 Btu per (hr) (sq ft) (F deg per in.) are given in Table 28, Chapter 24, which may be used as a guide because many of the commercial insulations offered for this purpose have conductivities very near the 0.30 value used. Fig. 6 is used to determine the thickness of insulation required to prevent condensation.

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, and if the velocity of the water flowing in the pipe is maintained at a sufficiently high rate, freezing will be prevented.

Table 4 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 of the damage and service interruptions which may result from frozen water in pipes, it is essential that an efficient insulation be utilized. Table 4 is based on the use of a material having a conductivity of 0.30. The initial water tem-

Table 4 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 First 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
$\frac{1}{4}$	0.42	0.50	0.57	0.54	0.45	0.40
1	0.83	1.02	1.16	0.63	0.53	0.45
$1\frac{1}{2}$	1.40	1.74	2.02	0.84	0.69	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	1.23	1.06
6	7.35	9.88	12.20	1.98	1.45	1.19
8	10.05	13.90	17.25	2.46	1.78	1.43
10	13.90	18.10	22.70	2.96	2.12	1.70
12	15.30	22.20	28.10	3.45	2.45	1.93

perature is assumed to be 10 F deg above, and the surrounding air temperature 50 F deg below, the freezing point of water (temperature difference, 60 F deg).

The last column of Table 4 gives the minimum quantity of water at initial temperature of 42 F which 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 Table 4. 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 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 Table 4, 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 4. For example, if the water enters the pipe at 34 F, it will be cooled to 32 F in one-fifth of the time given in Table 4. 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 deg) instead of -18 F, the time required to cool the water to the freezing point will be 60/80 of the time given in Table 4, 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 4, 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 outersurface 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 Table 4 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.

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

$$H = \frac{C_p(t_i - 32)}{q_o \left(\frac{\pi}{8} \times r_i \right)} \quad (3)$$

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

C_p may be obtained from Tables 1 and 2, Chapter 58 or from manufacturers' catalogs and handbooks.

$$q_o = \frac{k \left[\left(\frac{t_i + 32}{2} \right) - t_a \right]}{r_i \log \frac{r_o}{r_i}} \quad (4)$$

where

H = time for water to cool to 32 F, hours.

q_o = Btu per (hour) (square foot of outer surface of insulation).

r_i = inside radius of pipe, inches.

r_o = outer radius of pipe or inner radius of insulation, inches.

r_i = outer radius of insulation, inches.

k = thermal conductivity of insulation, Btu per (hour) (square foot) (Fahrenheit degree per inch).

t_i = initial water temperature, Fahrenheit degrees.