$t_s$ = temperature of outer surface of insulation, Fahrenheit degrees.

When water must remain stationary longer than the times designated in Table 4, 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. thickness of an efficient insulation may be applied.

### Underground Pipe Insulation

Both heated and cooled underground piping systems are insulated. The protection of underground insulated piping is a larger problem than protection of above-ground piping. Ground water conditions, including chemical or electrolytic contributions by the soil, plus existence of a water head, require a very special design to protect insulated pipes from corrosion. Walk-through tunnels, conduits, or integral protective coverings, are generally provided to protect the pipe and the insulation from water. Examples and general design features of conduits, and a description of tunnels, can be found in Chapter 9 of the 1964 GUIDE AND DATA BOOK. Little data are available on integral protective covering systems, but there are some data available in References 17 and 18. Detailed design criteria have been published by the National District Heating Association[18] and the National Research Council of the National Academy of Sciences.[20]

Piping for heated and cooled systems in walk-through tunnels is usually covered with sectional insulation to provide optimum thermal performance and is finished with good mechanical protection such as metal or waterproofing jackets. Walk-through tunnels are now declining in use because of cost.

Conduit systems are generally used for underground insulated piping systems. The system must be designed to eliminate wetting of the insulation due to accidental flooding, during installation or operation. Therefore, it is necessary to provide for adequate drying of the insulation before and after covering and sealing. In instances where actual submersion of hot piping may occur, experience has shown that where water does enter the insulation, it boils violently at the pipe surface, resulting in spalling, joint erosion, physical breakdown and eventual total system destruction. The use of sectional insulation with the conduit sized to provide a space between the conduit wall and insulation, provides for drainage and adequate drying of the insulation on heated piping in the event of accidental flooding. Detailed design criteria for conduit systems have been developed.[20] The criteria require that all systems be of the type to provide for draining and insulation drying, and that the insulation be of a type that can withstand boiling and drying without physical damage and loss of insulating value. It also requires that the conduit casing must be of a design that can prove its water-tightness in the field. Additionally, the insulation should be a nonconductor of electricity, vermin proof, chemically and dimensionally stable at the operating temperature of the pipe.

Suitable laboratory tests for compliance with the above criteria have been published.[21] Evaluative tests and field investigation reports,[22] have shown that calcium silicate is resistant to severe boiling action. Fibrous glass (4 to 7 pcf density) withstands limited boiling when a conduit becomes flooded and wet poured-in-place types of insulations are likely to remain partially wet for their installed life.

Integrally protected pipes buried directly in the ground are commonly used as chilled water lines, where the problems of heat loss and corrosion are not as severe as they are on hot pipes. For chilled lines where no heat is available to drive out moisture, it is extremely important to provide an absolute protective covering against water and water vapor, and to provide an insulation possessing very low permeance. Cellular glass has been widely used for this type of application. Foam plastics are obtaining increased acceptance for this type of application, but their long-term performance has not been established. It has been found that, with good pipe protection, underground chilled water piping can occasionally be left without insulation, where the temperature differences between the pipe (40 F) and the soil (55–60 F) are rather small.

The thickness of the insulation for underground piping is not determined on the same basis as for piping above ground. Further information can be found in References 19 and 20.

## TANKS, VESSELS AND EQUIPMENT

Flat, curved, and irregular surfaces such as tanks, vessels, boilers and breechings are normally insulated with flat blocks or bevelled lags, curved segments, blanket forms of insulation, or sprayed asbestos fiber-inorganic binder insulations. Since no general procedure can apply to all materials and conditions, it is important that manufacturer's specifications and instructions be followed for specific insulation applications.

### Methods of Securement

The insulation is secured in a variety of ways, depending upon the form of insulation and contour of the surface to be insulated. On small diameter cylindrical vessels, the insulation may be secured by banding around the circumference. On larger cylindrical vessels, banding may be supplemented by angle iron support ledges to support the insulation against slippage. Where diameters exceed 10 to 15 feet, slotted angle iron may be run lengthwise of the cylinder at intervals around the circumference as securement for and to avoid excessive length of banding.

On large flat and cylindrical surfaces, banding or wiring securement may be supplemented by fastening at frequent intervals to various types of welded studs. In many instances on large flat, cylindrical, and spherical surfaces there is advantage in securing the insulation by impaling on welded studs or pins and fastening with speed washers.

### Finish—Temperatures Above Ambient

For temperatures above ambient, insulation of suitable type and thickness is finished as required to provide protection against mechanical damage and weather, consistent with acceptable appearance. On smaller equipment indoors, the insulation is commonly finished by covering with hexagonal wire mesh tightly stretched and secured, and applying over this a base and hard finish coat of cement. This may be additionally finished by painting.

For the same equipment outdoors, the insulation may be finished with a coat of hard finish cement, hexagonal mesh properly secured, and a coat of weather-resistant mastic (preferably a breathing type). A variation may be just 2 coats of weather-resistant mastic reinforced with open-mesh glass fabric. Larger equipment may be finished indoors and out with suitable sheet metal. Outdoor finish of any type must be properly flashed around insulation penetrations such as manhole access openings, pipe connections, structural supports, etc., to maintain weather tightness.

### Finish—Temperatures Below Ambient

For temperatures below ambient, insulation of suitable type and thickness is finished as required to prevent condensation, as well as provide protection against mechanical damage and weather, consistent with acceptable appearance. The finish is required to provide a degree of vapor sealing in accordance with the operating temperature to avoid moisture entry from the surrounding air, which may cause an increase in thermal conductivity of the insulation, deterioration of the insulation or corrosion of metal equipment surface. For moderately low temperatures, the insulation may be finished with hexagonal mesh properly secured, a coat of hard finish cement, and several coats of suitable paint. Where a greater degree of vapor sealing is required, 2 coats of vapor seal mastic reinforced with open-mesh glass fabric may be used. A variation of this for an even greater degree of vapor sealing is 2 coats of asphalt vapor seal mastic reinforced with asphalt-saturated and perforated asbestos felt with edges lapped and cemented. Where this type of vapor sealing is required indoors, acceptable appearance and protection from mechanical damage may require the addition of hexagonal mesh, hard finish cement, and final finish painting.

For the same equipment outdoors, the insulation may be finished with heavier or additional coats of vapor seal mastic reinforced with open-mesh glass fabric to provide adequate protection against mechanical damage and weather. For appearance the mastic may be finished painted, but it is important that the mastics, which usually have solvent content, be properly dried before painting, and that paints of a proper type, as recommended by paint manufacturers, be used. In some cases the additional finish over the mastic may be suitable sheet metal. However, care must be taken that the metal be applied without damage to or penetration of the vapor barrier.

With all applications of vapor barrier finish, it is important that all penetrations such as manheads, pipe connections, structural supports, etc., be properly vapor sealed with mastic or other sealant reinforced with open-mesh glass fabric. Equipment should be insulated from structural steel by isolating supports from the steel with material of high compressive strength and reasonably low thermal conductivity. Hardwood block is commonly used for this purpose. It is important that vapor sealing carry over this insulation from the equipment to the supporting steel to insure proper vapor sealing. If the equipment sits directly on steel supports, the supports should be insulated for some distance from the points of contact. It is common practice to extend this insulation, with vapor barrier, a length of 8 to 10 times the thickness of the insulation applied to the equipment.



### Finish—Dual Temperature Service

For dual temperature service where vessels are alternately cold and hot, the materials and design of vapor barrier finish must be given particular attention to withstand movement due to temperature change and maintain vapor sealing.

### Reflective Insulation

Reflective insulation as described in this chapter is applicable on large refrigerated tanks. In this system the external finishing sheets of heavy gage metal form the vapor barrier with joints sealed to permit contraction and expansion. Drainage of this system is afforded by valved outlets at the bottom of the tank.

## DUCTS

Ducts may be used to distribute warm air in winter, cool air in summer, or for year-round air distribution. In addition to supply and distribution, they may provide a means of returning air to heating or cooling units, supplying outdoor air for ventilation purposes, or exhausting air from a conditioned space.

### Duct Locations

Ducts may be installed in conditioned spaces, in areas exposed to outdoor conditions such as ventilated attics or crawl spaces, or in conditions of intermediate temperature (unheated basements or garages), or embedded in floor slabs.

### Materials for Ducts and Insulations

Ducts may be of sheet metal, compressed fiber, asbestos-cement, ceramic tile, or other rigid materials. Several prefabricated, insulated duct systems, some of which are non-rigid, are available. Insulations include semi-rigid boards and flexible blanket types, composed of organic and inorganic materials in fibrous, cellular, or bonded particle forms. Insulations for exterior surface application may have attached vapor barriers or facings, or vapor barriers may be applied after the insulation is attached to the duct. When insulation is applied on the inside of the duct as a liner, it serves as a sound absorber as well as thermal insulation.

### Need for Duct Insulation

Whether duct insulation is needed will depend on several factors which include (1) the effect on equipment size and operating cost of the heat loss or gain from the duct, (2) thermal requirements to prevent condensation on ducts used for cooling, and (3) allowable temperature change in the duct lengths to outlets, (4) requirements of local building codes, especially those concerned with fire protection, prevention of mechanical or chemical damage, and isolation of high temperature surfaces.

Ducts within conditioned interior spaces do not require insulation, but all ducts exposed to outdoor conditions as well as cooling ducts passing through unconditioned spaces should be insulated. Heat loss from un-insulated warm air ducts may be used to temper conditions in garages or unheated basements, especially when they have a wall, floor or ceiling facing a heated space. Such losses should, however, be considered in making load calculations, equipment selection, and operating cost estimates.

Analyses of temperature drops, heat losses and factors affecting the economics of heat insulation are seldom made for residential applications, but are justified for large commercial and industrial projects. A method of determining heat gain or loss from ducts is given in Chapter 31.

### Insulation for Heating Ducts

It is unlikely that duct insulation on residential heating system ducts will reduce heating equipment size. Operating cost reduction, however, may be significant, dependent on unit costs for heating and extent of duct exposed to outside conditions. Insulation on ducts may be a good investment when operating savings over a 10 yr period are greater than the cost of insulating the ducts. More significant than operating savings may be the ability to supply warmer air to distant outlets because of the smaller temperature drop possible with insulation on the ducts, and the resulting increased comfort which is difficult to measure.

Calculations of heat loss require a knowledge of $U$ values for the duct walls. For un-insulated sheet metal the $U$ value is affected by air velocity and to some extent by the emittance of the metal and the shape of the duct. An approximate value of 1.0 may be used for estimating heat loss. For insulated ducts the losses may be estimated, using $U$ values of 0.24 and 0.12 for ducts with 1 and 2 in. thicknesses, respectively, of