CHAPTER 5

HEAT TRANSFER, INSULATION, AND FREEZE PROTECTION

This chapter will discuss the basic fundamentals of heat transfer, thermal insulation, freeze protection, and heat tracing.

CODES AND STANDARDS

Insulation is often regulated by code requirements. The individual sections of any code must be carefully read in order to determine how flame-spreading or smoke-developing characteristics restrict the use of particular materials in specific areas of a building.

Typically, codes define the class of any building erected into one of four types: I, II, III, or IV. Type I is fireproof, Type II is noncombustible and either protected or nonprotected, and Types III and IV are combustible. The allowable flame-spread rating for any construction material is based on each class of construction.

The specific areas within a building also have restrictions pertaining to the allowable smoke-developed rating. These areas are:

1. Concealed spaces such as chases and shafts, not serving the HVAC system as air supplies or returns.
2. The same spaces as above, but used for air supplies or returns.
3. Rooms and spaces that may have a higher allowable smoke-developed or flame-spread rating, such as mechanical equipment rooms. Here the interior finish and the insulation fire code requirements are relaxed because of the nature of the space.

The building class as a whole usually determines the flame spread, and the specific area within the building usually determines the smoke developed. It is important to determine the most cost-effective insulation based on the code interpretations.

FUNDAMENTALS OF HEAT TRANSFER

BASICS

Heat is a type of energy that is produced by the movement of molecules. The greater the movement, the greater the heat. All molecular motion stops at absolute zero.

Temperature measurement finds only the level (or intensity) of the heat energy, not the amount. There are four methods used to express temperature:

1. Degrees Fahrenheit (F) shows the temperature expressed in English units. The scale is determined by dividing the actual temperature difference between the ice point and steam point of water into 180 divisions. The ice point is 32°F and the steam point is 212°F. Absolute zero is −459.7°F.
2. Degrees Celsius (C) shows the temperature expressed in metric units. The scale is determined by dividing the actual temperature difference between the ice point and steam point of water into 100 divisions. The ice point is 0°C and the steam point is 100°C. Absolute zero is −273.2°C.
3. Degrees Rankine (R) shows an absolute temperature scale starting at absolute zero, using the same division units as the Fahrenheit scale. The ice point of water is 491.7°R, the steam point is 671.7°R, and absolute zero is 0°R.
4. Degrees Kelvin (K) shows an absolute temperature scale starting at absolute zero and uses the same division units as the Celsius scale. The ice point of water is 273.2 K, the steam point is 373.2 K, and absolute zero is 0 K.

The Rankine and Kelvin scales were created for laboratory use and are rarely used in facility design engineering calculations.

The quantity of heat is measured either in Btu, which is an abbreviation for British thermal units, or kcal, which means kilocalorie. A less frequently used form of measurement is the watt-hour.

One Btu is the amount of heat needed to raise 1 lb of water 1°F. One kcal is the heat needed to raise 1 kg of water 1°C.

There are two kinds of heat flow, transient and steady state. For transient heat flow, the temperature varies with time. For general engineering applications, the transient method is too complex. This book will use the steady state method of calculating the heat loss through insulation. The results of these calculations are well within the range of accuracy sufficient for engineering purposes. Steady state heat flow is further divided into series and parallel types. In order to simplify the calculations, the following conditions will be assumed:

1. The series concept of heat flow will be used. As the heat flows through continuous layers, the total resistance is the sum of all of the individual layers.
2. Heat in equals heat out. There will be no accumulation of heat in the system.
3. All factors, including temperature, have reached equilibrium.
4. The temperature and heat flow of all components remain constant with time.
5. The same heat flow exists through any plane in the system.

Heat transfer, or the movement of heat energy, always flows from a higher temperature to a lower temperature. It can occur in any one of three ways: convection, radiation, or conduction.

Convection is a large-scale movement of liquids or gases. It cannot occur in solids. Density differences between hot and cold fluids produce a natural gravity movement. When a fluid is heated, it becomes less dense. The lighter fluid will move upwards in the absence of forced circulation. Heat is transferred faster when forced circulation is created by means of a fan or pump. When a liquid or gas moves from one place to another, it takes heat energy with it. Convection is always accompanied by conduction in the region where warmer and colder fluids interact.

Radiant heat is similar to radio waves, but has a shorter wavelength. They are capable of traveling through air, some solids and liquids, and vacuums. All substances at a temperature above absolute zero will radiate heat. Radiant heat increases with temperature and is proportional to the fourth power of the absolute temperature of the radiating body.

Solids transfer heat by conduction. Whenever the molecules move about, their constant vibration or oscillation causes a collision between them and other adjacent molecules. The heat does not remain constant because faster-moving molecules strike the slower-moving ones with a resulting decrease in the speed of the faster molecule. This will eventually equalize the temperature throughout the solid unless heat is added or removed.

There are several methods used to calculate the flow of heat through material, or the material's resistance to such flow.

The ability of a specific solid to conduct heat is called thermal conductivity, and is measured in Btu/h. This is referred to as the *k* factor. The standard that is used to find *k* determines the amount of heat that will flow in 1 h through material measuring 1 in thick and 1 ft^2 in area and having a temperature difference of 1°F (0.5°C) between the faces of the material being measured. The total heat flow in $\text{Btu/ft}^2\text{/h}$ through any material is calculated by the following formula:

$$k = \frac{\text{KI} \times \Delta T \times A}{t} \tag{5.1}$$

where k = heat flow in $\text{Btu/h/ft}^2/°\text{F}$
KI = k factor of the insulation material
ΔT = temperature difference, °F
A = area in square feet, at insulation exterior
t = thickness of insulation, in

As the *k* factor increases, so does the flow of heat. Conductivity (conductance) measures heat flow through a standard arbitrary thickness sample of a specific material. Conductance (*C*) is measured in $\text{Btu/h/ft}^2/°\text{F}$, calculated with the following formula:

$$C = \frac{\text{thermal conductivity}}{\text{Thickness (in)}} \tag{5.2}$$

The resistance to the flow of heat through any individual solid is called thermal resistance *R*, and is measured in $\text{Btu/h/ft}^2/°\text{F}$. It is the reciprocal of the conductance value.

$$R = \frac{1}{\text{Conductance}} \tag{5.3}$$

As the resistance increases, the heat flow is reduced.

Total thermal resistance, *RT*, of a system measures heat flow in several materials layered together in series. It is found by adding together all the individual resistances *R* to obtain the total resistance of the entire system.

Thermal transmittance *U* is the rate of heat flow through several materials layered together, and is measured in Btu/h/ft^2/°F. It is the reciprocal of the total thermal resistance, and is calculated from the following formula:

$$U = \frac{1}{\text{Total thermal resistance}} \tag{5.4}$$

For insulation, conduction is the primary method in the transmission of heat. True thermal conductivity takes place only in homogeneous materials. In the range of materials used for thermal insulation, a homogeneous material is defined as a substance whose thermal conductivity does not change within the range of thickness normally used. For the most part, building materials such as brick and lumber are considered to be homogeneous. However, most thermal insulation is porous and actually composed of solid material surrounding small pockets of air. Therefore, conduction is not the sole means of heat transfer. In addition, a surface film of air, liquid, or even solid matter is almost always present around both the insulation and the pipe on which it is installed. This impedes the flow of heat. For this reason, the term *apparent thermal conductivity* is scientifically correct when referring to the *k* values used. With this explanation in mind, please note that the word *apparent* will be omitted in future discussions.

The term *heat flow* is defined as the total heat gain or loss from an entire system or component of that system, and is measured in Btu/h. The term *heat flux* is used to measure the heat gain or loss from only 1 ft^2 of a system or component. Heat flux is measured in Btu/h · ft^2 and is the product of the temperature differential and the conductance *C*.

Water Vapor Migration

Thermal insulation is fully effective only when completely dry. If water in either the form of vapor or liquid is present in or on insulation, it will have a serious effect both physically and thermodynamically. The loss of insulating capacity is well documented. If enough water is allowed to accumulate, it will cause rotting or other possible corrosive effects in most types of insulation.

Water vapor present in air has a measurable vapor pressure that is a function of both temperature and relative humidity. The lower the relative humidity and/or temperature, the lower the vapor pressure. Applying this fact specifically to an insulated body, the movement of water vapor is proportional to the difference in temperature between the ambient air and the wall of the pipe or vessel.

When the temperature of the insulated pipe or vessel is above ambient temperature, vapor pressure is higher at the pipe wall than on the outside surface of the insulation. This means that a vapor pressure differential exists between the pipe wall and the surrounding air, driving the water vapor away from the inner surface and towards the outside.

However, when the temperature of the pipe is below ambient, the opposite is true. The pressure is lower at the pipe wall than on the outside surface of the insulation, and the direction of water vapor flow is reversed. It is then possible for the vapor to permeate the insulation, allowing water to be absorbed and retained by the insulating material, and thereby reducing its effectiveness. It is also possible for water to actually condense as a liquid on the pipe wall. Certain types of insulation can become saturated over a period of time. If the insulation material does not absorb water, the air cells may become saturated. Another possibility is that the water may start corroding the pipe exterior.

The water vapor transmission rate (WVTR) is a measure of water vapor diffusion into or through any total insulation system. This flow of water vapor, called permeance, is measured in U.S. perms, or perm. A *perm* is the weight of water, in grains, that is transmitted through a 1-in (25 mm) thickness of the material in question in 1 h/ft^2, having a pressure difference between faces of 1 in of mercury. There are 7000 grains in 1 lb.

In order to restrict the flow of water vapor from the warm to the cold side of the object being insulated, a vapor barrier is installed on the warm side of the insulation. Since there is no perfect vapor barrier, the insulation materials used should also have some resistance to moisture in addition to having a good thermal resistance. The ideal material would absorb little or no moisture, would allow quick elimination of any that did enter, and would not be affected by moisture during the time it was present. A generally accepted figure of 0.30 perm is the maximum rate of an effective vapor barrier.

In addition to the primary purpose of retarding the flow of heat and water vapor, there are other important secondary factors that must be considered when selecting the type of insulation or covering for a particular application. They are:

1. Smoke and fire requirements
2. Space limitations
3. Personal protection
4. Protection from physical damage
5. Acoustical properties
6. Health and safety requirements
7. Dimensional stability
8. Corrosion resistance
9. Hygiene
10. Installed cost

If a fire were to start inside a building, it is possible that any part of the structure including its contents can contribute to the fire either by supporting combustion or generating smoke if noncombustible. In order to control the amount of combustible material inside buildings, code limitations for flame spread and smoke developed have been established for the components used in the interior of fireproof and noncombustible buildings. Material ratings have been established as follows.

The so-called tunnel test is used to obtain fire-related data for different kinds of insulation. The same test has been given different names by each agency conducting it. They are ASTM E-84, NFPA 255, and UL 723. The particular material is tested for flame spread, fuel contributed, and smoke developed. The materials tested are compared to red oak flooring (rated at 100) and asbestos-cement board (rated at zero) in all three categories. Caution should be used when trying to establish these values separately for the insulation, jacket, and some adhesives rather than as a complete system. Tests have shown that elements of an insulation system that have the same values when tested separately may have quite different ratings when tested as a composite unit.

The generally accepted maximum value for flame spread is 25, and the value for both fuel contributed and smoke developed is 50. These values are used when the building is of fireproof construction, which is the predominant type of building. For other kinds of construction, these values may be different.

Space limitations can be a factor in areas where insulated pipe is to be installed. Different types of insulation must be evaluated in order to obtain the best compromise between thickness and the *k* value.

Insulation will protect personnel from being scalded by touching a bare pipe. The insulation and jacket should be selected such that the surface temperature of its exterior will be no higher than 110°F (43°C).

Protection of the insulating material from physical damage may be a consideration when insulated piping is installed in an area of a building where there is storage of material that is regularly moved or where maintenance operations are carried out next to the pipe on a regular basis. This protection can be obtained by using a strong jacket or other insulating material that will not deform after repeated blows. Another consideration might be the strength of the insulation needed during the time it is being stored, transported, and installed in a possibly adverse climate or location.

The properties that make insulation effective will also attenuate sound made by the flow of contents through the pipe. When a pipe is installed where sound transmission could be a problem, for example, as a theater, adding extra thickness of insulation or special jacketing could reduce the sound to an acceptable level.

The potential health and safety hazards of insulation and accessories fall into two categories: (1) those related to storage, handling, and installation and (2) those that occur after installation. Correct procedures can reduce or eliminate most or all of the problems in the first category. However, exposure to materials such as asbestos could cause extremely serious health hazards.

The rate at which any particular insulation system will expand or contract has a definite effect on efficiency. The possible difference in expansion between the pipe and the insulation may eventually produce voids or gaps after repeated flexing. An insulation with a high *k* factor that might fail because of a large difference in the rates of expansion between it and the pipe will prove less economical over time than another insulation system with a lower *k* factor.

When an insulated pipe is to be installed in a corrosive atmosphere, the insulation system, particularly the jacket, must be capable of resisting whatever substance is causing that corrosion.

Insulation that is used for the food-processing, chemical, cosmetics, and pharmaceutical industries (or in other similar operations), must have the ability to withstand cleaning or sterilizing by a wide variety of methods. The important properties are:

1. Smooth finish
2. Resistance to fungus, bacteria, or mildew growth
3. Resistance to washing by detergents, steam, and chemicals
4. No chipping, cracking, or peeling
5. Nontoxicity and fire resistance

TYPES OF INSULATION

The following general designations are generic names of the materials. The individual manufacturers have different trade names for each of them. For each of the separate types, various properties will be compared, with the following properties common to all.

1. They must have been tested for fire-related values by the ASTM, NFPA, and UL as previously discussed, and meet the minimum standard for a flame spread of 25 and smoke-developed rating of 50 or less except where otherwise noted.
2. The temperature at which the *k* and *R* figures have been calculated is 75°F (24°C).

Fiberglass

Fiberglass insulation (ASTM C 547) is fibrous glass, made either plain or with a heat-resistant binder in order for the fiberglass to hold its shape. Typical values for material with a density of 3 to 5 $\mathrm{lb/ft^3}$ (48 to 80 $\mathrm{kg/m^3}$) are $k = 0.22$ to 0.26 and $R = 3.8$ to 4.5.

Fiberglass is the most popular insulation, and it comes in many forms. Felted glass fiber without any binder is available in rolls. Made with a thermosetting resin binder, it comes in several different stiffnesses. In the form most commonly used for pipe, it is molded and shaped into semicircular sections. The binder is the critical factor for the ultimate temperature for which it can be used.

Fiberglass by itself is not strong enough to stay permanently on a pipe without falling off in layers. Since fiberglass is porous, there is no way to seal it to prevent water vapor from flowing freely from the air to the pipe and then condensing on the pipe and saturating the fiberglass. In addition, there is no way to finish fiberglass that would be considered pleasant to look at. For these reasons, a covering, or jacket, must be added to protect it from physical damage, allow it to be firmly and permanently attached to the pipe, and prevent the penetration of water vapor.

Fiberglass is recommended for temperatures ranging from 35 to 800°F (1.5 to 422°C). It is available in thicknesses from ½ to 5 in (DN 15 to 125) for ½- to 33-in (DN 15 to 750) piping, with manufacturers providing various thicknesses for certain size pipes. For insulating tanks, fiberglass is also available in boards 48 to 96 in (1200 to 2400 mm) long, 12 to 24 in (300 to 2400 mm) wide, and up to 4 in (100 mm) thick. A high temperature, flexible blanket can be used with temperatures up to 1000°F (530°C).

Cellular Glass

Cellular glass insulation (ASTM C 552) is pure glass with closed cell air spaces. This material has a flame spread of 5 and smoke developed of 0. It also has a 0 perm rating. The typical *k* value is 0.38 and the *R* value is 2.6. A jacket is necessary for abrasion resistance; the type used depends upon the expected severity of service.

This extremely rigid and strong insulation is available for pipe sizes up to 36 in (900 mm) and 1 to 4 in (25 to 100 mm) thick. Form-fitting covers are used for any standard component. Flat blocks come in sizes 12 × 18 in (300 × 450 mm), 1½ to 5 in (40 to 125 mm) thick, and in sizes 18 × 24 in (450 × 450 mm). Factory fabricated shapes can be made to fit specific requirements. Recommended applications include temperatures ranging from −450 to +450°F (−265 to +230°C), with limitations based on the type of adhesive used with the material. Cellular glass is used where an extremely strong and impermeable material is required. It is also impervious to common acids and corrosive environments, and must be cut with a saw. It is available either plain or with a variety of factory-applied jackets.

Expanded Plastic Foam

Elastomeric plastic insulation (ASTM C 534) is an expanded foam, closed cell material, made from nitrile rubber and polyvinyl chloride resin. The typical *k* value is 0.27 and the *R* value is 3.6. This material has a perm rating of only 0.17, and does not require a jacket except for appearance; it can also be painted. The flame ratings of 50 are valid for all thicknesses. For material ½ in (15 mm) thick and less, a smoke-developed rating of 100 has been established; up to 1 in (25 mm), the rating is close to 150. Because of the high rating, building codes do not allow it to be used in all types of construction. A recent development has enabled manufacturers to reduce the smoke-developed rating down to 50 or below.

Commonly called rubber, this flexible insulation is available for pipe sizes up to 5 in ips (DN 125), and ½- and ¾-in (15 and 20 mm) thicknesses. In sheets, it is available in sizes up to 36 × 48 in (900 × 1200 mm) with 24 × 48 being the most common. Sheet thickness ranges from ⅛ to 1½ in. It is also available in 48 in (1200 mm) wide rolls, with thicknesses of ½, ¾ and 1 in (15, 20 or 25 mm). Yet another product is a 2-in-wide roll, 1/8 in thick, with self-sealing adhesive. Recommended applications for pipes include temperatures from 35 to 220°F (1.5 to 103°C), and for sheets up to 180°F (81°C), due to the adhesive required to apply it to a tank. It is used in pipe spaces and boiler and mechanical equipment rooms, where code requirements may be relaxed and the ease of application could make it more cost effective.

Foamed Plastic

Foamed plastic insulation is a continuously molded, rigid product made from foaming plastic resin, which results in a closed cell material. Typical insulation materials are polyurethane (ASTM C 591), polystyrene (ASTM C 578), and polyethylene. A factory-applied jacket is usually provided. The typical *k* value is 0.15; *R* value is 6.7.

Due to the possibly wide variations in the composition of the materials that fall into this category of insulation, the fire rating varies between manufacturers. Although the materials are combustible, they can be made self-extinguishing. Foamed plastic is recommended for low temperatures including cryogenic, and for moderate temperatures, generally up to a maximum of about 220°F (103°C).

Calcium Silicate

Calcium silicate (ASTM C 533) insulation is a rigid material compounded from silica, asbestos-free reinforcing fibers, and lime. At 500°F (260°C), it has a *k* value of 0.5 and an *R* value of 2.0. A field-applied jacket is required. This insulation is commonly referred to as ‘‘calsil.’’

Mineral Fiber

Mineral fiber (ASTM C 553) insulation is a rigid material composed of rock and slag made into fibers bound together with a heat-resistant inorganic binder. The typical *k* value is 0.28, and the *R* value is 4.9. This material is very well suited for high temperature work.

Insulating Cement

Insulating cement is produced from fibrous and/or granular insulation and cement, then mixed with water to form a plastic mass. Typical *k* values range between 0.65 and 0.95, depending upon the composition of the cement. They can be of either the hydraulic setting or the air drying type. This material is best suited for irregular surfaces or as a finish for other insulation applications. It can also be used in situations where space is at a premium and some kind of insulation is required. Installation costs are very high.

JACKETS

In order to function more efficiently and extend service life, most insulation must be protected from damage and degradation by the application of an effective cover, or jacket material. A *jacket* is defined as any material, except cements and paints, that can be used to cover or protect insulation installed on a pipe or vessel. The choice of jacketing will depend upon its use, which can be divided into seven general functional categories:

1. Weather barriers are used to prevent the entry of liquid water into insulation and also the entry of chemicals that would affect the inside or outside of the insulation. Materials include plastic, aluminum, and stainless steel as well as weather barrier mastics.
2. Vapor barriers are used to reduce the entry of water vapor into the surface of the insulation. In order to be effective, the vapor barrier must be completely sealed at every opening. A vapor barrier is used on cold surfaces primarily for eliminating the possibility of entrapped water vapor condensing on the pipe.
3. Mechanical abuse-resistant coverings are used to protect the underlying insulation from mechanical damage due to abuse or accidental contact by personnel or equipment. The compressive strength of the insulation used should be considered when selecting a jacket. Metal products are most commonly used.
4. Corrosion- and fire-resistant coverings are used as part of a complete hazard resistance system. Almost any type of jacket or mastic increases the fire rating. The most successful corrosion jackets are plastic or stainless steel depending upon the nature of the spill, leak, or atmosphere expected. Some mastics are also useful.

5. The visual appearance of some jackets over piping in exposed areas is an important feature in the selection of various coatings, finishes, cements, and covers. Since this consideration must often be approved by an architect or client, he or she should be consulted before final selection.
6. Jackets capable of being disinfected are used to present a smooth surface that will resist fungal and bacterial growth. They must withstand cleaning with powerful detergents coupled with steam and high pressure water. This requires a jacket with high mechanical strength.
7. Plain jackets are used on hot services and in other cases when a jacket is desired for ease of installation and appearance.

Jackets come in various forms and types, and can be divided into three general categories: rigid (plastic, aluminum, or stainless steel), membrane (glass cloth, coated papers, treated papers, and papers laminated with foils and/or cloth), and mastic. Jackets can be specified separately or factory applied. Separate jackets are used for special situations when a factory applied jacket is not available or possible, for example, jackets made of aluminum or plastic sheets. The factory applied jacket is by far the most common and is available in three types: the so-called all-purpose jacket, which has a vapor barrier, a plain jacket, and a weatherproof jacket.

Each manufacturer has a different combination of materials that are laminated to each other to provide flexibility, strength, and fire resistance. Kraft paper that has been coated or treated with chemicals is the most common base. The next layer is usually fiberglass cloth, used for strength, and the third layer is usually an aluminum foil. All three layers are permanently bonded together with a special adhesive to give the desired strength and water vapor retardation characteristics.

All-Service Jacket (ASJ)

The all-purpose, or all-service, jacket has a vapor barrier. The complete jacket is a lamination of kraft paper, fiberglass cloth (skrim) and either aluminum foil or metalized film. This is commonly referred to as an FSK jacket, for foil, skrim, and kraft.

The kraft paper is a bleached 30-lb (13.5 kg) basis weight material, which means 30 lb (13.5 kg) for each 30,000 ft^2 (2790 m^2) area (or one ream). There is also a 45-lb (20.2 kg) basis weight paper available if a heavier paper is desired.

The fiberglass scrim is used for strength and reinforcement of the paper. The standard weave is 5 × 5, which means five lines per inch. Other weaves are available, ranging from 1 × 1 to 10 × 10, and also a 10 × 20. Also available is a bias weave, which adds diagonal threads in a third direction. The closer the weave, the stronger the jacket.

The foil used is aluminum, ranging in thickness from 0.35 to 1.0 mil. The standard thickness is 0.50 mil. Metalized film is also available. Although thinner than foil, it retains its shape better under impact. One manufacturer described its product as a white, metalized polypropylene film with a perm rating of 0.02.

The composition of the adhesive and the actual methods used to bind the components together are proprietary. It is the adhesive that imparts the fire resistant rating to the entire jacket system. After a layer of adhesive is applied to the kraft paper, the scrim is added and the adhesive forced through the weave. Finally, the foil or metalized film is put on next. The three layers are then laminated together to form the complete jacket system.

Lagging

Lagging is the process of insulating a pipe or vessel and then covering the insulation with a cloth jacket. The jacket is primarily used to improve the surface appearance of any insulation, offering very little in the way of protection. Lagging materials are available in a full spectrum of colors and may eliminate the need for painting. This cloth can be canvas or fiberglass, for example, and is secured to the insulation with lagging adhesive and/or sizing. Also available is a combination system that serves as both an adhesive and protective coat.

Aluminum Jackets

Aluminum jackets (ASTM B-209) are available in a corrugated or smooth shape and in thicknesses ranging from 0.010 to 0.024 in, with 0.016 in being the most commonly used. Also available are different tempers or hardness. These range from H 14 (half hard) to H 19 (full hard), with H 14 being the most common. Aluminum jackets can be secured by one of three different methods: banded by straps on 9-in centers, by a patented seam in an S or Z configuration, or by sheet metal screws. The ends are overlapped 2 in and secured with straps or screws (or nothing for the interlocking type). Since they are usually applied over insulation, a variety of vapor barrier materials can be factory applied to the aluminum jackets, which may be necessary if the insulation has any ingredient that causes galvanic or corrosive attack on the aluminum, or if an additional vapor barrier is thought to be necessary. Fittings are fabricated from roll material in the shop.

There are four different alloys of aluminum commonly used for jacketing material: 1100, 3003, 3105, and 5005. Although there are differences among them, it is not usually necessary to specify which alloy is to be used. The properties of all types are so closely matched that the service or performance of the material is not affected by different choices. It is common practice for the fabricator of the jacket to interchange any of the four types depending upon availability and price. By specifying the ASTM code alone, the engineer is allowing the contractor to use any of the types (since they are all acceptable), and avoids the possibility of a delay caused by waiting for the particular alloy specified and the extra cost involved.

One alloy, 1100, is mostly used for fittings because it is the most malleable of the four. If the jacketing is used on a pipe that may expand and contract often because of system operation, corrugated aluminum jackets should be used. These jackets easily expand and contract.

Aluminum jackets have the following advantages:

1. Easy application in any weather
2. Easy formation into different shapes
3. Good resistance to abuse
4. Ready availability

Aluminum jackets have the following disadvantages:

1. Low resistance to pH ranging from 7 to 11
2. Low fire rating
3. Low emittance value

4. High initial cost
5. Low resistance to strong cleaning chemicals

Stainless Steel Jackets

Stainless steel jackets (ASTM A-240) are available in either flat or corrugated forms and in standard thicknesses of 0.010, 0.016, and 0.019. They are secured in the same manner as aluminum jackets. A factory applied moisture barrier can also be added.

The most commonly available alloys are types 301, 302, 303, 304, 305, and 316; 304 is the most popular. It is best to consult with the manufacturer for the criteria that will help determine which alloy would be best for any particular application. Several types of finishes are available, from polished to dull. Stainless steel jackets have the following advantages:

1. Excellent fire rating
2. High resistance to mechanical abuse
3. Excellent corrosion and weather resistance
4. Easy application in any weather
5. Excellent hygienic characteristics

Stainless steel jackets have the following disadvantages:

1. High initial cost
2. Corrosion cracking where chlorine or fluorine exists
3. Low emittance value
4. Long lead time

There are often strict union regulations requiring that stainless steel jackets over 0.20 in thick be installed by sheet metal workers. Jackets 0.20 in thick or less can be installed by the insulation contractor. The insulation contractor is more knowledgeable about this kind of work, so when job conditions permit, it is usually more cost effective to specify the thinner thickness to ensure that the work will be done by the insulation contractor.

Wire Mesh

Wire mesh is a little-known jacket material. It's mainly used when a strong, flexible, abrasion-resistant covering that must be easily removed is needed. It is available in widths from 1 to 43 in (25 to 1075 mm), with 12, 18, 24, and 30 in (300, 450, 600, and 750 mm) used most often. Common wire diameter of the mesh is either 0.008 or 0.011 in. The thicker wire is used where greater strength is needed or heavy use expected. The openness of the weave is expressed in density, which gives the number of openings per inch. Densities of 48 to 130 are used, with 60 being the most common. Material of the mesh can be Monel, Inconel, or stainless steel. It is attached with lacing hooks or sewn with stainless steel wire. In addition, it must be secured with either tie wires or metal straps.

Plastic Jackets

Plastic jackets are manufactured in a great variety of materials, including PVC, ABS, PVF, PVA, and acrylics. Thickness ranges from 3 to 35 mils. The manufacturers should be consulted to determine the criteria necessary to select the best material and thickness for any particular application. Plastic jackets have the following advantages:

1. Lowest cost of any solid jacket
2. Best resistance to chemical corrosion
3. Excellent resistance to bacterial and fungal growth

Plastic jackets have the following disadvantages:

1. Poor fire rating
2. Low impact resistance
3. Softening at high temperatures
4. Vulnerability to infrared and ultraviolet rays and ozone
5. Cold weather embrittlement

COATINGS, ADHESIVES, AND SEALANTS

There are a large number of products available. Rather than listing them here, the design criteria necessary to the selection of the proper material will be discussed.

Manufacturers specify where to use specific products, but regulations from government and, in some cases, private agencies may dictate the choice of product that will be used. Some of the considerations are the following:

1. Flammability in the wet or dry state
2. Type of system—solvent or water based (depending on whether the material will attack the substrate to which it is applied)
3. Recommended dry film thickness
4. Temperature conditions required for application
5. Limitations on toxicity levels while being applied and drying
6. Method of application—brush, trowel, spray, or palm
7. Resistance to chemical and mechanical factors, such as abrasion, temperature, impact, and expansion

The choice of material is also governed by the size, shape, and location of the surface to be protected. Large irregular shapes may require a thicker material, which will cling to surfaces offering no other means of application.

Adhesives are used to permanently bond the insulation either to itself or to the surface on which it is applied. Each different type of insulation requires its own special type of adhesive. This information should be obtained directly from the insulation or adhesive manufacturer, who will recommend the adhesive best suited for the material and service conditions established by the engineer.

Weather barrier coatings are used to seal an insulation system from the elements, thereby protecting the underlying insulation from damage. In cold service the use of a breather final coat over a vapor barrier will prevent liquid water from penetrating the coating while allowing water vapor to pass through. When used on a hot service, a breather coat will allow the escape of the minimal amount of water vapor trapped inside. When additional strength or protection is required, glass cloth membranes as well as metal mesh should be used to reinforce the weather barrier application.

Vapor barrier coatings are used on the outer layer of cold service insulation to inhibit the passage of water vapor. These coatings are formulated to be used alone as the top coat, or with factory or field-applied jackets made of FSK, cloth, or other membranes as an adhesive or sealer.

Lagging adhesives are used to apply cloth lagging both to itself and to the insulation surface. In some cases, the surface may be rough or irregular, and a sizing may be necessary to seal the substrate in order for the lagging to adhere properly or for a finish to be correctly applied. The correct adhesive can fill the rough surfaces and gaps to provide a smooth and decorative finish. Coatings for application over almost any material used for insulation can be obtained. Acoustical mastics are available for use as sound barrier coatings, and can be used alone or with acoustical jacket material.

INSULATION MATERIAL AND THICKNESS SELECTION

The general criteria needed to make a choice among various insulation materials are as follows:

1. The reason insulation is needed
2. Service temperature expected
3. Code requirements
4. The location where insulation will be installed
5. Accessibility for the insulated pipe
6. Installed cost of the complete insulating system

Reasons for Using Insulation

There are four reasons to use insulation:

1. Condensation prevention
2. Reduction of heat loss
3. Personnel protection
4. Noise reduction

Condensation Prevention. Insulation applied to pipes carrying storm water, city water, chilled water, and drinking water is done to prevent condensation. On pipes containing chilled and drinking water condensation prevention is the secondary consideration after heat gain prevention. Each of the various insulating manufacturers has prepared charts giving the necessary thickness of the insulation in question to prevent condensation. The design temperature of the fluids is: storm water, 35°F (2°C); domestic water, 60°F (15°C); and chilled water, 50°F (10°C). The design ambient temperature is 90°F (32°C), the relative humidity, 90 percent. A vapor barrier jacket is required on fiberglass, mineral wool, and calsil. It is not necessary over rubber or cellular glass. The total system perm rating must be no more than 0.30.

For insulation thickness to prevent condensation, refer to Tables 5.1 and 5.2 for service temperatures of 50°F (10°C) and 34°F (2°C), respectively. Find the pipe size, relative humidity, ambient temperature of the space where the pipe is located, and lowest service temperature of the pipe in the table. Read the recommended minimum thickness of insulation at the intersection of the pipe size and humidity columns.

Reduction of Heat Loss. For hot systems, the most important consideration is the reduction of heat loss. As a result of this reduction, operating cost will be lowered, due to savings in fuel and increase in process efficiency. Capital costs may also be reduced.

The economic evaluation of a particular insulation system includes either the selection of the optimal thickness of insulation for a particular service or the comparison between two or more different insulation systems to find which will return the most savings in conserved energy over a specific period of time. For a given set of economic variables, there is only one solution. The reason for this is that

TABLE 5.1 Insulation Thickness to Prevent Condensation, 50°F Service Temperature and 70°F Ambient Temperature*

		Relative humidity, %														
Nom. Pipe		20			50			70			80			90		
DN	size, in	TNK†	HG‡	ST§	THK	HG	ST	THK	HG	ST	THK	HG	ST	THK	HG	ST
15	0.50				0.5	2	66	0.5	2	66	0.5	2	66	1.0	2	68
20	0.75				0.5	2	67	0.5	2	67	0.5	2	67	0.5	2	67
25	1.00				0.5	3	66	0.5	3	66	0.5	3	66	1.0	2	68
32	1.25				0.5	3	66	0.5	3	66	0.5	3	66	1.0	3	67
40	1.50				0.5	4	65	0.5	4	65	0.5	4	65	1.0	3	67
50	2.00				0.5	5	66	0.5	5	66	0.5	5	66	1.0	3	67
65	2.50				0.5	5	65	0.5	5	65	0.5	5	65	1.0	4	67
75	3.00				0.5	7	65	0.5	7	65	0.5	7	65	1.0	4	67
90	3.50	Condensation control not required for this condition			0.5	8	65	0.5	8	65	0.5	8	65	1.0	4	68
100	4.00				0.5	8	65	0.5	8	65	0.5	8	65	1.0	5	67
125	5.00				0.5	10	65	0.5	10	65	0.5	10	65	1.0	6	67
150	6.00				0.5	12	65	0.5	12	65	0.5	12	65	1.0	7	67
200	8.00				1.0	9	67	1.0	9	67	1.0	9	67	1.0	9	67
250	10.00				1.0	11	67	1.0	11	67	1.0	11	67	1.0	11	67
300	12.00				1.0	12	67	1.0	12	67	1.0	12	67	1.0	12	67

*25 mm = 1 in.

†THK—Insulation thickness, inches.

‡HG—Heat gain/lineal foot (pipe) 28 ft (flat), BTU

§ST—Surface temperature, °F

TABLE 5.2 Insulation Thickness to Prevent Condensation, 34°F Service Temperature and 70°F Ambient Temperature*

		Relative humidity, %														
Nom. Pipe		20			50			70			80			90		
DN	size, in	TNK†	HG‡	ST§	THK	HG	ST	THK	HG	ST	THK	HG	ST	THK	HG	ST
15	0.50				0.5	4	64	0.5	4	64	0.5	4	64	1.5	2	68
20	0.75				0.5	4	64	0.5	4	64	0.5	4	64	1.5	3	67
25	1.00				0.5	6	63	0.5	6	63	1.0	4	66	1.5	3	67
32	1.25				0.5	6	63	0.5	6	63	1.0	5	65	1.5	3	67
40	1.50				0.5	8	62	0.5	8	62	1.0	5	66	1.5	4	67
50	2.00				0.5	8	63	0.5	6	63	1.0	6	66	1.5	4	67
65	2.50				0.5	10	63	0.5	10	63	1.0	6	66	1.5	5	67
75	3.00				0.5	12	62	0.5	12	62	1.0	8	65	1.5	6	67
90	3.50	Condensation control not required for this condition			0.5	14	61	0.5	14	61	1.0	7	66	1.5	6	67
100	4.00				0.5	15	62	0.5	15	62	1.0	9	65	1.5	7	67
125	5.00				0.5	16	63	0.5	16	63	1.0	11	65	2.0	7	67
150	6.00				0.5	22	61	0.5	22	61	1.0	13	65	2.0	8	67
200	8.00				1.0	16	65	1.0	16	65	1.0	16	65	2.0	10	67
250	10.00				1.0	20	65	1.0	20	65	1.0	20	65	2.0	11	67
300	12.00				1.0	22	65	1.0	22	65	1.0	22	65	2.0	13	67

*25 mm = 1 in.
†THK—Insulation thickness, inches.
‡HG—Heat gain/lineal foot (pipe) 28 ft (flat), BTU
§ST—Surface temperature, °F

increasing thickness beyond the optimal thickness does not give increased return on investment.

A high design service temperature of piping could eliminate some insulating material from consideration. The manufacturer's technical literature will indicate the highest temperature recommended for a particular insulating system. The adhesive is usually the weakest link in the insulating system chain.

To find the amount of heat lost through piping installed outdoors covered with various insulation types and thicknesses, refer to Table 5.3. Heat loss tables for various types and thicknesses of insulation installed indoors are available from insulation manufacturers. Although the base figures are for fiberglass, insulation factors are provided for other types of insulation. Multiply the figures in the table by the factor for other insulation types to obtain the figure for the new insulation. Also included is heat loss in Btu/in of insulation. Use the average thickness obtained from Table 5.6.

Personnel Protection. If system economy is not a consideration for any particular piping system, a hot pipe must be insulated to bring the surface temperature of the insulation to 120°F (48°C) or below, the point that would burn a person's skin. Refer to Table 5.4 for the thickness of fiberglass insulation necessary to achieve a surface temperature of 110°F (43°C) with a conservative ambient temperature of 80°F (26°C). Enter the table with the service temperature and size of the pipe. Read the required thickness and resulting surface temperature for the thickness selected at the intersection of the appropriate columns. Use the 250°F column for lower service piping temperatures.

TABLE 5.3 Heat Loss from Piping*

Insulation type	Insulation factor	Heat loss per inch thickness, based on K factor @ 50°F mean temp (Btu/hr · °F · ft^2)
Glass fiber (ASTM C547)	1.00	0.25
Calcium silicate (ASTM C533)	1.50	0.375
Cellular glass (ASTM C552)	1.60	0.40
Rigid cellular urethane (ASTM C591)	0.66	0.165
Foamed elastomer (ASTM C534)	1.16	0.29
Mineral fiber blanket (ASTM C553)	1.20	0.30
Expanded perlite (ASTM C610)	1.50	0.375

Insulation thickness, in	ΔT, °F	IPS												
		½	¾	1	1¼	1½	2	2½	3	4	6	8	10	12
		Tubing size, in												
		¾	1	1¼	1½	2								
0.5	10	0.5	0.6	0.7	0.8	0.9	1.1	1.3	1.5	1.8	2.6	3.3	4.1	4.8
	50	2.5	2.9	3.5	4.1	4.8	5.5	6.5	7.7	9.6	13.5	17.2	21.1	24.8
	100	5.2	6.1	7.2	8.6	9.9	11.5	13.5	15.9	19.9	28.1	35.8	43.8	51.6
	150	8.1	9.5	11.2	13.4	15.5	17.9	21.0	24.8	30.9	43.8	55.7	68.2	80.2
	200	11.2	13.1	15.5	18.5	21.4	24.7	29.0	34.3	42.7	60.4	76.9	94.1	110.7
	250	14.6	17.1	20.2	24.1	27.9	32.2	37.8	44.7	55.7	78.8	100.3	122.6	144.2
1.0	10	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	1.0	1.4	1.8	2.2	2.6
	50	1.6	1.9	2.2	2.5	2.9	3.2	3.7	4.4	5.4	7.4	9.4	11.4	13.4
	100	3.4	3.9	4.5	5.2	5.9	6.8	7.8	9.1	11.2	15.5	19.5	23.8	27.8
	150	5.3	6.1	7.0	8.2	9.3	10.5	12.2	14.2	17.4	24.1	30.4	37.0	43.3
	200	7.4	8.4	9.7	11.3	12.8	14.6	16.8	19.6	24.0	33.4	42.0	51.2	59.9
	250	9.6	11.0	12.6	14.8	16.7	19.0	22.0	25.6	31.4	43.6	54.9	66.9	78.2
1.5	10	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.8	1.0	1.3	1.6	1.8
	50	1.3	1.5	1.7	1.9	2.2	2.4	2.8	3.2	3.9	5.3	6.6	8.0	9.3
	100	2.7	3.1	3.5	4.0	4.5	5.1	5.8	6.7	8.1	11.1	13.8	16.7	19.5
	150	4.3	4.8	5.5	6.3	7.1	7.9	9.1	10.4	12.6	17.2	21.5	26.0	30.3
	200	5.9	6.7	7.6	8.7	9.8	11.0	12.5	14.5	17.5	23.8	29.7	36.0	41.9
	250	7.8	8.7	9.9	11.4	12.8	14.4	16.4	18.9	22.8	31.1	38.9	47.1	54.8
2.0	10	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.6	0.8	1.0	1.2	1.4
	50	1.1	1.3	1.4	1.6	1.8	2.0	2.3	2.6	3.1	4.2	5.2	6.3	7.3
	100	2.4	2.7	3.0	3.4	3.8	4.2	4.8	5.5	6.5	8.8	10.9	13.1	15.2
	150	3.7	4.2	4.7	5.3	5.9	6.6	7.5	8.5	10.2	13.7	17.0	20.4	23.6
	200	5.2	5.8	6.5	7.4	8.2	9.1	10.3	11.8	14.1	19.0	23.5	28.2	32.7
	250	6.8	7.5	8.5	9.6	10.7	11.9	13.5	15.4	18.5	24.8	30.7	36.9	42.7
2.5	10	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.7	0.8	1.0	1.2
	50	1.0	1.1	1.3	1.4	1.6	1.8	2.0	2.3	2.7	3.6	4.4	5.2	6.0
	100	2.2	2.4	2.7	3.0	3.3	3.7	4.1	4.7	5.6	7.4	9.1	10.9	12.6
	150	3.4	3.7	4.2	4.7	5.2	5.8	6.5	7.3	8.7	11.5	14.2	17.0	19.6
	200	4.7	5.2	5.8	6.5	7.2	8.0	9.0	10.2	12.1	16.0	19.6	23.5	27.1
	250	6.1	6.8	7.5	8.5	9.4	10.4	11.7	13.3	15.8	20.9	25.7	30.7	35.4
3.0	10	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.5	0.6	0.7	0.9	1.0
	50	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.0	2.4	3.1	3.8	4.5	5.2
	100	2.0	2.2	2.4	2.7	3.0	3.3	3.7	4.2	4.9	6.5	7.9	9.4	10.8
	150	3.1	3.4	3.8	4.3	4.7	5.2	5.8	6.5	7.7	10.1	12.3	14.7	16.8
	200	4.3	4.8	5.3	5.9	6.5	7.2	8.0	9.0	10.7	14.0	17.0	20.3	23.3
	250	5.7	6.2	6.9	7.7	8.5	9.4	10.5	11.8	13.9	18.3	22.3	26.5	30.5

*Pipe heat loss (Q_B) is shown in watts per foot. Heat loss calculation is based on metal pipes insulated with glass fiber (ASTM C547) and located outdoors in a 20 mph wind. A 10% safety factor has been included. (Note: Watts/ft = Btu/ft × 0.293.)

Source: RAYCHEM.

TABLE 5.4 Insulation Thickness for Personnel Protection

120° Maximum Surface Temperature, 80° Ambient

Nom. pipe size, in	Service temperature															
	250				350				450				550			
		HL†				HL				HL				HL		
	TH*	LF‡	SF§	ST¶	TH	LF	SF	ST	TH	LF	SF	ST	TH	LF	SF	ST
0.50	0.5	25	51	109	1.0	30	40	104	1.0	48	64	118	1.5	55	52	113
0.75	0.5	25	41	104	0.5	42	68	120	1.5	45	43	107	1.5	64	61	118
1.00	0.5	34	55	112	1.0	37	40	105	1.0	60	66	120	1.5	69	58	117
1.25	0.5	37	49	109	1.0	47	51	112	1.5	55	42	107	1.5	77	59	118
1.50	0.5	46	61	117	1.0	48	46	109	1.5	62	47	110	2.0	70	40	106
2.00	0.5	50	55	114	1.0	56	47	110	1.5	70	48	111	2.0	84	48	112
2.50	0.5	59	56	115	1.5	45	26	97	1.5	72	41	107	1.5	102	59	119
3.00	0.5	75	64	120	1.0	76	52	114	1.5	93	53	115	2.0	110	55	117
3.50	1.0	43	25	96	1.0	71	41	107	1.5	93	46	111	2.0	112	49	113
4.00	0.5	89	61	119	1.0	90	52	114	1.5	112	56	117	2.0	131	58	119
5.00	1.0	67	33	102	1.0	110	55	117	1.5	134	59	120	2.5	131	46	112
6.00	1.0	79	35	103	1.0	130	57	119	2.0	124	44	110	2.5	150	48	114
8.00	1.0	95	33	103	1.0	157	55	118	2.0	153	45	112	2.5	177	48	114
10.00	1.0	121	36	105	1.5	136	37	106	2.0	179	45	112	2.5	215	51	117
12.00	1.0	129	32	103	1.0	212	54	118	2.0	207	46	113	2.5	248	52	118

*TH—Thickness of insulation, inches.

†HL—Heat loss, Btu/h.

‡LF—Heat loss per lineal foot of pipe, Btu/h.

§SF—Heat loss per square foot of outside insulation surface, Btu/h.

¶ST—Surface temperature of insulation, °F.

Noise Reduction. Some types of insulation and/or special jackets can reduce the noise that may be generated or transmitted by pipes, depending on the degree of reduction desired. Manufacturers have compiled data on the reduction factors of various insulation and jackets, which will aid in the selection of materials for that purpose.

Expected Temperature

The expected temperature of the pipe is an important factor in the selection of insulation systems. For hot pipes, the highest expected temperature will affect the choice of thickness and type of insulation and the adhesives used to adhere the insulation or jackets to the pipe and itself. For cold pipes, the coldest expected temperature will affect the selection of the insulation and vapor barrier required to stop condensation. The expansion of the pipe and insulation should also be compared to see if the difference is excessive.

Location of Insulation

Where the insulated pipe or equipment is located may dictate the type of insulation, jacket, or covering and the method used to attach it to the pipe. Factors such as outdoor installation, high humidity, and low ambient temperature will affect the selection of system components.

Accessibility

There may be a need to remove portions of the insulation to allow maintenance, inspection, or repair to a section of the piping system on a regular basis. Fiberglass and rubber are the easiest to remove, simply by cutting the cover and insulation with a knife and removing them. Putting them back is just as simple as installing them originally, and no harm is done to the surrounding insulation and covering on either side. If this is to be done often or on a regular basis, another popular method is to use a blanket insulation and wrap it with a wire mesh that is secured with straps. This last method is limited to hot lines that are not subject to any physical abuse whatsoever.

CALCULATION OF INSULATION THICKNESS

The following examples will illustrate the use of previously presented formulas of heat transfer fundamentals involving practical solutions to selecting the actual thickness of the insulation intended to be used for any specific project.

In all probability, there are charts and tables available to determine some of the heat loss figures to be calculated. But, there are bound to be situations that will not allow the use of standard conditions or standard figures. Also, most charts do not go into enough detail or provide criteria for the specific conditions that may be present in the design of a specific project. It is for these circumstances that the formulas will be used. Before proceeding with actual calculations, the following paragraphs will describe several typical factors and basic formulas from which the design criteria are derived.

First is the surface film factor (SFR). A film of air exists on the surface of any solid in direct contact with air. This surface film has a definite resistance to the passage of heat. Table 5.5 gives the surface resistance (film factor) for a variety of conditions. In order to simplify the figures, the pipe is assumed to be at the same temperature as its contents.

When calculating the heat flux for piping (as compared to flat surfaces), the fact that the inner surface of the insulation has a different area than its outer surface must be taken into account. Since the measurement is the amount of heat loss per square foot of exposed surface, a means must be found to determine the actual area that should be used. This is done by using an equivalent insulation thickness (ET), which is equal to the logarithmic mean of the inner and outer surfaces (see Table 5.6). Enter this table with the pipe size and thickness of insulation intended to be used.

Also included in Table 5.6 is the actual square foot area (A) along the outside of the selected insulation per linear foot of pipe length. This will be necessary to find the actual heat loss for the installation. Simply multiply the calculated heat loss by A to obtain the heat loss per foot of pipe.

The variables below will be used in the following series of formulas:

HF = heat flux in Btu/h/ft^2
T_1 = temperature of pipe
T_2 = ambient temperature
ET = equivalent thickness of insulation (Table 5.6)
AT = actual thickness of insulation
ST = surface temperature at insulation exterior
k = insulation k factor (manufacturer's rating)
SFR = surface film factor, or resistance (Table 5.5)
HL = heat loss per linear foot of pipe
A = area of insulation exterior, ft^2 (Table 5.6)

TABLE 5.5 Surface Film Factor

Condition	Resistance R
Still air (0 mph)	
Heat flow up	0.61
Heat flow down	0.92
Heat flow horizontal	0.68
Moving air	
7.5 mph (12 km/hr) (summer)	0.25
15.0 mph (24 km/hr) (winter)	0.17
Round pipe	0.65

Note: Surface resistances decrease as air velocities increase. All values are taken from *ASHRAE Handbook of Fundamentals.* Some of these examples consider only the insulation surface-to-ambient film factor. It is assumed that the inside surface area is at the same temperature as the contents (air, gas, or liquid), such as in a duct, pipe, or tank. Generally, the inside air film factor is used only for cases involving occupied spaces, 60 to 90°F (15 to 32°C).

Courtesy: Owens/Corning.

TABLE 5.6 Equivalent Thickness

	½		1		1½		2		2½		3	
NPS	L_1	A	L_1	A	L_1	A	L_1	A	L_1	A	L_1	A
½	0.76	0.49	1.77	0.75	3.12	1.05	4.46	1.31	—	—	—	—
¾	0.75	0.56	1.45	0.75	2.68	1.05	3.90	1.31	—	—	—	—
1	0.71	0.62	1.72	0.92	2.78	1.18	4.02	1.46	—	—	—	—
1¼	0.63	0.70	1.31	0.92	2.76	1.31	3.36	1.46	—	—	—	—
1½	0.60	0.75	1.49	1.05	2.42	1.31	4.13	1.73	—	—	—	—
2	0.67	0.92	1.43	1.18	2.36	1.46	3.39	1.73	4.43	1.99	—	—
2½	0.66	1.05	1.38	1.31	2.75	1.73	3.71	1.99	4.73	2.26	—	—
3	0.57	1.18	1.29	1.46	2.11	1.73	2.96	1.99	3.88	2.26	4.86	2.52
3½	0.92	1.46	1.67	1.73	2.46	1.99	3.31	2.26	4.22	2.52	5.31	2.81
4	0.59	1.46	1.28	1.73	2.01	1.99	2.80	2.26	3.65	2.52	4.68	2.81
4½	0.94	1.74	1.61	1.99	2.35	2.26	3.15	2.52	4.11	2.81	5.02	3.08
5	0.58	1.74	1.20	1.99	1.89	2.26	2.64	2.52	3.54	2.81	4.40	3.08
6	0.54	2.00	1.13	2.26	1.79	2.52	2.60	2.81	3.36	3.08	4.17	3.34
7	—	—	1.11	2.52	1.84	2.81	2.54	3.08	3.27	3.34	4.25	3.67
8	—	—	1.18	2.81	1.81	3.08	2.49	3.34	3.39	3.67	4.15	3.93
9	—	—	1.17	3.08	1.79	3.34	2.62	3.67	3.32	3.93	4.06	4.19
10	—	—	1.09	3.34	1.85	3.67	2.50	3.93	3.18	4.19	3.90	4.45
12	—	—	1.22	3.93	1.82	4.19	2.45	4.45	3.10	4.71	3.79	4.97
14	—	—	1.07	4.19	1.65	4.45	2.26	4.71	2.90	4.97	3.57	5.24
16	—	—	1.06	4.71	1.63	4.97	2.23	5.24	2.86	5.50	3.50	5.76
18	—	—	1.05	5.24	1.62	5.50	2.21	5.76	2.82	6.02	3.45	6.28
20	—	—	1.05	5.76	1.61	6.02	2.19	6.28	2.79	6.54	3.41	6.81
24	—	—	1.04	6.81	1.59	7.07	2.16	7.33	2.74	7.59	3.35	7.85

NPS = nominal pipe size

L_1 = equivalent thickness in inches

$$L_1 = r_2 \ln\left(\frac{r_2}{r_1}\right)$$

where r_1 = inner radius of insulation, inches

r_2 = outer radius of insulation, inches

ln = log to the base e (natural log)

A = square feet of pipe insulation exterior per lineal foot of pipe

The formula used to find heat flux from a round surface is:

$$\text{HF} = \frac{T_1 - T_2}{(\text{ET}/k) \times \text{SFR}} \tag{5.5}$$

The following examples will demonstrate the use of the formulas. The first example will involve the following conditions:

Temperature of pipe contents = 200°F
Ambient temperature = 80°F
Pipe size = 8 in
Insulation = fiberglass, 2 in thick

Substituting in Eq. (5.5)

$$\mathrm{HF} = 200 - \frac{80}{(2.49/0.23) + 0.68} = \frac{120}{9.2 + 0.68} = \frac{120}{9.88}$$

$$= 12.1\ \mathrm{Btu/h \cdot ft^2}$$

To find the actual heat loss per linear foot, use the formula:

$$\begin{aligned} \mathrm{HL} &= \mathrm{HF} \times A \\ &= 12.1 \times 3.34 = 40.4\ \mathrm{Btu/h \cdot ft} \end{aligned} \tag{5.6}$$

To find the heat loss from the entire system, find the total length of run and multiply that figure by HL. In order to do an accurate calculation, the different lengths of pipe run in various temperature-controlled areas will each have to be calculated separately.

To find the surface temperature of the insulation exterior, use the formula:

$$\begin{aligned} \mathrm{ST} &= T_2 + (\mathrm{HF} \times \mathrm{SFR}) \\ &= 80 + (12.1 \times 0.68) = 80 + 8.2 = 88.2^\circ\mathrm{F} \end{aligned} \tag{5.7}$$

In order to calculate the heat loss from a tank, the only substitution in the above formula should be AT instead of ET, and there is no need to find HL. To find the heat loss from the whole tank, multiply HF by the area of the tank.

When calculating the heat gain for a cold line, the same formula as for a hot pipe is used, except that the result is the amount of heat gained by the pipe from the ambient air.

General Design Considerations

The following paragraphs describe the general selection criteria for different materials under average situations.

1. *Domestic cold water or chilled water service.* Fiberglass with ASJ should be secured with staples. The reasons are that fiberglass is the least expensive insulation to install and the staples can be applied in any weather and regardless of the dust conditions on the job. Fittings should be covered with plastic-fitting covers. The staples must be coated with a vapor barrier mastic. If the working conditions are reasonably dust-free, self-sticking lap joints are a cost-saving alternative.
2. *Domestic hot water, hot water return, and other services under 240°F (114°C).* The same materials as for cold water service (see Number 1 above) are used.
3. *Hot tanks under 240°F (114°C).* Stiff fiberglass board covered with a breather coat of mastic or fiberglass cloth should be used. Insulating cement can be used if additional protection from abuse is needed.
4. *Cold (not cryogenic) tanks.* Rubber insulation with no jacket can be used if the area where it will be installed is reasonably clean. A jacket is not required and the surface can be painted. If there is a problem with dust or dirt, the material of choice would be fiberglass boards with a coating of cut back mastic as a vapor barrier.

5. *Outdoor service.* Rubber insulation with an ASJ should be used in order to resist moisture penetration into the insulation. The final cover should be aluminum secured with bands or a lock seam. Field experience has shown that screws often fall out if subject to vibration.
6. *Sanitary exterior.* The best choice is a stainless steel jacket if the cleaning is to be severe. If not, a plastic jacket is more cost effective.
7. *Hazardous environment.* Where there is a danger that the contents of the pipe or chemicals in the surrounding area could possibly penetrate the jacket and cause a potentially dangerous situation, cellular glass insulation should be used because it is nonadsorbent. A jacket capable of resisting the chemical hazard, usually plastic, must be used over the glass insulation.
8. *Special fire resistance.* Again, cellular glass is the best material because it is completely noncombustible. A jacket of stainless steel provides the best protection.
9. *Very hot piping (450°F (230°C) or higher).* Calsil or mineral wool is the material of choice because of its superior qualities at higher temperatures. A plain jacket or a breather coating is a good covering. Insulation thickness should be determined to ensure a low surface temperature, if the piping is accessible to people.
10. *Cryogenic piping.* Four-inch (100 mm) thick polypropylene should be used.
11. *Steam and condensate piping.* Calsil or mineral wool should be used.

There are four specific problem areas that have been found to cause the most failures. First is where workers can walk on insulated pipe after it has been installed, for example, in boiler rooms and MERs. This will ruin any insulation in short order. Observation of seams no longer bound together is good evidence that this has occurred. Second is a failure to properly and completely seal a vapor barrier, particularly around valves and fittings. Water vapor will enter at these points and saturate the insulation very quickly. On occasion, the water will run along the pipe and drip far from the actual fault. Third is the failure to properly support the insulated pipe on a hanger. In order to keep the insulation from becoming compressed (causing tearing and a loss of insulating value), the weight of the pipe must be distributed by using a metal shield (if the pipe is small), a length of rigid insulation between the hanger and the insulated pipe, or, if the pipe and contents are large and heavy, a block of wood placed on the bare pipe (under the vapor barrier) to support the weight of the pipe at the hanger. Fourth is the installation of adhesives and self-sticking jacket seals under extremely dusty conditions, causing dust to be deposited on the adhesive before it is installed permanently.

FREEZE PROTECTION

FREEZING OF WATER

Much time, effort, and money must be spent to restore service when pipes and mains freeze. In addition, many times these efforts must be made under very difficult working conditions and with great urgency. Because of this, it is preferable to design systems that will not freeze.

Studies at the U.S. Army Cold Region Research and Engineering Laboratory (CRREL) have shown that the dynamics of the freezing process of water in pipes are much more complicated than originally thought, and that this process is different for static and flowing water. It was found that when water starts to freeze, flow in a piping system can become blocked much earlier than previously believed. It was also established that the actual mechanics of the freezing process are less predictable in terms of both time and heat loss than was previously believed.

Previously, it was believed that when ice formed inside a pipe or vessel, it started on the pipe wall and grew uniformly inward until the entire pipe was blocked. It was also thought that the only apparent difference between the freezing that occurred in static and flowing water was a difference in the rate due to the heat created by the flowing water.

THE MECHANICS OF THE FREEZING PROCESS

Static Water

When the temperature outside a pipe falls below freezing, before any ice can form, the water inside must be cooled below the freezing point. This is called supercooling, and in the CRREL studies the temperature fell as low as 29°F (−1.6°C) before ice started to form. The initial ice formation is called *nucleation.* As the process continues, the ice takes the shape of thin feathery crystals interspersed with water, similar in shape to a Christmas tree. This new formation is called *dendritic* ice. As the dendritic crystals rapidly grow larger, they release latent heat of fusion due to the change of state of the water. Since the surrounding soil or air cannot absorb all this heat, the temperature of the water is then raised back to the 32°F (0°C) level. This brings the dendritic phase to an end. Only after all the heat is absorbed by the surrounding medium does the annular growth of ice actually start. The dendrils become more and more dense and are gradually incorporated into the growing annulus. Eventually, the annulus increases in size, becomes solid, and occupies the entire cross section of pipe. The pipe and its contents will continue to cool until the ambient temperature is reached. The freezing of still water is illustrated in Fig. 5.1.

Flowing Water

Prior to the CRREL studies, it was believed that flowing water began to freeze in a pipe with the formation of annular ice along the inside of the pipe perimeter, assuming a tapered cross section and having the smaller end at the downstream

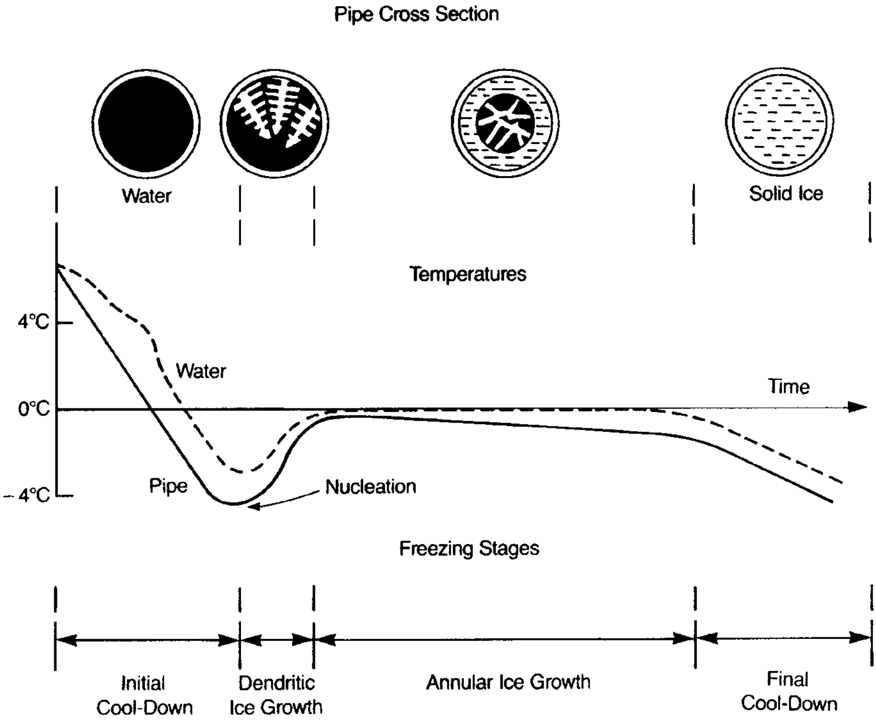


FIGURE 5.1 Freezing of still water.

side. Blockage was thought to occur when the smaller cross section thickened and eventually closed, filling the pipe at that point. As the ambient temperature dropped, the remainder of the water in the pipe froze until the entire pipe became filled.

In actuality, it was found that as the ambient temperature fell, an ice-water mixture was produced in the shape of rippled ice surfaces that moved along with the flow of water. This mixture was found to be in the shape of a taper in cross section with the smaller end pointed downstream. At regular intervals there was sudden enlargement. A further lowering of the ambient temperature did not lead to a thickening of the ice but rather, a progressively closer spacing of the narrow ice bands. The friction factor of the flowing water was found to be greatly affected by this type of ice formation. Since the friction head loss of pressure consists primarily of wall drag and the nozzle losses that occur at each band, the hydraulics become very unstable. Any further decrease in the discharge rate of the system or an increase in the friction loss due to more ice will quickly create a condition where the total head requirements for flow are greater than the source can provide. It is at this point that all flow would stop and the water would start to freeze immediately. The freezing of flowing water is illustrated in Fig. 5.2.

PIPE DAMAGE DUE TO FREEZING

Water falls into the category of substances that have a temperature of maximum density. Above that temperature it has a positive coefficient of expansion, which

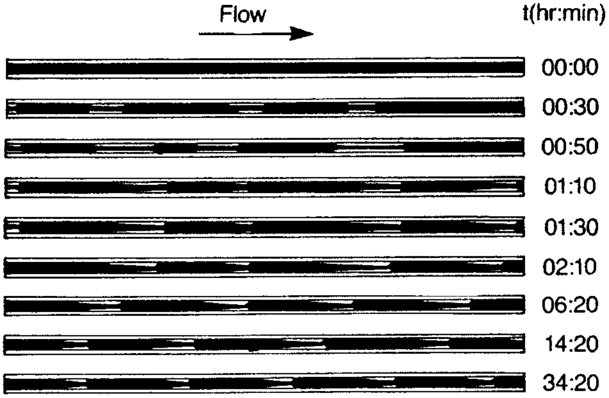


FIGURE 5.2 Freezing of flowing water.

means that water will expand upon heating. However, if water is cooled below that temperature, it has a positive coefficient of expansion since it will also expand when cooled. The relationship between temperature and volume is shown in Table 5.7. Because of this expansion, water (or ice) will exert considerable pressure when confined within any enclosed space. The relationship between temperature and pressure is shown in Table 5.8.

A mathematical analysis of the actual stress produced by the freezing of water in an enclosed space has shown that the circumferential stress exceeds the longitudinal stress in all cases. What this means in practical terms is that any pipe can be expected to fail along its length in the absence of a weak joint or a flaw in the piping material. In tests conducted at the National Bureau of Standards, it was observed that in all cases of failure due to freezing, liquid water was released from the pipe at the point of failure.

Applying these facts to a piping system, differences in heat transfer, caused by variations present in all piping systems, will result in the freezing of pipe in some locations but not others along the same run. This will cause a rupture in one or more of the unfrozen sections of the piping network that are the last to freeze.

TABLE 5.7 Relationship between Water Temperature and Volume

Temperature		Specific volume, mL/g	
°C	°F	Water	Ice
−10	14	1.002069	
−5	23	1.000825	
0	32	1.0001324	1.0908
3	37.4	1.0000078	
4	39.2	1.0000000	
5	41	1.0000081	
10	50	1.0002720	

Source: Data of J. F. Mohler, at 1 atm pressure.

TABLE 5.8 Relationship between Freezing Point and Pressure for Water

Freezing point		Pressure	
°C	°F	atm	psi
0	32	1	0
− 5	23	590	8660
−10	14	1090	16000
−22	−7.6	2047	30000

THE FREEZING OF WATER IN ATMOSPHERIC VESSELS

General

The most common method used to store water is in an on ground or elevated water storage tank made of either wood or steel. If enough heat cannot be added by means of new water flowing into the tank to keep the water from freezing, it must be added by some other means. In addition to the tank itself, the riser from grade up to the bottom of an elevated tank must be protected also. It is generally thought that adequate heating of any tank is almost as important as proper structural design.

The Mechanics of Ice Formation

Water in an open tank or vessel loses heat on all of the sides exposed to the atmosphere. For a tank on grade, the loss of heat into the surrounding soil is not as great due to the insulating factor of that soil. However, the greatest amount of heat is lost through the surface of the water. As the water cools, an internal circulation takes place because the surface layer of water cools faster than the deeper water. This causes the surface layer to become denser, resulting in that water migrating to the bottom of the tank and displacing the warmer water to the top. This circulation will continue to take place until the temperature of most of the water reaches about 32°F. When this occurs, the water is at its maximum density. At this point, an inversion takes place. The coldest water, at a lesser density, now rises to the surface. Continued cooling of the surface water further reduces its density, and the temperature rapidly falls to the point of freezing.

Ice generally appears first at the sides of the tank, then quickly forms a continuous layer over the surface. This same progression is true for similar installations such as pools and lagoons. A formula for the determination of ice formation on the surface of an open vessel has been developed. It considers the insulating effect that the forming layer of ice will have on the transfer of heat from the surface of the water to the air. One assumption is that the time is constant. The following formula calculates the thickness of ice formation in any period of time. The formula is:

$$X = \frac{25\,l}{32 - T} \tag{5.8}$$

where X = time, h
I = ice thickness, in (A generally accepted figure of $\frac{1}{16}$ in is required to stop operation of float valves, etc.)
T = design air temperature, °F

A design air temperature value based on the mean of the high and low reading is considered adequate for design of tanks storing potable water. For tanks used to store fire protection water only, it would be advisable to use the lowest one-day mean temperature. The lowest one-day mean temperature can be found in Fig. 5.3.

Selecting the Heating System Type

Selecting the most economical type of heating system depends on the tank height, amount of heat required, and the availability and cost of any particular fuel or heating medium. The basic methods or devices are:

1. Direct discharge of steam into the water
2. Steam coils inside the tank
3. Hot water coils inside the tank
4. Electric immersion heating elements inside the tank

The direct discharge of steam into a tank is the method used most often for nonpotable water where steam is available. A steam supply line of adequate size is piped directly into the tank. This line ends in a tee placed about one-third of the height of the tank from the bottom. A condensate return line may be required, but it does not penetrate the tank.

When there is a potable water supply in combination with fire reserve water in a tank, the possibility of cross-contamination from an outside source must be minimized to the greatest extent possible. As a result, the following three methods should be considered.

The use of steam in coils at the bottom of a tank is mostly limited to tanks that have a flat bottom, are not elevated to a great height, and do not need too much heat transferred. Based on past experience, this method is not considered very reliable because a large number of problems have been reported.

Gravity circulation of hot water requires a heat exchanger or a hot water generator to be placed in close proximity to the tank, usually under the tank in the valve pit if provided or in a separate building adjacent to the tank. Cold water is taken from the discharge pipe and run through the heater. Since the now heated water is lighter than the colder supply, a natural circulation is obtained. Long runs of heater piping are not practical due to the heat loss from the piping and the expense of insulation needed to keep the heat from being lost. In addition, the hot water generator takes space in what might be a small valve pit under the tank.

The use of electric immersion heaters is practical only when the cost of the electricity is low. An advantage is the lowest initial cost of the heating methods discussed when used for potable water.

Calculating Heat Loss from Elevated Tanks

A method to determine the amount of heat lost from water tanks developed by the National Fire Protection Association (NFPA) has become the standard for design,

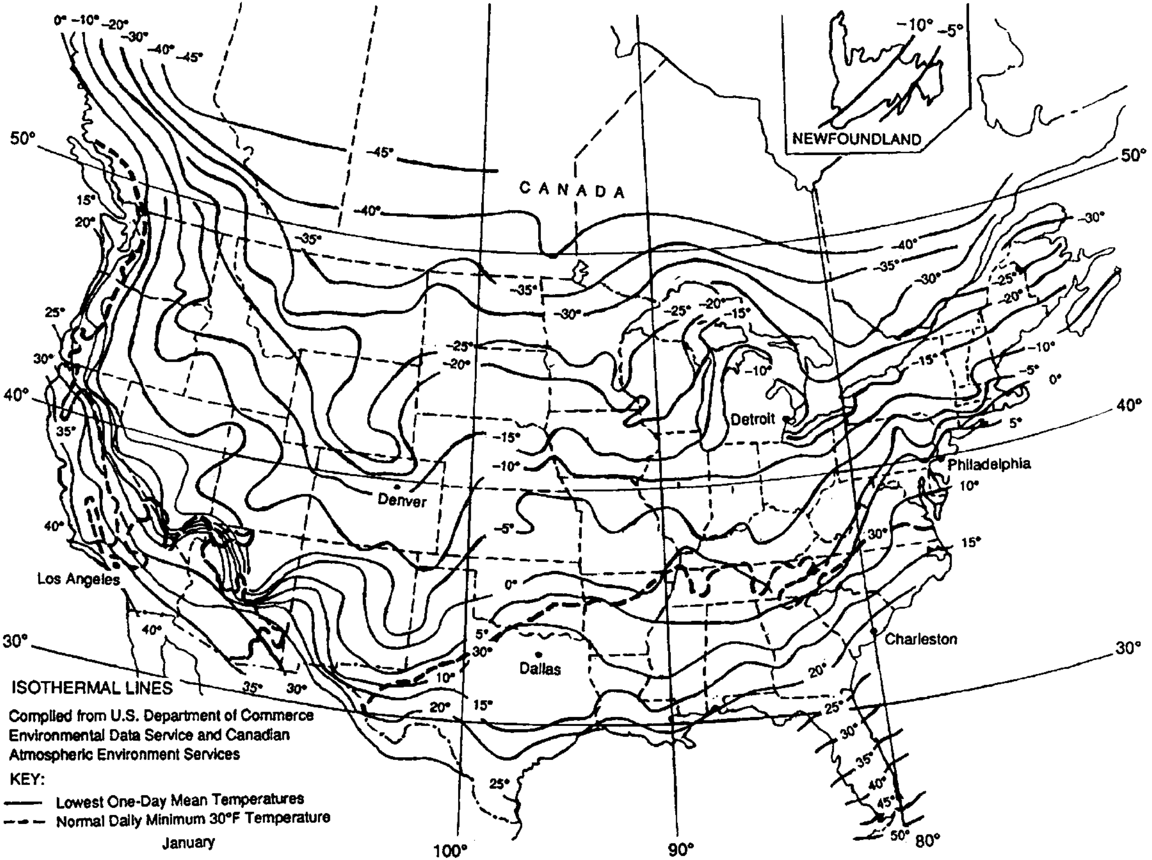


FIGURE 5.3 Lowest one-day mean temperature. (*NFPA.*)

and is very conservative in its approach. The basic consideration is not to allow the temperature of the water to fall below 42°F. This is a safe temperature above freezing that makes allowance for tolerances in various equipment and for variations in weather design data.

The procedures required to calculate the amount of heat necessary to replace the heat that was lost to the atmosphere are as follows:

1. Determine the lowest one-day mean temperature at the proposed site. Refer to Fig. 5.3 for this information.
2. Determine the number of gallons the tank will hold. Use the nominal, not actual, capacity.
3. Using the lowest temperature and the capacity from steps 1 and 2, refer to either Table 5.9 (for elevated wood or steel tanks or wood tanks on grade) or Table 5.10 (for steel tanks on grade) for the heat loss in thousands of Btu/h.
4. Refer to Table 5.11 to find the heat loss in Btu/h from the riser for each foot of length from grade to the bottom of the tank.
5. Add the two figures obtained in steps 3 and 4 together to calculate the total heat loss for the installation. This figure is the capacity in thousands of Btu/h that the heating system must be capable of providing.

SEWER AND WATER SUPPLY PIPING DESIGN

Designing a complex piping system to prevent freezing is a very involved procedure that requires a thermal analysis of the piping network. The types of systems discussed in this book are not considered complex.

In current practice, precise analysis is not necessary and therefore is not made. The empirical methods discussed have been verified under actual field conditions and are considered sufficiently accurate for engineering design calculations. Although the following discussions are for a flowing sewage system, the same calculations can be made for flowing water piping.

The following assumptions have been made to simplify the solution of the heat transfer process. These are

1. The thermal characteristics of sewage are essentially the same as that of water.
2. The sewer is assumed to be flowing full and at a minimum velocity of 2 ft/s.
3. There are critical flow periods that will last about 6 to 8 h, during which the flow will be approximately 25 percent of the 24-h average flow, and a 1- to 2-h period when the flow is about 5 percent of the 24-h flow rate.
4. The losses through manholes, catch basins, cleanouts, and the like are the same as those through the pipe run itself.
5. Heat is transferred mainly through conduction.

A basic equation the steady state heat flow by conduction is used to calculate the heat loss from sewers. It is based on the Fourier law, and is stated:

$$Q = \frac{K}{X} \times A \times (T_1 - T_2) \tag{5.9}$$

TABLE 5.9 Heat Loss from Typical Elevated Wood or Steel Tanks or Wood Tank on Grade

Thousands of British thermal units lost per hour when the temperature of the coldest water is 42°F (4°C)

		Wooden tanks—capacities, in thousands of gallons								
°F	°C	10	15	20	25	30	40	50	75	100
35	2	8	10	11	13	14	19	21	28	33
30	−1	11	14	16	19	21	27	31	40	49
25	−4	15	20	21	25	28	36	42	54	65
20	−7	19	25	27	32	35	46	54	69	83
15	−10	24	31	34	39	44	57	66	85	102
10	−13	28	36	40	46	51	68	78	100	121
5	−15	33	43	47	54	60	78	92	117	142
0	−18	38	49	53	62	69	90	106	135	164
−5	−20	43	56	61	71	79	103	120	154	187
−10	−23	49	63	69	80	89	116	136	174	211
−15	−26	54	71	77	89	100	130	153	195	236
−20	−29	61	79	86	99	111	145	169	217	262
−25	−33	68	87	95	110	123	160	188	240	291
−30	−34	74	96	104	121	135	176	206	264	319
−35	−37	18	105	115	133	148	193	226	289	350
−40	−40	88	114	125	144	162	210	246	317	382
−50	−45	104	135	147	170	190	246	290	372	450
−60	−51	122	157	171	197	222	266	307	407	490

		Steel tanks—capacities, in thousands of gallons							
°F	°C	30	40	50	75	100	150	200	250
35	2	43	51	59	77	92	120	145	168
30	−1	62	72	83	110	132	171	207	242
25	−4	82	96	111	146	175	228	275	323
20	−7	103	120	139	183	220	287	346	405
15	−10	145	146	169	222	267	267	347	419
10	−13	147	172	200	263	316	411	496	582
5	−15	171	200	233	306	367	478	577	676
0	−18	197	231	268	352	423	551	664	779
−5	−20	224	262	304	400	480	626	755	884
−10	−23	253	296	344	452	543	707	853	1000
−15	−26	283	331	384	506	607	790	954	1118
−20	−29	314	368	427	562	674	878	1059	1241
−25	−33	348	407	473	622	747	972	1173	1375
−30	−34	382	447	519	683	820	1068	1288	1510
−35	−37	419	490	569	749	900	1171	1413	1656
−40	−40	456	534	620	816	979	1275	1538	1803
−50	−45	538	629	731	962	1154	1503	1814	2126
−60	−51	624	730	848	1116	1340	1745	2105	2467

TABLE 5.10 Heat Loss from Typical Steel Tank on Grade

		Tank capacities—in thousands of gallons							
°F	°C	100	150	200	300	400	500	750	1000
35	2	85	114	135	175	206	238	312	380
30	−1	121	162	193	248	294	340	445	543
25	−4	161	216	257	330	393	453	594	722
20	−7	202	271	323	414	493	568	745	907
15	−10	245	329	391	502	537	689	904	1099
10	−13	290	389	463	595	707	816	1071	1302
5	−15	337	452	539	691	822	949	1244	1514
0	−18	388	521	620	796	947	1093	1434	1744
−5	−20	441	592	705	905	1076	1241	1628	1981
−10	−23	498	669	797	1023	1216	1403	1841	2239
−15	−26	557	748	891	1143	1360	1569	2058	2503
−20	−29	619	830	989	1270	1510	1742	2286	2781
−25	−33	685	920	1096	1406	1673	1930	2532	3080
−30	−34	752	1010	1203	1545	1837	2119	2781	3383
−35	−37	825	1108	1320	1694	2015	2325	3050	3710
−40	−40	898	1206	1437	1844	2193	2531	3320	4039
−50	−45	1059	1422	1694	2175	2586	2984	3915	4762
−60	−51	1229	1651	1966	2524	3002	3463	4544	5528

TABLE 5.11 Heat Loss in Riser of Elevated Storage Tanks

Btu loss per hour through 4-ft-diameter (3.3 m) riser per foot-length

Atmospheric temperature, °F	°C	Btu/h
35	2	69
30	−1	192
25	−4	340
20	−7	506
15	−10	692
10	−13	893
5	−15	1092
0	−18	1309
−5	−20	1536
−10	−23	1771
−15	−26	2020
−20	−29	2291
−25	−33	2568

where Q = heat loss from pipe, Btu/h · ft
K = mean thermal conductivity, Btu/ft^2 · h · °F
T_1 = temperature at outside of pipe, °F
T_2 = ambient temperature at a distance from pipe that would not be affected by the heat of the pipe. (This would be either the ground temperature for buried pipe or the design temperature of the air.)

A = area, in square feet, normal to the direction of heat flow of a 1-ft long section of pipe. (Where there is insulation, the cylinder of insulation should be used to calculate the arithmetic mean of the area between the pipe wall and the outside of the insulation. Refer to Table 5.6.)
X = distance, in inches, from the outside of the pipe wall where T_1 is measured to where T_2 is taken.

Equation (5.9) has been used to create Fig. 5.4, which is a nomogram that shows the temperature drop of flowing water in a pipeline. Before Fig. 5.4 can be entered, the following values must be known:

V = velocity of flow, ft/s
H = heat-transfer coefficient (By field experience, a value of 6 has been found to be an average value.)
S = length of pipe run, ft

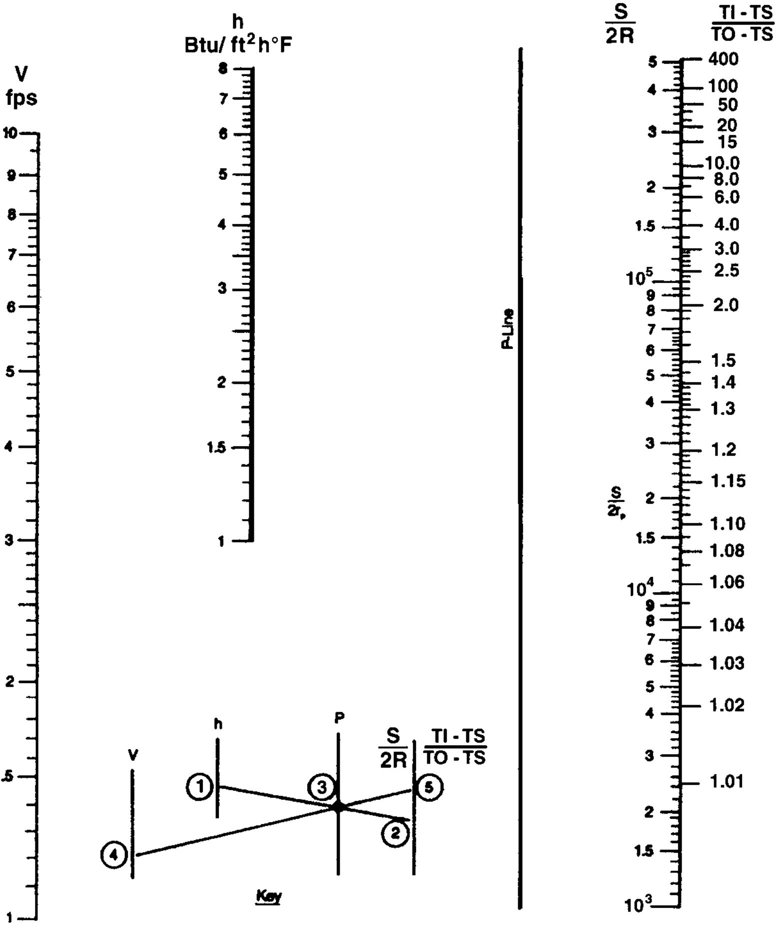


FIGURE 5.4 Temperature drop of flowing water in a pipeline.

R = radius of pipe, ft
TI = inlet water temperature, °F
TO = outlet water temperature, °F (It is recommended that a minimum temperature of 35°F be used to provide a safety factor to allow for variations in the thermal properties of soil along the run, intermittent flow in the pipe, and temperature fluctuations of both the air and ground.)
TS = ambient temperature of either air or soil around pipe (Soil temperature can be approximated by adding 5°F to the lowest monthly mean temperature.)

The following example illustrates the use of the nomograph in Fig. 5.4 to find the temperature drop in flowing water in a sewer, given the following conditions:

Pipe diameter = 12 in
Inlet water temperature = 40°F
Proposed velocity = 2 ft/s
Length of run = 2.2 mi
Estimated ground temperature = 25°F (T_2)

Step 1. Find

$$\frac{S}{2R} = \frac{2.2 \times 5280}{2 \times 0.5} = 1.16 \times 10^4$$

Step 2. $H = 6.0$ (from previous discussion).

Step 3. Enter Fig. 5.4 and connect points 1 and 2 (6.0 and 1.16×10^4).

Step 4. Using pivot point 3 as the anchor, connect points 3 and 4. On the other side of the line, read a value of 1.77. We will call this value Z.

Step 5. Use the following formula to find TO.

$$Z = \frac{\mathrm{TI} - \mathrm{TS}}{\mathrm{TS} - \mathrm{TO}} \qquad 1.77 = \frac{40 - 25}{\mathrm{TO} - 25} \qquad \mathrm{TO} = 33.5°\mathrm{F} \tag{5.10}$$

The recommended minimum temperature of water flowing in a sewer pipe is 35°F, which allows a small safety factor. The calculated temperature of 33.5°F is therefore considered unsafe. Using Fig. 5.4, and a temperature of 35°F as a guide, the velocity can be raised to 3 ft/s, or perhaps the inlet temperature raised to about 43°F by adding water.

To prevent the freezing of water in a sewer line, the following methods have proven successful:

1. Providing insulation around the pipe to limit heat loss. The addition of insulation will not prevent the freezing of the water in time, but will considerably delay it from occurring.
2. Providing an enclosure around the pipe in such a manner that the enclosure does not touch the pipe walls. This will provide additional insulation to the system.
3. Heat tracing the pipe with electric cable, steam, or hot water.

4. Providing sufficient velocity to the liquid so that it will reach its terminus without freezing.
5. Adding warm water at the origin of the sewer, or at several places along the run (if possible), to counteract the heat loss of the water to the surrounding soil.

FROST CLOSURE OF VENTS

During cold weather, exposed vents on a roof may become wholly or partially blocked by frost on the inside portion of the exposed pipe. This is due to the fact that in cold weather, a current of warm, moist air rises through the plumbing piping when there is little or no flow through the system. This upward flow of air is caused by the temperature difference between the air outside the building and the air inside the pipe. Since the air inside the building is warmer than the free air, the inside air is lighter, causing the upward current. This is the so-called chimney effect. When this warm, moist air reaches the chilled surface of the exposed pipe, moisture condenses on the colder surface of the pipe in the form of droplets. If the correct conditions exist, these droplets will freeze. If this continues long enough, the pipe will become blocked.

There are actually two phenomena that can occur. The more common is the formation of ice in the form of an annular ring in the pipe interior. Another kind of blockage takes the form of a frost cap on top of the pipe. This problem of frost closure was the subject of a study at the National Bureau of Standards in 1922. The conclusions resulting from that study are still valid today.

The best method to prevent frost closure is to increase the size of the vent pipe just below the roof level, allowing the warm air to bypass the side of the exposed pipe as much as possible. It was shown that a 4-in (DN 100) pipe would not close up except under the most adverse conditions. One of these conditions was observed in the vicinity of Niagara Falls, New York, where the spray from the falls solidified on the pipes regardless of their size. The solution was to run either an electric heat trace line or circulate hot water around the perimeter of the pipe to keep it warm. For more unusual conditions, it was found that keeping the vent pipe as low to the roof as possible was acceptable. Blocking by snow at that low height never occurred, because the snow was porous enough to pass air and had a tendency to melt very quickly.

DEPTH OF FREEZE IN SOILS

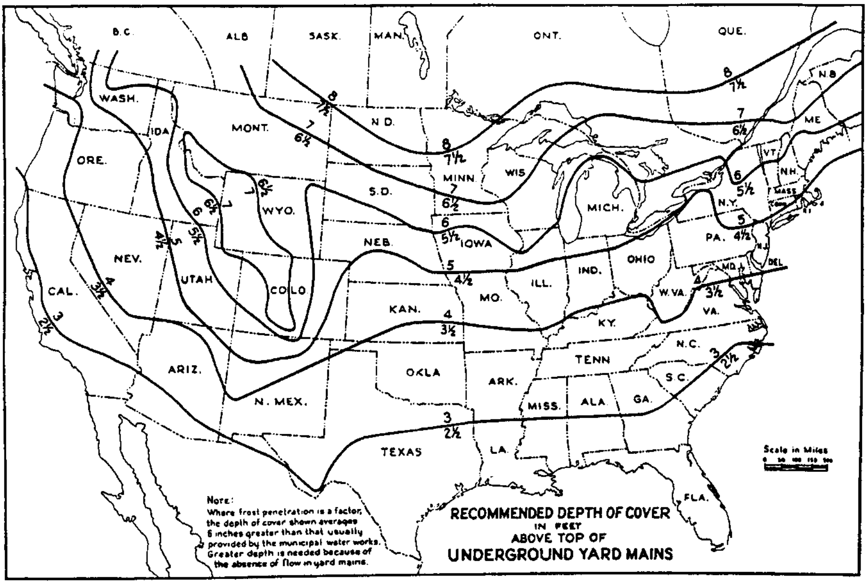
In order to prevent the freezing of water in underground piping systems, the pipes must be buried far enough below grade so that the soil used as backfill provides enough insulation from the air temperature to prevent the freezing process from starting. This depth is called the frost depth, which is the level to which the 32°F isotherm will penetrate.

There are various methods used to determine the frost depth in a particular area: the local authorities such as the building department or fire marshal for information and advice based on past experience; recommendations of fire insurance carriers; or the use of maps such as the one shown in Fig. 5.5.

The following discussions will show how to calculate the frost depth and how to obtain the required criteria in order to perform the calculations with an acceptable degree of accuracy.

DERIVATION OF THE BASIC FORMULA FOR FROST DEPTH

The U.S. Army Cold Region Research and Engineering Laboratory (CRREL) has developed a practical method for calculating the frost depth of soil. The method used to calculate frost penetration is based on heat transfer principles involving a phase change (from water to ice) of pore water, or water held in the voids of soil. The actual freezing process under these conditions is very complex and does not lend itself to a fixed mathematical solution. In order to reduce the complexities



RECOMMENDED DEPTH OF COVER IN FEET ABOVE TOP OF UNDERGROUND YARD MAINS

Note: Where frost penetration is a factor, the depth of cover shown averages 6 inches greater than that usually provided by the municipal water works. Greater depth is needed because of the absence of flow in yard mains.

FIGURE 5.5 Approximate frost depth in feet (*NFPA*).

involved for the exact determination of each value that follows, several assumptions have been made. These assumptions have the effect of simplifying the solution, but also introduce some slight error. All of the following derivations have been verified under actual field conditions and found to be well within the accuracy necessary for engineering design purposes. These assumptions are:

1. The soil is considered homogeneous throughout.
2. All pore water is converted to ice at 32°F.
3. Average thermal properties are applicable.

The depth to which the 32°F isobar will penetrate can be calculated by using the modified Berrigan equation, which is:

$$X = C\sqrt{\frac{48K \cdot NF}{L}} \tag{5.11}$$

where X = penetration of frost into soil, ft
C = coefficient, dimensionless (This is a function of the freezing index, the mean winter temperature at the site, and the thermal properties of the soil.)
N = conversion factor, air index to surface index
AF = air freezing index
SF = surface freezing index
K = thermal conductivity of the soil, Btu/ft^2/h/°F
F = air freezing index, degree days Fahrenheit/year
L = volumetric latent heat of fusion, Btu/ft^3

Each of the elements of the formula will now be discussed and defined.

1. *Coefficient C.* This is a general coefficient that considers the overall effect of the temperature change in the soil mass around a buried pipe. It is a function of the site freezing index, the mean annual site air temperature, and the thermal properties of the soil. To find this coefficient, two factors must be determined. They are the thermal ratio and the fusion parameter.

The thermal ratio TR is calculated from the following formula:

$$\text{TR} = \frac{\text{ST}}{\text{AD}} \tag{5.12}$$

where TR = thermal ratio
ST = mean annual site air temperature, °F, minus 32 (The mean annual site air temperature can be obtained from the NOAA publication "Comparative Climatic Data." It is available only in tabular form and much too large to be reproduced in this book.)
AD = average surface temperature differential [This is found by dividing the surface freezing index (SF) by the number of days in the freezing season.]

The surface freezing index is derived from the formula:

$$\text{SF} = N \times \text{AF} \tag{5.13}$$

The number of days in the freezing season, which is defined as the estimated number of days the temperature will fall to 32°F or below, can be found in Fig. 5.9.

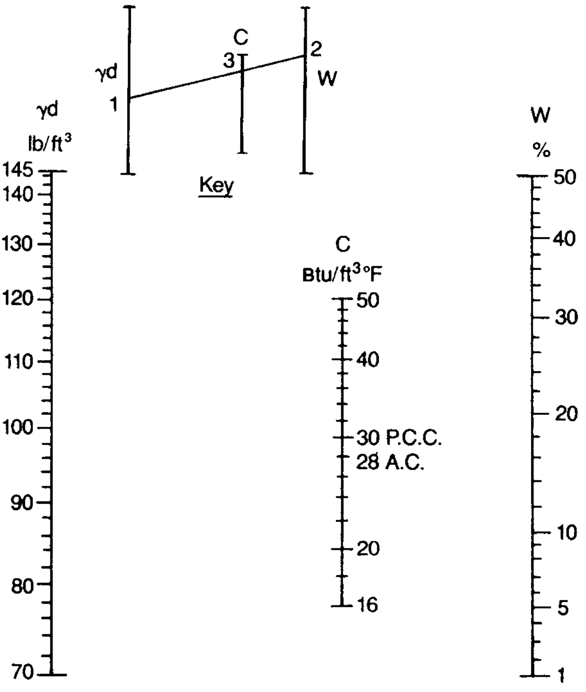
The fusion parameter FP is calculated from the following formula:

$$\text{FP} = \text{AD} \times \frac{\text{volumetric heat capacity}}{\text{latent heat of fusion in soil}} \tag{5.14}$$

AD is calculated from Eq. (5.13). Volumetric heat capacity is found in Fig. 5.6. The latent heat of fusion is found in Fig. 5.7. Table 6.8 gives the soil weight and average value for moisture content.

2. *Air ground conversion factor N.* This factor is necessary in order to approximate the temperature of the ground when only the air temperature is known. The combined effects of radiative, convective, and conductive heat exchange at the ground air junction have been considered in the determination of the actual value. Refer to Table 5.12 for values that have been established by experimentation under freezing conditions.

3. *Air freezing index AF.* The penetration of freezing temperatures into the soil is partially dependent upon the duration and magnitude of the temperature difference between the air and the ground. The lower the air temperature and the longer the freezing persists provide a cumulative increase in the penetration of frost. The



Note: Specific heat of soil solids assumed to be 0.17 Btu/lb.°F

FIGURE 5.6 Volumetric heat capacity for soils.

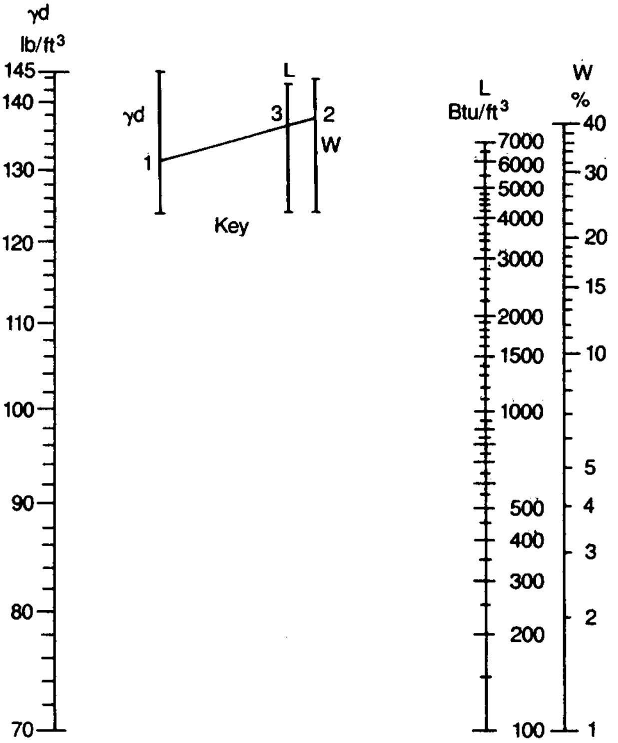


FIGURE 5.7 Latent heat of fusion for soils.

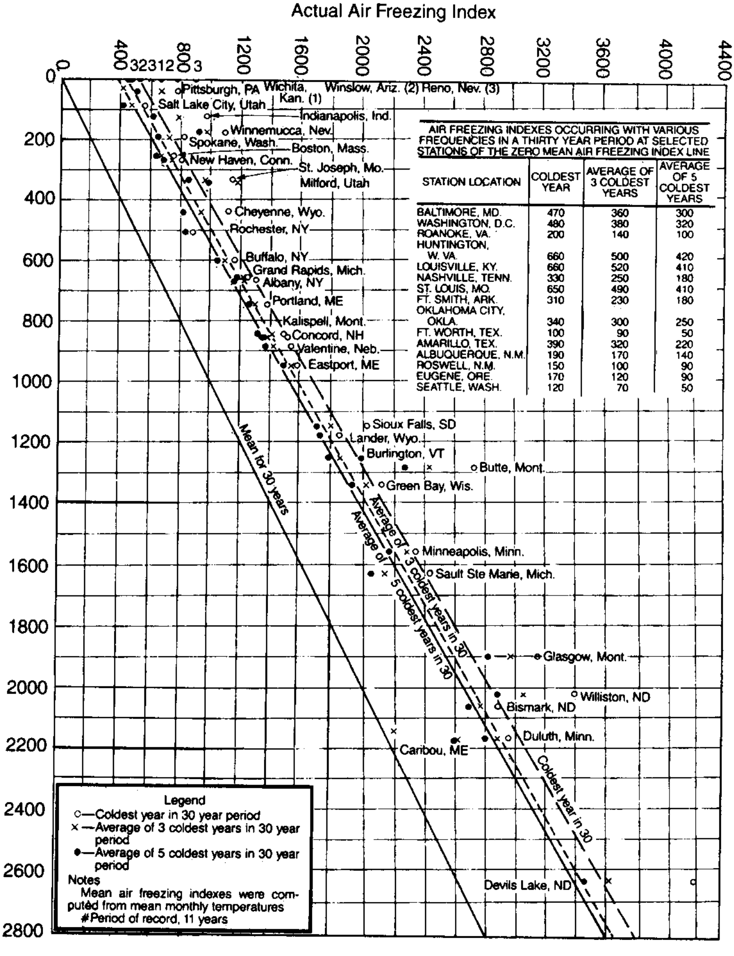
TABLE 5.12 Air–Ground Conversion Factor

Surface type	*N* Factor
Snow	1.0
Pavement free of snow and ice	0.9
Sand and gravel	0.9
Turf	0.5

method used to express the freezing temperature-duration measurement is in degree days Fahrenheit. In order to find the value, the high and low temperatures for any 24-h period are averaged. Then 32 is subtracted from that number to obtain the freezing index for that day. If it is found to be 10°F below freezing for one day, this amounts to 10 degree days. If the number calculated comes to 1°F below freezing, and if this continues for 10 days, the figure would also be 10 degree days. The freezing index should not be confused with the normal degree-day measurement used by HVAC engineers for heating calculations.

Four separate methods have been established to determine the freezing index, each based on the number of years that weather information has been available. The first uses the single coldest year in a 30-yr period. The second uses an average of the three coldest years in a 30-yr period. The third method calculates the average of the five coldest years in a 30-yr period. The fourth method, called the design freezing index, uses the single coldest year in a 10-yr period of time. The relationship between all three of these methods appears in Fig. 5.8. Isobaric maps of the North American continent show the mean freezing index, illustrated in Fig. 5.9, and the design freezing index, illustrated in Fig. 5.10. With all of this information available, what is the "correct" value? The best possible information is data obtained at the proposed site or the records of the nearest U.S. National Weather Service first order weather station. If obtaining this information is not practical, use Fig. 5.9 to find the mean index, then refer to Fig. 5.8 to obtain a value. Generally accepted practice is to use the coldest index possible.

4. *Thermal conductivity K.* Thermal conductivity is a measure of heat flow through a substance, given as Btu/ft of material per unit of time per degree tem-



AIR FREEZING INDEXES OCCURRING WITH VARIOUS FREQUENCIES IN A THIRTY YEAR PERIOD AT SELECTED STATIONS OF THE ZERO MEAN AIR FREEZING INDEX LINE

STATION LOCATION	COLDEST YEAR	AVERAGE OF 3 COLDEST YEARS	AVERAGE OF 5 COLDEST YEARS
BALTIMORE, MD.	470	360	300
WASHINGTON, D.C.	480	380	320
ROANOKE, VA.	200	140	100
HUNTINGTON, W. VA.	660	500	420
LOUISVILLE, KY.	660	520	410
NASHVILLE, TENN.	330	250	180
ST. LOUIS, MO.	650	490	410
FT. SMITH, ARK.	310	230	180
OKLAHOMA CITY, OKLA.	340	300	250
FT. WORTH, TEX.	100	90	50
AMARILLO, TEX.	390	320	220
ALBUQUERQUE, N.M.	190	170	140
ROSWELL, N.M.	150	100	90
EUGENE, ORE.	170	120	90
SEATTLE, WASH.	120	70	50

FIGURE 5.8 Relationship between mean and other freezing indexes.

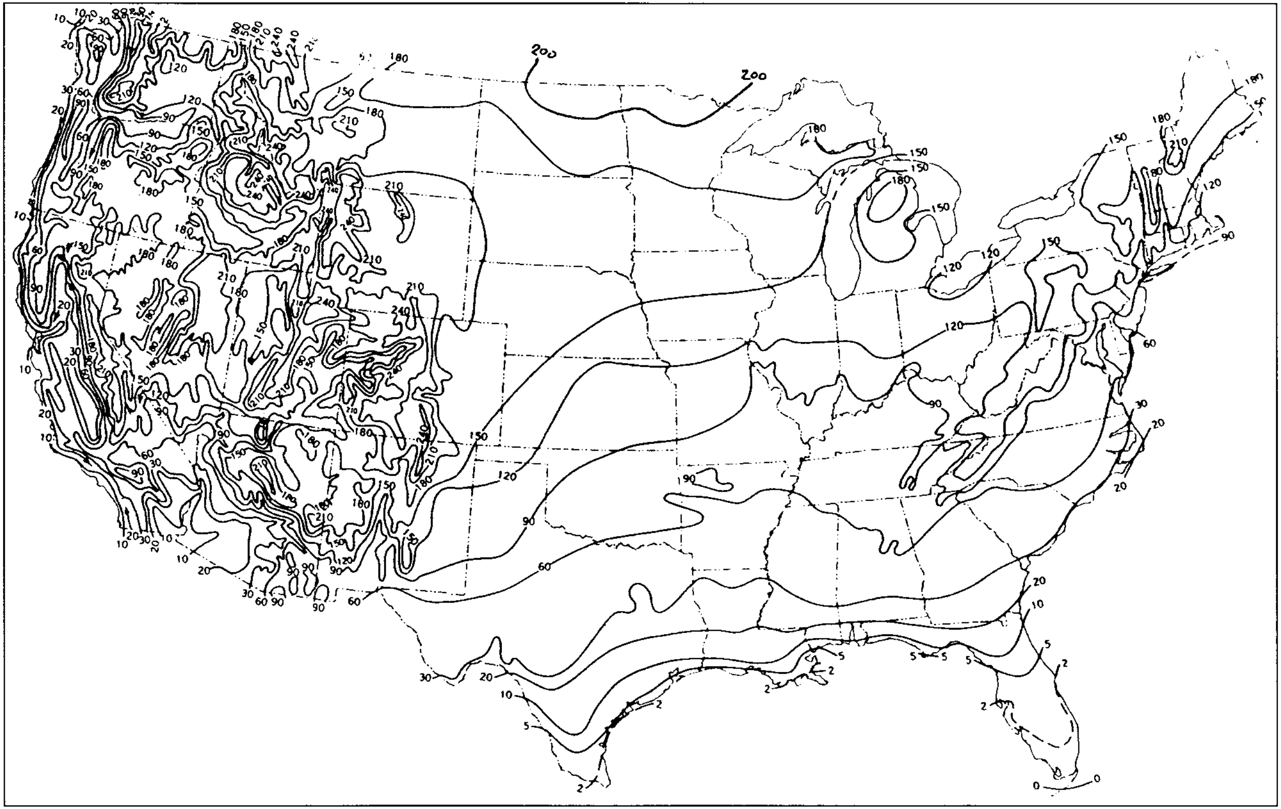


FIGURE 5.9 Mean freezing index. Mean annual number of days with minimum temperature 32°F and below.

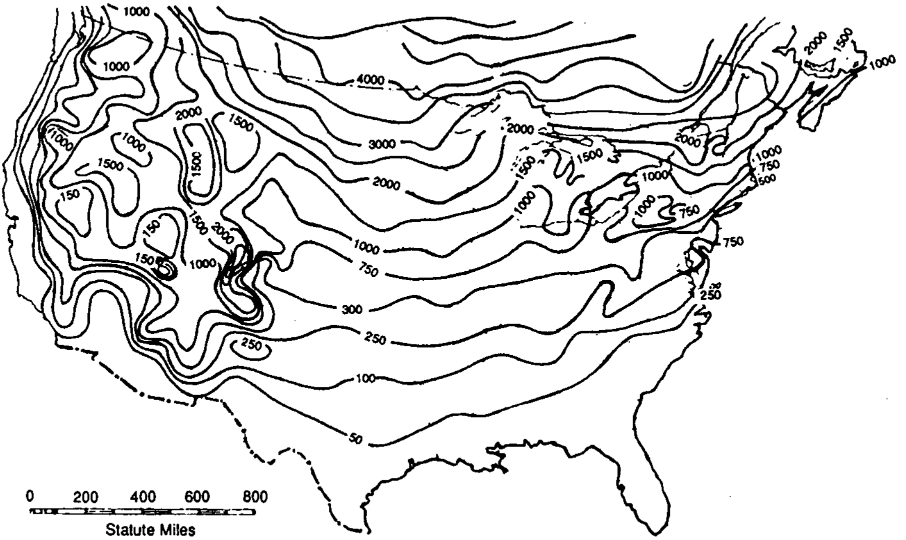


FIGURE 5.10 Design freezing index.

perature difference (in °F). The thermal conductivity of soil is dependent upon soil density, actual moisture content, temperature and state of pore water, and particle shape. Field tests have determined that the average values presented here are of sufficient accuracy for engineering design purposes. For this discussion only, soil groups are divided into three general categories, sand, silt with clay, and peat. Table 6.8 lists the soil weights used in the calculations following. Table 6.20 separates soils into unified soil groups and describes their composition. Average moisture content of these soils is about 15% for sand, 30% for clay, and 80% for peat. To find the value of *K*, use Fig. 5.11 for sand, Fig. 5.12 for clay, and Fig. 5.13 for loam, entering with the weight of the soil and the moisture content. If the project under design has building construction associated with it, the structural engineer will have the soil tested for bearing strength. Part of this test is the determination of moisture content. A copy of the engineer's report should provide the necessary information.

5. *Volumetric latent heat of fusion L.* This is a measure of the additional heat that must be absorbed by the surrounding medium in order for the pore water to change its phase state from water to ice. The more moisture a soil contains the higher the *L* value. To find *L*, multiply the latent heat of water (144) by the weight of the soil and by the moisture content of the soil. This calculation is presented in graphic form in Fig. 5.14, where *L* can be read directly.

To illustrate the use of the modified Berrigan formula, the following example will determine the frost depth for a project in Green Bay, Wisconsin, with the following conditions:

Mean annual temperature	43.7°F (from NOAA)
Length of freezing season	200 days (obtained from Fig. 5.10)

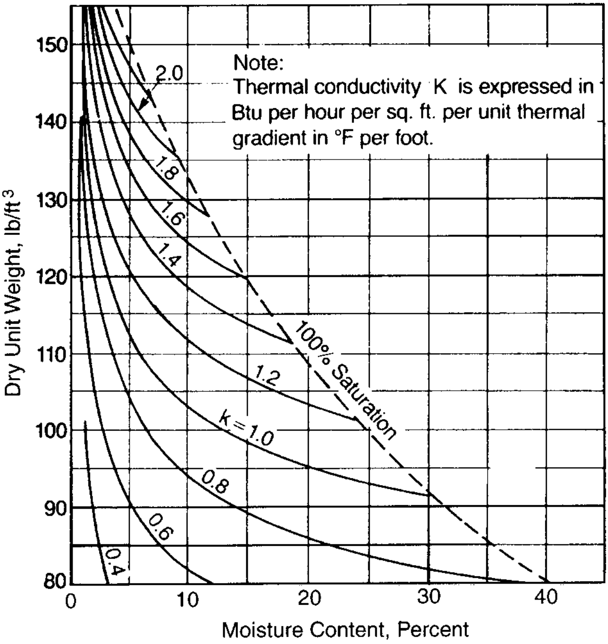


FIGURE 5.11 Average thermal conductivity for sandy soils.

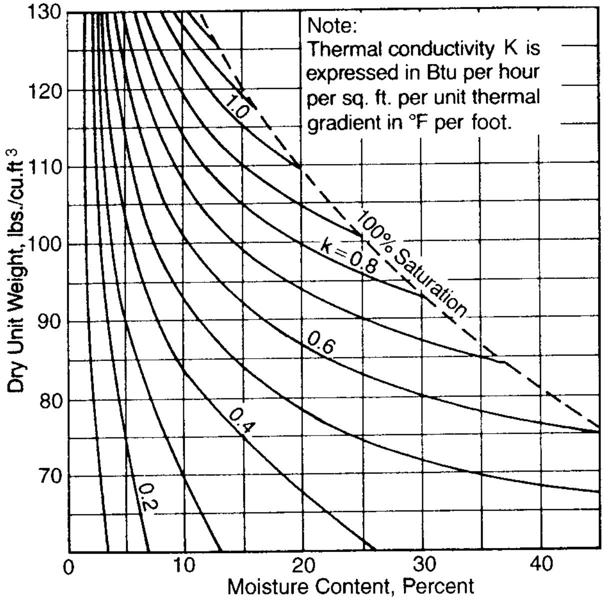


FIGURE 5.12 Average thermal conductivity for silt and clay soils.

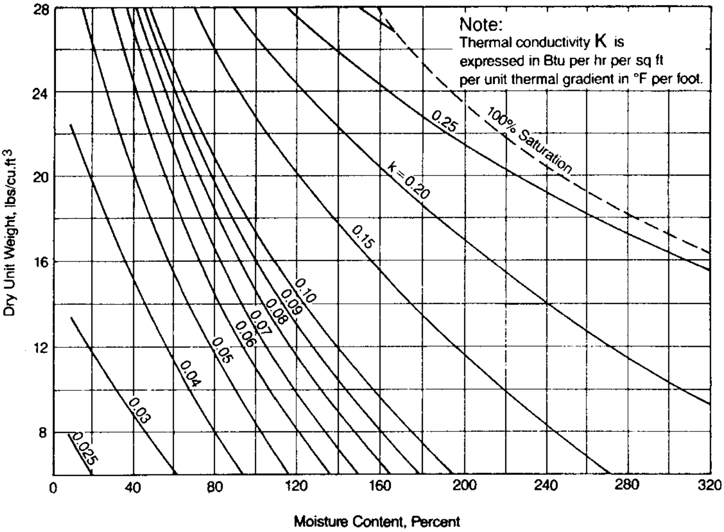


FIGURE 5.13 Average thermal conductivity for peat.

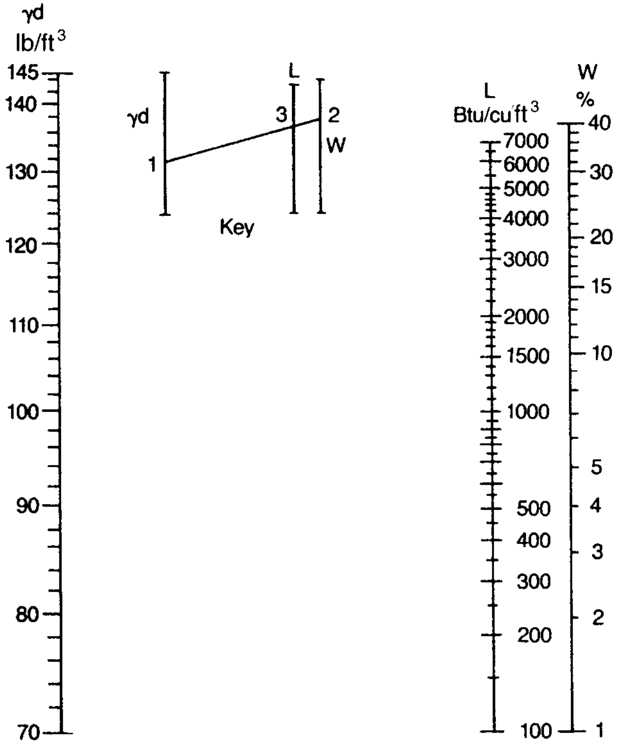


FIGURE 5.14 Volumetric latent heat of fusion.

Soil properties	Sandy soil, snow cover
Weight	100 lb/ft^3
Moisture content	15%
Latent heat of fusion	2160 Btu/ft^3 (obtained from Fig. 5.14)
Thermal conductivity	1.01 Btu/h/ft^2/°F (obtained from Fig. 5.13)
Surface freezing index	N 3 AF = 2150 degree days. (AF is obtained from Fig. 5.9, coldest reading; N is obtained from Table 5.12, snow cover; therefore, 2150 × 1.0 = 2150 surface freezing index.)

To obtain the coefficient C refer to Fig. 5.15. Enter with the fusion parameter and thermal ratio. To find the fusion parameter [FP in Eq. (5.14)], first calculate AD:

$$\mathrm{AD} = \frac{2150}{200} = 10.7$$

Therefore

$$\mathrm{FP} = 10.7 \times \frac{28.2}{2160} = 10.7 \times 0.013 = 0.14$$

To find the thermal ratio [TR in Eq. (5.12)] calculate the following:

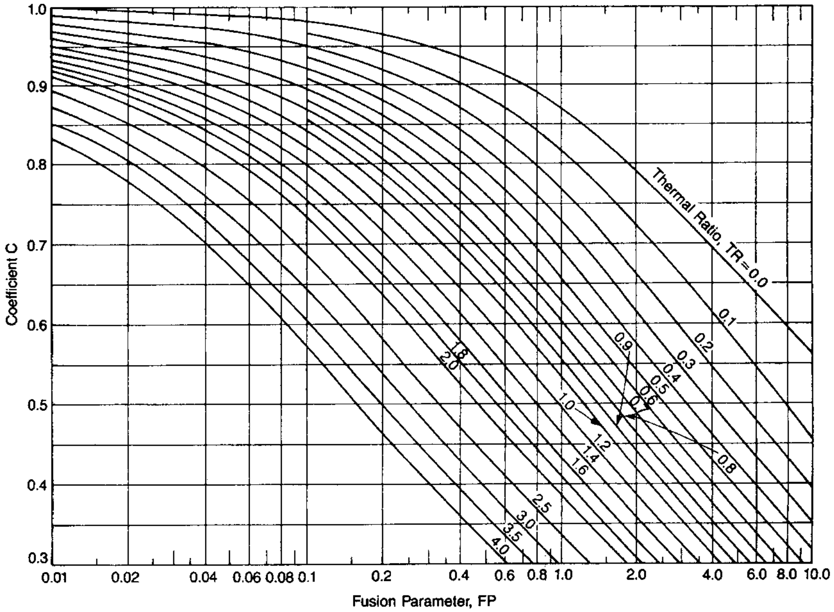


FIGURE 5.15 Coefficient in the modified Berrigan formula.

$$\mathrm{TR} = \frac{\mathrm{ST}}{\mathrm{AD}} = \frac{(43.7 - 32)}{10.7} = \frac{11.7}{10.7} = 1.09$$

It is now possible to enter Fig. 5.13 with 0.14 and 1.09. Read $C = 0.8$. This gives us all the information needed to solve the modified Berrigan formula, Eq. (5.11),

$$X = 0.8\sqrt{\frac{48 \times 1.01 \times 2150}{2160}} = 0.8\sqrt{\frac{104.232}{2160}}$$

$$= 0.8 \times \sqrt{48.25} = 0.8 \times 6.94 = 5.55 \text{ ft}$$

Estimated depth of frost penetration is 5.55 ft.

Several nomographs have been prepared based on the modified Berrigan formula that are easier to use than the original formula. The first is shown in Fig. 5.16, giving the frost depth for various conditions as a direct reading.

In some cases, a pipe may have been buried under a road and a nonsusceptible fill used. This means that the fill will not be affected by frost, and so the condition known as frost heave will not occur. Use Fig. 5.17 to find the depth of fill that will prevent frost penetration below the fill. For a direct reading of the actual frost penetration under pavements, refer to Figs. 5.18, 5.19, and 5.20. Use the combination of soil weight and moisture content applicable to the project under design.

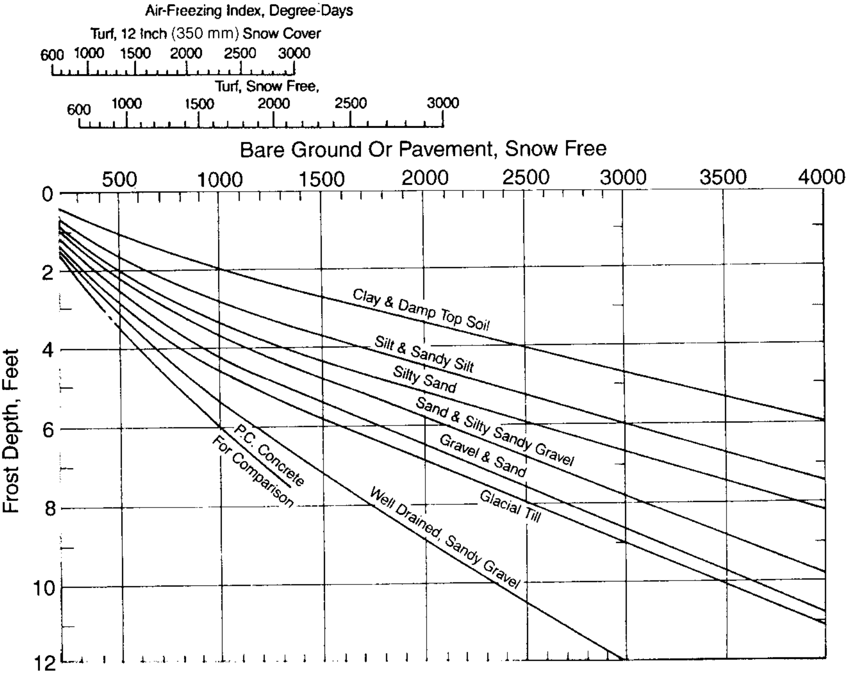
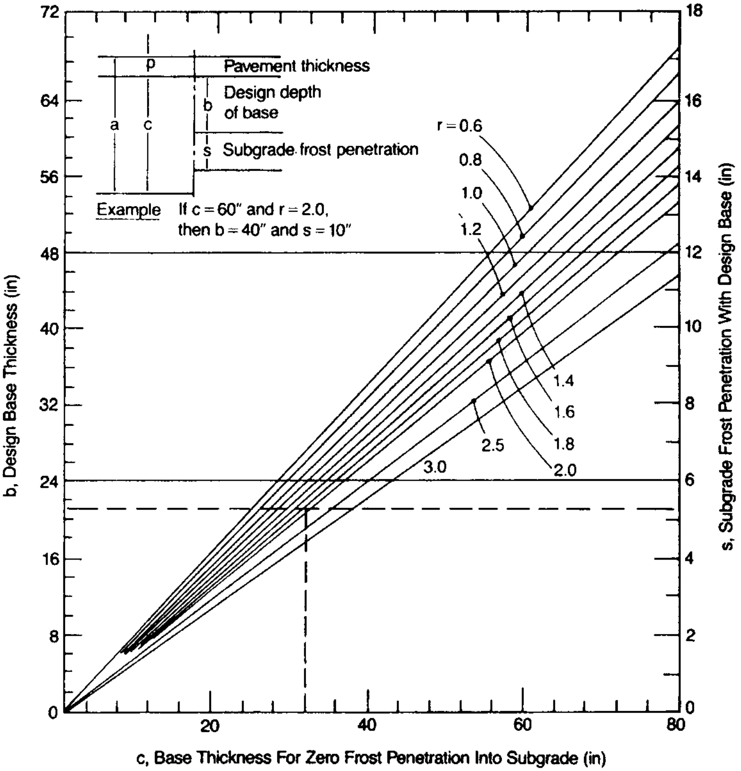


FIGURE 5.16 Nomograph to determine frost depth using modified Berrigan formula.



NOTES

a = Combined thickness of pavement and non-frost-susceptible base for zero frost penetration into subgrade.

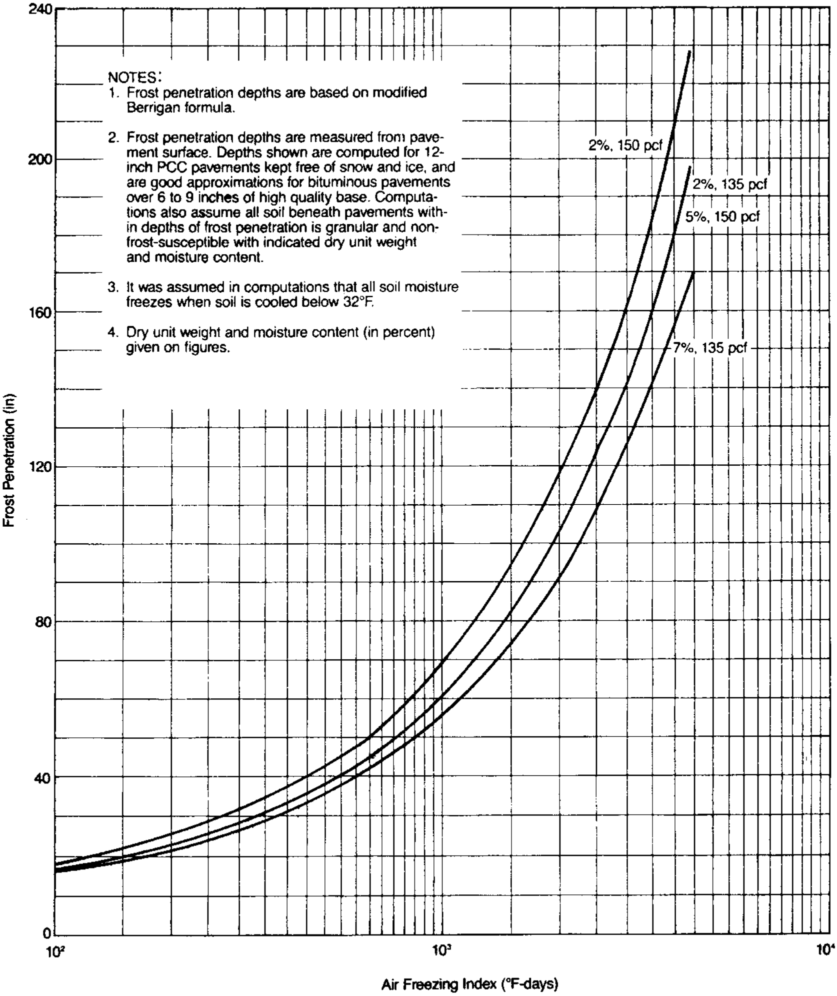
c = a − p

w_b = Water content of base.

w_s = Water content of subgrade.

$r = \frac{w_s}{w_b}$, Not to exceed 2.0 for type A and B areas on airfields and 3.0 for the other pavements.

FIGURE 5.17 Frost penetration in a nonsusceptible base.



NOTES:
1. Frost penetration depths are based on modified Berrigan formula.
2. Frost penetration depths are measured from pavement surface. Depths shown are computed for 12-inch PCC pavements kept free of snow and ice, and are good approximations for bituminous pavements over 6 to 9 inches of high quality base. Computations also assume all soil beneath pavements within depths of frost penetration is granular and non-frost-susceptible with indicated dry unit weight and moisture content.
3. It was assumed in computations that all soil moisture freezes when soil is cooled below 32°F.
4. Dry unit weight and moisture content (in percent) given on figures.

FIGURE 5.18 Frost penetration beneath pavement: 135 to 150 PCF base material.

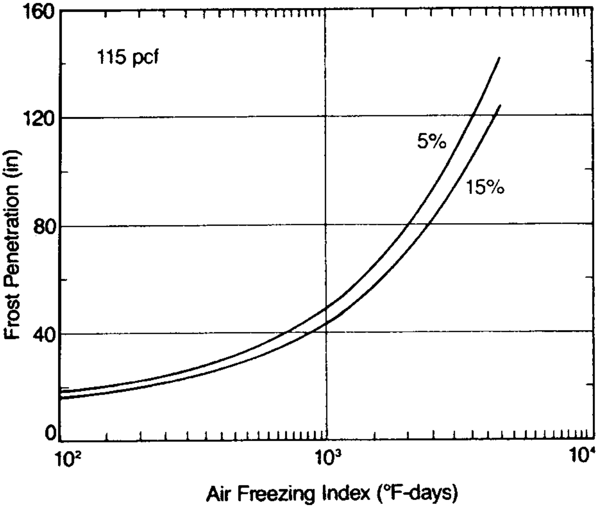


FIGURE 5.19 Frost penetration beneath pavement: 115 PCF base material.

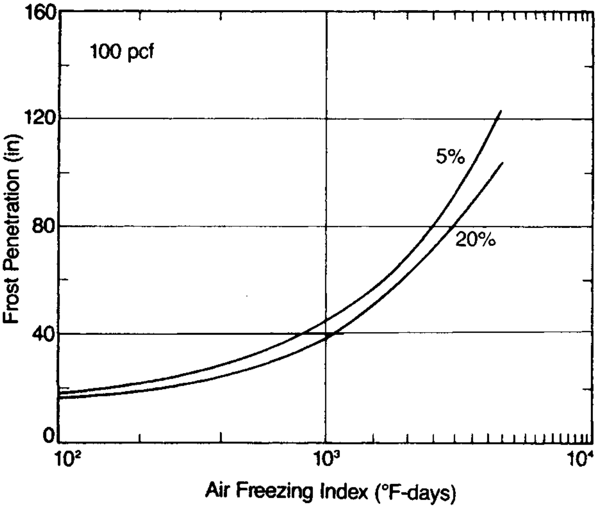


FIGURE 5.20 Frost penetration beneath pavement: 100 PCF base material.

HEAT TRACING

Heat tracing is the continuous or intermittent application of heat to a pipe or vessel in order to replace the heat lost to ambient air. Heat tracing is used for preventing freezing, for thawing, for maintaining the temperature of pipe contents, and for facilitating product transport in a pipe (for example, by increasing the viscosity of Number 6 fuel oil). Heat tracing used for domestic hot water temperature maintenance is discussed in Chap. 9, Plumbing Systems. This section will be concerned with freeze protection. Other aspects of this subject are outside the scope of this book.

There are two broad classes of heat tracing methods, electric and fluid. Electric heat tracing systems convert electric energy into heat. Fluid methods generally utilize water or steam at an elevated temperature to transfer heat from one pipe to another. Fluid heating media are usually contained in a small tube or pipe directly attached to the pipe being protected. Of the two fluids, steam is the more prevalent method of heat tracing.

Steam is more costly to install and maintain than electrical resistance. Periodic steam leaks and failed steam traps waste energy and require constant maintenance. In addition, a steam tracer produces 2 to 10 times more heat than is actually required for most applications. Choosing the most appropriate and cost-effective option for any specific application involves many factors. If both systems are available, Table 5.13 can be used as a checklist of the most important information needed to decide which option to choose. In general, if steam is not present in sufficient quantities to provide the necessary heat, it is almost always more practical and far less costly to use electric heat tracing.

ELECTRIC HEAT TRACING

General

This type of system consists of a heat-producing conductor (or cable), a controller to sense the temperature of the air or pipeline, and a relay to turn on the current. As the electricity flows through the cable, the resistance of the conductors causes the wire to become hot.

There are three general categories of heating cable. The first is mineral insulated, series circuit-resistant cable, which has a constant heat output for its full length. It has a metal sheath for cable protection. It is used when close temperature control is necessary, the liquid (or pipe) may reach a very high temperature, protection from physical abuse is required, the cable may be placed in a wet or moist environment, or close supervision of the system is needed. The second type is constant wattage, parallel circuit-constant resistant cable. It should be considered for use when long runs of cable are required, the length of cable is not known, or close monitoring is necessary. Care must be exercised so as not to exceed the temperature rating in use. The third type is the self-regulating, parallel circuit-variable resistant cable. It could be used when the liquid has a wide temperature range, the length of cable is unknown, or liquid temperatures will not exceed 185°F. All three of these cables are suitable for freeze protection.

In order to design and specify an efficient and cost-effective system, the following information should be obtained or calculated:

TABLE 5.13 Checklist for Steam and Electric Heat Tracing

	Electric	Steam
Preexisting project constraints		
Heat tracing recommended in company engineering practices (Yes/No)		
Other		
Project design phase criteria		
Total feet of traced pipe		
Cost of electricity, $/kWh, and steam energy ($/1000 lb)		
Estimated annual maintenance cost per foot of tracing, $/ft		
Number of heat-tracing circuits required		
Needed accuracy of temperature control, degrees		
Temperature control cost per circuit for needed accuracy, $		
Cost of monitoring one circuit in distributed control system, $		
Design time per circuit, h		
Design tools available for engineers (Good, Fair, Poor, None)		
Capital cost of steam capacity, condensate return, etc., $		
Capital cost for required electrical power, $		
Other		
Project installation criteria		
Labor cost to install tracing and accessories, $/ft		
Training time per plant laborer, h		
Labor and overhead costs, $/h		
Total installed heat-tracing costs, $/ft		
Other		
Project operation criteria		
Annual maintenance required, h/ft		
Annual cost for replacement parts, $/ft		
Annual energy cost, $/ft		
Total annual maintenance cost, $		
Total annual operating cost, $		
Other		

1. Minimum temperature of the fluid to be maintained
2. Ambient temperature of the area where installed
3. Wind velocity of the area where installed, if outdoors
4. Pipe or vessel size and material
5. Tolerance of components allowed
6. Type and thickness of insulation over heating cable
7. Whether monitoring of operation will be required
8. Whether an alarm or enunciating of alarms will be required in the area in which the cable is installed
9. Area where the cable is to be installed
10. Type of temperature control, if any
11. Whether a dedicated or emergency power supply will be needed

These factors are discussed in detail in the following paragraphs:

1. The minimum temperature to which water should be allowed to fall is 40°F. This is a safe temperature, which provides a safety factor to allow for variables over which there is no control, such as new record low temperatures, higher than expected wind velocities, uneven heat distribution of the cable selected, and the types of control devices used.

2. The ambient temperature in the area where the heating cable is to be installed can be obtained from Fig. 5.3. This is the mean low temperature, not the absolute low.

3. A wind velocity of 20 mph (9 mls) (12 km/hr) has been selected as an average value. For indoor installations, the requirements for heating can be reduced by 10 percent. Conversely, if a velocity of 40 mph is used, the value should be increased by 10 percent.

4. Pipe or vessel size speaks for itself. The material of the container affects the transmission of heat from the cable to the liquid. The charts provided here are based on metal. When plastics are used, the heat produced must be increased by 30 percent. This value is acceptable for pipes up to 6 in and most plastic tanks. Be careful to check the surface temperature of the cable and make sure the plastic material is capable of withstanding that temperature without harm.

5. Tolerance of various control elements, such as sensing devices (used to detect the temperature of liquids) and control thermostats, is important if the liquid temperature must be closely maintained.

6. The type and thickness of the insulation is an important factor in the heat loss from the pipe and cable. The charts provided are based on fiberglass. If another type of insulation is used, refer to Table 5.6 for the insulation factor.

7. Special monitoring of the operation of the heating cable system will affect the selection of the heating cable type. If close control is required, the use of an ammeter and an adjustable current sensing monitor (set to between 3 and 20 percent of base current) will be required. If a self-regulating system is used, there will be no base current since the system current varies. Therefore, the only kind of monitoring that could be used would be the continuity type, which detects a break in the conductor.

8. If an alarm is desired, the type (for example, a bell, a light, or both) and the location must be chosen.

9. The area in which the cable will be installed will affect the choice of cable. The conditions of the area, such as whether the cable will be immersed or merely become wet, whether there is very high humidity or not, whether the location is hazardous or subject to explosions are very important when specifying the system.

10. The type of temperature control desired will affect the specific device used to turn the system on. There are two possible modes of sensing: the air temperature or the surface temperature of the pipe. Although there may be some special case in which the air temperature is most important, sensing the actual temperature of the liquid in the pipe is usually much more significant. There are two types of sensors, capillary-bulb and electronic. Both of these types can be used for either application, but the electronic device is selected mostly for surface measurement. The bulb has a tolerance of 2 percent full scale. The electronic type is very accurate, on the order of hundredths of a degree.

Sensing bulbs generally have a tolerance of about 4°F, and a repeatability error of about 1°F. The longer the distance from the bulb to the actual controller, the greater the possibility of error. Therefore, it is not good practice to use these types of sensors if the distance is longer than 10 ft.

The electronic, or solid-state, sensor is extremely accurate, far beyond the normal requirements of a freeze protection system, but has the advantage of maintaining the programmed accuracy for a distance of longer than a mile, if necessary.

11. Very often, the line being heat traced is a critical one and must be assured of continuous operation. The options available are an emergency power supply or two separate supplies each connected to a different circuit.

System Design Procedure

The following example will describe the design procedure for an electric heat tracing system to provide freeze protection for an exterior potable water pipe. The installation will be in the city of Chicago. The pipe will be installed on an exposed roof, run for 100 ft, be 3 in in size, be made of copper, and have 1-in mineral fiber insulation. There is one valve and 10 supports.

1. Determine the true heat loss from the pipe and insulation. Referring to Fig. 5.3, the low temperature on the map is -15°F (-5°C). The water temperature is to be maintained at 40°F. This is a difference, or ΔT, of 55°F (-26°C). Referring to Table 5.3, using the insulation type and thickness, pipe size, and temperature difference of 50°F (30°C) (closest to 55), read 4.4 watts per foot (W/ft) of pipe. Because of the additional 5°, add another 0.6 W to make the value 5.0 W/ft. Since cellular glass is being used and not fiberglass (which the chart is based on), refer to the insulation correction factor in Table 5.3. For mineral fiber, read 1.20. Therefore, to find the true heat loss, multiply 5.0 × 1.20 to calculate the true loss of heat from the pipe and insulation together of 6.0 W/ft of pipe. This is the minimum amount of heat the cable must be capable of producing.
2. Select the cable type. With the true heat loss calculated, the type of environment where it will be installed, and the maximum temperature that the cable might attain, consult a manufacturer's catalog and select a cable type.
3. If the proposed cable is not capable of providing the necessary heat, for example, the cable selected is capable of producing only 4.0 Btu/ft, there are three options available:

A. Select a thicker or different insulation.

B. Install two cables to give the required heat.

C. Spiral the heating cable around the pipe.

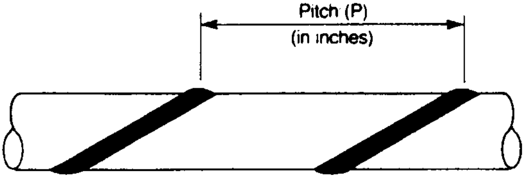
The spiral option will be selected. To design for the spiral condition, the following steps are required:

(1) Determine the required length of cable, since some cables have a maximum permitted length.

(2) Starting with a run of 100 ft, add the additional cable required because of spiraling, valves, and supports. To find the spiraling factor, divide the required heat by the available cable heat, 6 ÷ 4 = 1.5. Thus, for a cable capable of 4 W/ft if installed straight to now give 6 W/ft, more than 1 ft of cable must be placed on 1 ft of pipe. This is done by spiraling the cable around the outside of the pipe. The figure just calculated (1.5) is the actual number of feet of cable per foot of pipe that will give the required amount of heat. Therefore, we must add 50 feet for spiraling.

(3) For installation purposes, use Table 5.14 to find the spiral pitch factor, which is the actual installed distance between cable spirals. Enter with the calcu-

TABLE 5.14 Spiral Pitch Factors P



DN	Nominal pipe, in	Feet of pipe tracing per foot of pipe						
		1.1	1.2	1.3	1.4	1.5	1.6	1.7
13	0.50	5.8	4.0	3.2	2.7	2.4	2.1	1.9
20	0.75	7.2	5.0	4.0	3.4	3.0	2.6	2.4
25	1.00	9.0	6.2	5.0	4.2	3.7	3.3	3.0
32	1.25	11.4	7.9	6.3	5.3	4.7	4.2	3.8
40	1.50	13.0	9.0	7.2	6.1	5.3	4.8	4.3
50	2.00	16.3	11.2	9.0	7.6	6.7	6.0	5.4
65	2.50	19.7	13.6	10.9	9.2	8.1	7.2	6.6
75	3.00	24.0	16.6	13.2	11.2	9.8	8.8	8.0
90	3.50	27.4	18.9	15.1	12.8	11.2	10.1	9.1
100	4.00	30.8	21.3	17.0	14.4	12.6	11.3	10.3
125	5.00	38.1	26.3	21.0	17.8	15.6	14.0	12.7
150	6.00	45.4	31.4	25.1	21.2	18.6	16.7	15.1
200	8.00	59.1	40.8	32.6	27.7	24.2	21.7	19.7
250	10.00	73.7	50.9	40.7	34.5	30.2	27.0	24.6
300	12.00	87.4	60.4	48.2	40.9	35.8	32.1	29.1

lated spiraling factor (1.5) and the pipe size (3 in), read 9.8 at the intersection. That is the separation, in inches, that the cable should use when wound around the pipe.

4. If spiraling is not necessary, refer to Table 5.15 for the additional valve losses, in Btu. Multiply the factor found by the Btu heat loss from the pipe.
5. To find the additional length of cable needed for valves, fittings, and supports, refer to Table 5.16. Entering with the pipe size, find 3 ft for the valve and three times the diameter of the pipe for each support. Ten supports multiplied by 9 in equals 90 in, or about 8 ft. Adding all of the above together:

Basic run of pipe	100 ft (33 m)
Spiraling	50 ft (17 m)
Valve	3 ft (1 m)
Supports	8 ft (2.0 m)
Total	161 ft (53 m) of cable required

Heat Tracing for Indoor Tanks

The information presented previously applies to tanks as well as piping. The pitch most commonly used for winding the cable around a tank is two revolutions per foot length of the tank. The design procedure is as follows:

1. Find the area of the tank in square feet. For a square or rectangular tank, multiply the length, width, and height dimensions of the tank. For a round tank, refer to Table 5.17.
2. Determine the difference in temperature between the tank wall and the ambient air (ΔT).
3. Select the thickness and type of insulation.
4. Refer to Fig. 5.21 to find the heat loss in watts per square foot from the tank. If the insulation is other than fiberglass, use the correction factor in Table 5.6 to find the actual heat loss. If two lengths of cable are used for each square foot of the tank area, remember to divide the heat requirements in half to determine the watts per foot of the cable itself.
5. Calculate the amount of heat necessary to replace that lost and select an electric cable capable of providing that amount.

TABLE 5.15 Valve Heat Loss Factor

Valve type	Heat loss factor
Gate	4.3
Butterfly	2.3
Ball	2.6
Globe	3.9

Courtesy: Raychem.

TABLE 5.16 Cable Footage Allowance for Valves and Fittings

	Nominal pipe size, in								
	0.5	0.75	1.0	1.5	2.0	2.5	3.0	4.0	6.0
Screwed or welded	0.5	0.75	1.0	1.5	2.0	2.5	3.0	4.0	7.0
Flanged valves*	1.0	1.5	2.0	2.5	2.5	3.0	3.5	5.0	8.0
Butterfly	0	0	1.0	1.5	2.0	2.5	2.5	3.0	3.5
Flanges	Use two times the nominal pipe diameter								
Pipe supports	Use three times the nominal pipe diameter								

*Valves include: gate/globe wedge plug.

Note: If cables are spiraled on pipe, use the amount of cable shown times the spiral factor. Example: 2-in gate valve—(screwed)—2.0 ft. Spiral factor 1.1 ft/ft of pipe 2 × 1.1 = 2.2 ft.

Courtesy: Smith Gates Corp.

Safety Factors

Various safety factors have been included as part of the design criteria. The water maintenance temperature of 40°F is used, which gives a safety factor of 8°F. Table 5.17 has a built-in safety factor of 10 percent. Additional safety factors are not necessary or economical.

STEAM TRACING

For several reasons, steam is the most practical and economical method to provide heat to piping systems. Being a gaseous vapor, steam is easy to distribute—it requires no pumping, and because it is under pressure, it can be piped to remote locations in lines of relatively small diameter.

A steam tracing system consists of a pipe of small diameter (carrying the steam) attached to the outside of the pipe being protected, a connection to an adequate steam supply, a pressure-reducing valve assembly from the steam supply if required, a control valve or device to turn the steam on and off or modulate the amount of steam at predetermined set points, and a steam condensate return and disposal system (if desired). A simplified detail of a typical steam tracing system is illustrated in Fig. 5.22.

Another type of steam heating for a pipeline is a steam jacket, in which the steam for heating is introduced into the space between the pipe to be protected and an outer jacket placed around the pipe for this specific purpose. This is a very costly method, used generally for precise product temperature maintenance, and is outside the scope of this book.

General

It is generally accepted practice to install tracing lines on horizontal runs symmetrically at the bottom of the pipe being protected. Typical placement of tracer pipes

	Nominal pipe size, in								
	8.0	10.0	12.0	14.0	16.0	18.0	20.0	24.0	30.0
Dn	200	250	300	350	400	450	500	600	750
Screwed or welded	9.5	12.5	15.0	18.0	21.5	25.6	28.6	34.0	40.0
Flanged valves*	11.0	14.0	16.5	19.5	23.0	27.0	30.0	36.0	42.0
Butterfly	4.0	4.0	5.0	5.5	6.0	6.5	7.0	8.0	10.0

is illustrated in Fig. 5.23. The tracer should be placed at the center, but if this is not practical because of supports, it should be installed as close as possible to the center line of the pipe. Some engineers, however, consider it satisfactory to install multiple tracer pipes equally around the circumference of the pipe. Vertical pipe should have the tracer line(s) placed as illustrated in Fig. 5.24. It is recommended that a condensate trap be provided at the base of the vertical riser. Table 5.18 gives the recommended number of tracer lines and their size that should be used to protect various size pipes.

Another method of tracing a pipe is spiral tracing, where the tracer is wound around the pipe. This is used when a single tracer is desired but cannot supply enough heat if run straight.

Steam Tracing Pipe Size and Materials

The most popular size for tracer pipe is ½ in (DN 15). Smaller ⅜-in (DN 6) pipe is more easily plugged by sediment or debris in the system and is generally not recommended. However, since the amount of heat available from ½-in (DN 15) pipe is generally much more than required, and if the steam is clean, ⅜-in (DN 6) pipe should be considered. Larger sizes are more costly and generally not necessary unless a very large amount of heat is required for a specific purpose. The main advantage of using a single size pipe is that a facility can stock pipes, fittings, and valves in one standard size.

The most common materials used for tracing service lines are copper, stainless steel, and carbon steel. Copper tube is the most popular because of its heat transfer characteristics. Copper type L, ASTM B-88, is used often for piping and ASTM B-75 for tubing. Stainless steel tubing should be selected if there is the possibility of a corrosive environment. Carbon steel, ASTM A-53, schedule 40, is often a client preference based on existing standard pipe specifications, but is not generally recommended for tracer lines because of its tendency to corrode easily and produce rust that flakes off inside the tracer pipe and produces stoppages. In addition, the carbon steel pipe is subject to corrosion, which will cause the pipe to fail much more quickly than copper or stainless steel. Carbon steel is frequently used for steam and condensate headers.

Fittings for copper and stainless steel are usually the compression type, similar to Swagelok. Screwed or welded joints are used to install steel piping. Bends in copper pipe are made with a tube bender, rather than fittings, with care taken not

TABLE 5.17 Square Foot Surface Area of Round Tanks

	Two end areas, ft^2													
	6.3	9.8	14.1	19.2	25.1	31.8	39.3	47.5	56.5	66.3	77.0	88	101	113
Tank height, H, ft	Tank diameter, D, ft													
	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5
0.5	3.1	3.9	4.7	5.5	6.3	7.1	7.8	8.5	9.4	10	10.9	12	12.6	13
1	6.3	7.8	9.4	11	12.6	14.1	15.7	17	18.8	20	22	24	25.1	27
2	12.6	15.7	18.8	27	25.1	28	32	35	37.7	41	44	47	50.2	53
3	18.9	23.5	28.3	33	37.7	42	47	52	56.5	61	66	71	75.4	80
4	25.1	31.4	37.7	44	50.2	57	63	69	75.4	82	88	94	101	107
5	31.4	39.3	47.1	55	62.8	71	79	86	94.2	102	110	118	126	133
6	37.7	47.1	56.5	66	75.7	85	95	104	113	123	132	141	151	160
7	44.0	54.9	66.9	77	87.9	99	110	121	132	143	154	165	176	187
8	50.2	62.8	75.4	88	101	113	126	138	151	163	176	188	201	213
9	56.5	70.6	84.8	99	113	127	142	155	170	184	198	212	226	240
10	62.8	78.5	94.2	110	126	141	158	173	188	204	220	236	251	267
12	75.4	94.2	113	132	151	170	189	207	226	245	264	283	301	320
14	87.9	110	132	154	176	198	221	242	264	286	308	330	352	374
16	101	126	151	176	201	226	252	276	301	327	352	377	402	427
18	113	141	170	198	226	254	284	311	339	367	396	424	452	480
20	126	157	188	220	251	283	315	354	377	408	440	471	502	534
30	188	236	287	330	377	424	473	518	565	612	659	707	754	800
40	251	314	377	440	502	565	630	691	754	816	879	942	1005	1068
50	314	393	471	550	628	707	788	864	942	1021	1099	1178	1256	1335

	Two end areas, ft^2													
	126	142	157	226	308	402	509	628	981	1413	1923	2512	3179	3925
Tank height, H, ft	Tank diameter, D, ft													
	9	9.5	10	12	14	16	18	20	25	30	35	40	45	50
0.5	14	15	15.7	18.8	21.9	25.1	28.3	31.4	39.3	47.1	55	62.8	70.6	78.5
1	28	30	31.4	37.7	43.9	50.2	56.5	62.8	78.5	94.2	110	126	141	157
2	57	60	62.8	75.5	87.9	101	113	126	157	188	220	251	283	314
3	85	90	94.2	113	132	151	170	188	236	283	330	377	424	471
4	114	119	126	151	176	201	226	251	314	377	440	502	565	628
5	141	149	157	188	220	251	283	314	393	471	550	628	707	785
6	170	179	188	226	264	301	339	377	471	565	659	753	848	942
7	198	209	220	264	308	352	396	440	550	659	769	879	989	1099
8	226	239	251	301	352	402	452	502	628	754	879	1005	1130	1256
9	254	268	283	339	396	452	509	565	707	848	989	1130	1272	1413
10	283	298	314	377	440	502	565	628	785	942	1099	1256	1413	1570
12	339	358	377	452	515	603	678	754	942	1130	1319	1507	1697	1884
14	396	418	440	528	615	703	791	879	1099	1319	1539	1758	1978	2198
16	452	477	502	603	703	804	904	1005	1256	1507	1758	2010	2261	2512
18	509	537	565	678	791	904	1017	1130	1413	1696	1978	2261	2543	2826
20	565	597	628	754	879	1005	1130	1256	1570	1884	2198	2512	2826	3140
30	848	895	942	1130	1319	1507	1695	1884	2355	2826	3297	3768	4239	4710
40	1130	1193	1256	1507	1758	2010	2260	2512	3140	3768	4396	5024	5652	6280
50	1413	1492	1570	1884	2198	2512	2825	3140	3925	4710	5495	6280	7065	7850

Source: *Power Trace.*

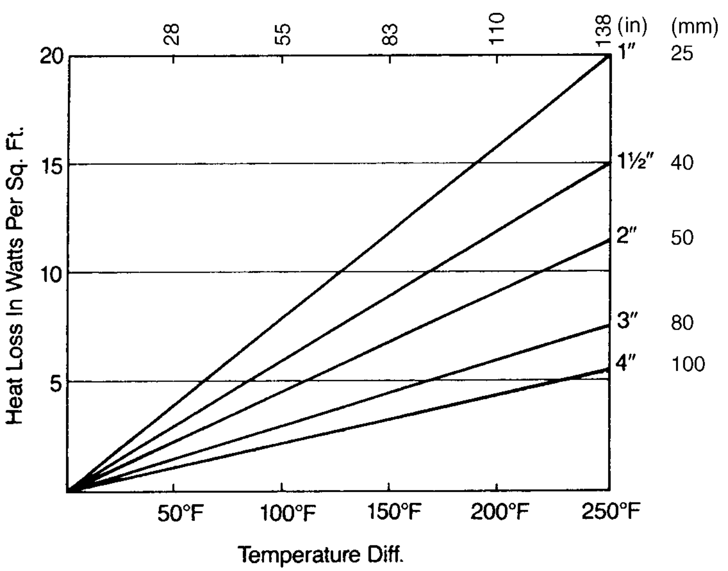


FIGURE 5.21 Heat loss through insulated vessel walls.

to crimp the tracer pipe. Unions are commonly provided in tracer lines at flanges and other connections. The purpose of the joints at these points is to allow replacement of the pipe in the future and to allow for expansion. Often, a union is installed to allow for changes, testing, and blowout, eliminating the need to make up another fitting whenever these actions are required.

Valves include gate valves, IBBM for main supplies, and bronze for tracer lines, with screwed or flanged ends.

The tracer pipe is commonly attached to the main line with thin galvanized or stainless steel bands about ½ in (15 mm) wide, between 18 to 20 gauge. The spacing between bands depends on the size main line, with ⅜-in (DN 12) tracers secured 12 to 18 in apart, ½-in (15 mm) tracers secured 18 to 24 in apart and ¾-in tracers secured 24 to 36 in apart. Fittings should have three bands to assure close contact between the tracer and the pipe. Where it is not desirable to use bands, such as at valve bodies, soft annealed 18-gauge stainless steel wire is an acceptable alternative.

Application of Insulation

Insulation must cover both the pipe being protected and the tracer line. It is important that the air space is kept clear. This can be achieved in several ways.

The first method is to wrap both the pipe and tracer with aluminum foil or a thin galvanized steel sheet attached by wire. The insulation is applied over this wrapping. Small mesh galvanized netting can also be used instead of the foil. The second method is to use insulation one or two sizes larger than the pipe being protected. This method is the least costly but the insulation can be easily crushed. The third method is to use special preformed insulation designed to cover both the pipe and tracer.

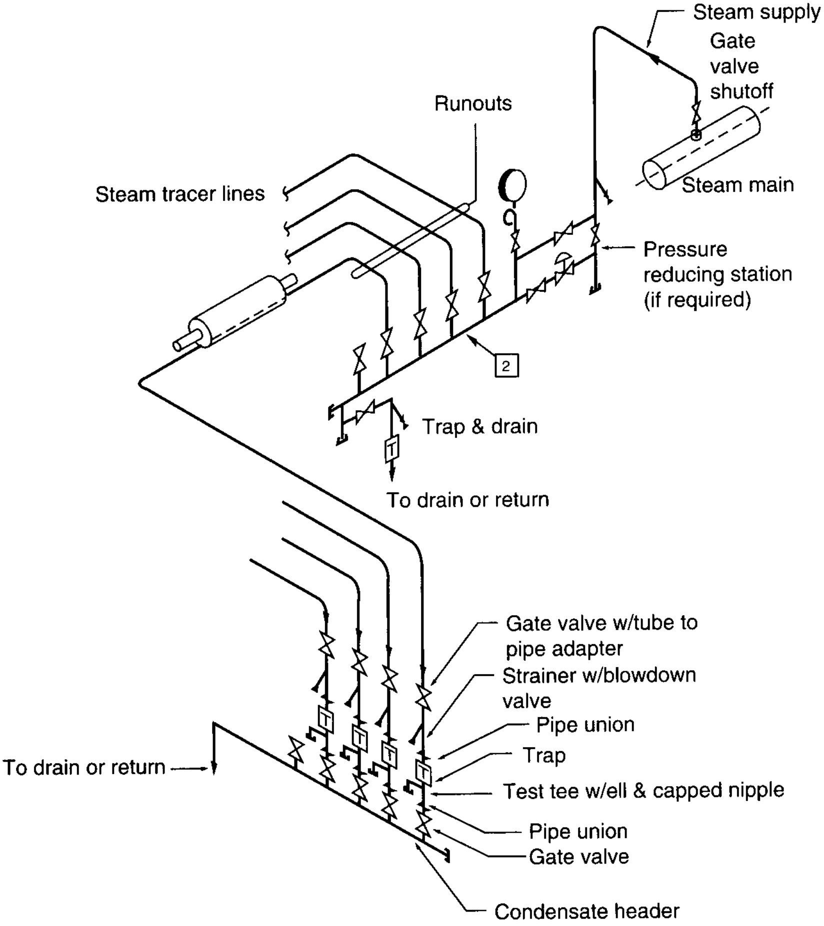


FIGURE 5.22 Simplified detail of a typical steam heat tracing system.

The insulation must be covered or finished in a manner that will protect it from mechanical damage and the elements, if installed outdoors.

Steam Pressure

The choice of steam pressure used for tracing must be consistent with the temperature to be maintained in the pipe to be protected. Low pressure steam of less than 100 psi (680 kPa) is used unless the temperature must be kept very high. Normally, saturated steam is used for tracing. Table 5.19 gives the temperature of saturated steam as a function of steam pressure. If the only steam pressure available is higher than that needed for tracing, a steam pressure-reducing station should be provided. In general, most steam tracing systems use a pressure of 50 psi (340 kPa) or less.

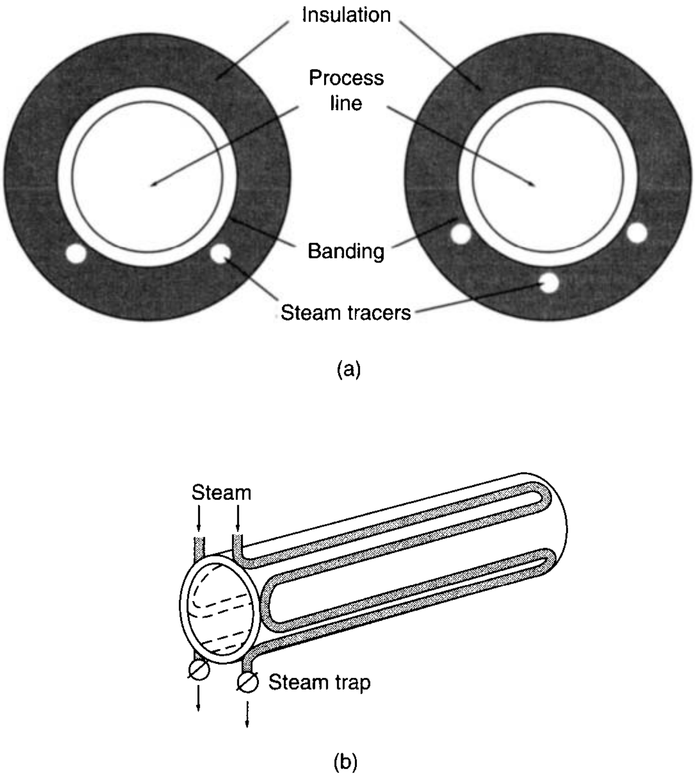


FIGURE 5.23 Typical installation of steam tracing lines for horizontal piping. (*a*) Single and multiple tracing; (*b*) multiple tracing.

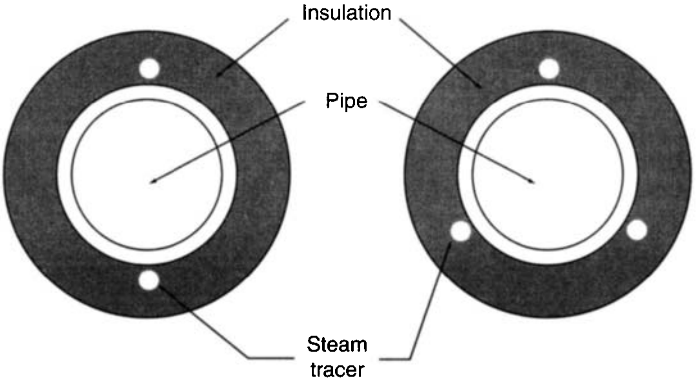


FIGURE 5.24 Typical installation of steam tracing lines for vertical piping.

TABLE 5.18 Recommended Number of Tracer Lines Based on Pipe Size

Pipe size, in	DN	Number of tracer lines	Nominal pipe size, tracer, in	DN
1–3	25–80	1	⅜	12
4–6	100–150	1	½	15
8–20	200–500	2	½	15
24–30	600–750	3	½	15

TABLE 5.19 Relationship of Steam Pressure to Temperature

Pressure, psig	kPa	Steam temperature, °F	°C
15	105	250	120
30	210	274	133
50	350	298	146
75	525	320	160
100	700	338	168
150	1050	366	183
200	1400	388	196

Steam Supply

Steam for tracing is generally obtained from the facility's steam service. Normally, saturated steam is used for tracing purposes. If multiple tracing lines are required, it is standard practice to connect to the main steam supply once and use a tracer supply manifold, or header, to feed all the individual tracers. The connections to the header should be made from the top. This steam supply to the header should have a manual shutoff valve, and each of the individual tracers should also have its own isolation valve. Refer to Table 5.20 for a general guide to the number of ½-in tracer lines that can be supplied from a header with a maximum steam pressure of 50 psi (350 kPa). A steam trap assembly should be provided on the header to remove condensate. A typical steam supply manifold is illustrated in Fig. 5.25.

Condensate Return

The condensate can be either returned for reuse or, when a condensate return is not practical, disposed of (to drain). Exterior tracer lines commonly discharge condensate into a dry well placed into the ground. Condensate is pure water and thus causes no damage to the environment. When located inside a building, condensate is often discharged into a floor drain. If the temperature of the condensate is above 140°F (60°C), mixing with cold water may be necessary for the drain to be routed into the sanitary drainage system. Refer to Table 9.30 for mixture proportions. If discharged into a chemical or industrial system, a higher temperature is acceptable up to the temperature limit of the piping system and jointing method into which it is discharging. For a detail of nonreturned condensate, refer to Fig. 5.26.

A problem potentially occurs in the tracer line after the control valve closes. Because the steam in the tracer line will condense to water at a much lower specific

TABLE 5.20 Recommended Number of Tracer Lines Based on Class of Service

		Number of ½-in (DN 15) tracers		
		Type A	Type B	Type C
Product line size, in	DN	Gneral frost protection or where solidification may occur at temps below 75° F (55°C)	Where solidification may occur at temps between 75–150°F (55–64°C)	Where solidification may occur at temps between 150–300°F (64–147°C)
1	25	1	1	1
1½	40	1	1	2
2	50	1	1	2
3	80	1	1	3
4	100	1	2	3
6	150	2	2	3
8	200	2	2	3
10–12	250–300	2	3	6
14–16	350–400	2	3	8
18–20	450–500	2	3	10

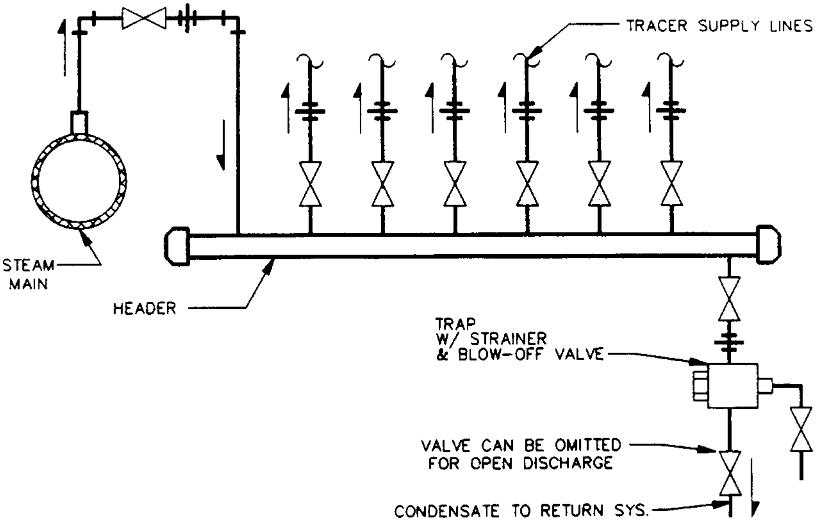


FIGURE 5.25 Typical detail of steam supply manifold.

volume (0.017 ft^3/lb for 50 psi condensate) than saturated steam (6.8 ft^3/lb), a vacuum will be created in the tracer line. To eliminate this vacuum, a vacuum breaker should be installed after the control valve to allow air to enter the tracer pipe to replace the volume formerly filled with steam.

There are conditions where branch lines are distant from the steam header or are installed in cold climates. In these cases, it is recommended that the steam supply line have a trap immediately before the temperature control. Each separate tracer should be provided with a steam trap and a strainer with a blowdown valve should be installed before the steam trap at the end of each tracing run.

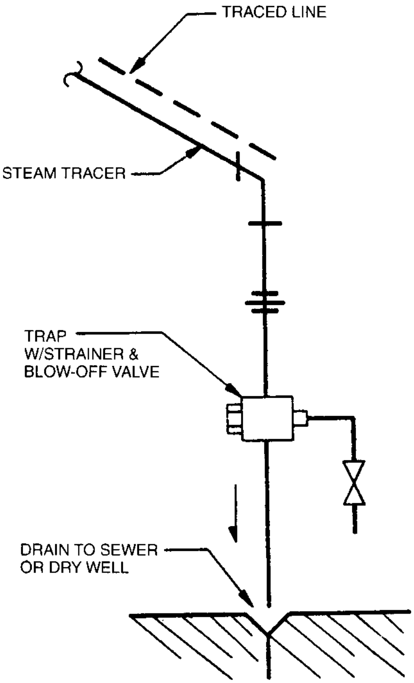


FIGURE 5.26 Detail of nonreturned condensate.

When condensate is to be disposed of, a subcooling trap will enhance the energy efficiency of a tracer system by allowing sensible heat to contribute to the heating duty. These traps release condensate only after it has cooled well below the saturation temperature. Where supply temperature control valves are used, the condensate traps at the end of the tracer run will be in the closed position when the tracing duty is satisfied and the steam is shut off. Since the pressure driving the condensate through the trap will be zero, it is important that the selected trap not require pressure to operate. These traps are classified as free-draining, and are known as temperature-sensing or thermostatic steam traps. The trap should be installed in a free-draining position. A typical thermostatic condensate trap installed at a tracer line end is illustrated in Fig. 5.27. A typical condensate header is shown in Fig. 5.28.

Temperature Control

For most systems, the simplest way to control the temperature is to use an adjustable steam pressure reducing assembly on the steam supply to the tracer line. The pressure can be adjusted based on operating experience to produce the required temperature. This method allows only approximate temperature control and so is used when the line to be protected has a fairly constant flow and the heat makeup is

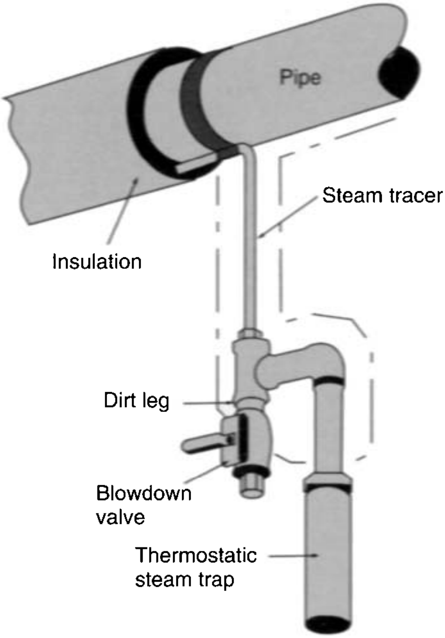


FIGURE 5.27 Detail of thermostatic steam trap.

constant. Operating experience has shown that reliable temperature control of steam is not practical below 250°F (121°C). Above this temperature, control to within 50°F (10°C) is reasonably achievable, but expensive.

When closer control is necessary, an automatic, direct-acting temperature control valve often provides an economical solution. One advantage of this type of valve is that it does not require either electricity or compressed air to operate. The valve operation is controlled by an attached sensor that can be arranged to sense the appropriate relevant temperature—ambient air, surface wall of the protected pipe, or the fluid stream to be protected. Modulating temperature control valves can reduce shocks to the system by opening and closing slowly, thus reducing thermal shock, water hammer, and abrupt temperature changes. An additional advantage is that the automatic feature relieves operating personnel from having to manually turn on and off steam supply lines at various points throughout the facility.

Other methods used less often include electric, pneumatic, and electric-pneumatic controlling devices that also require positioners, set point controllers, temperature sensors, and power supplies. These methods of controlling the steam supply to the tracer line are more costly, but generally more accurate, and their use depends on the specifics of the application.

Freeze protection requirements for piping within a facility should be controlled by a temperature-sensing device attached directly to the pipe being protected. When the pipe temperature falls below a set point, the steam is turned on, and when it rises above a set point, the steam is turned off. This sensor should be located as far away from the tracing line as possible.

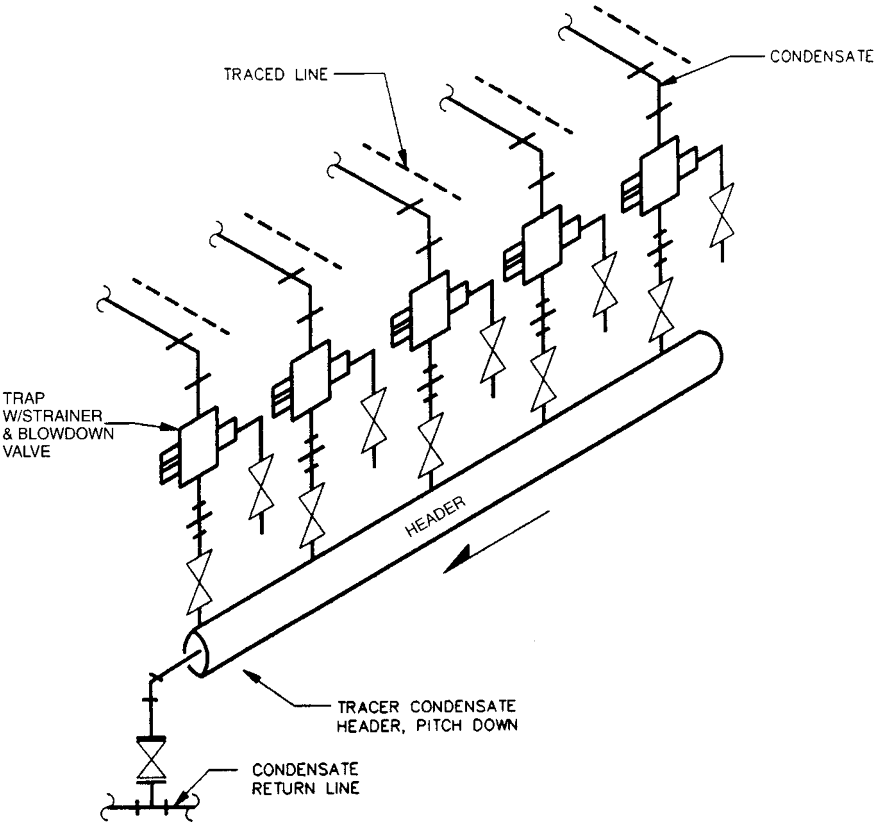


FIGURE 5.28 Detail of condensate return manifold.

System Design Procedure

1. Determine the number and size(s) of the pipe(s) to be protected. Use Table 5.18 or 5.20 as a guide to select the number and pipe size of the tracer lines. Freeze protection is considered type A, noncritical, in Table 5.20. Establish the total number of tracer lines required, the steam supply location and pressure, and the method of condensate removal or return. The steam supply must be taken from a source that is continuously available.

2. From the steam supply location, determine whether a pressure-reducing station is required. Locate the manifold for a multiple tracer system. Based on the pressure available, select a subheader size from Table 5.21 (30 to 50 psig [210 to 350 Kpa) steam) or Table 5.22 (100 to 150 psig [700 to 1050 kPa) steam). With the proposed tracer line size and the steam pressure available, select the subheader size to supply the selected number of tracer lines based on the steam pressure. Accepted practice limits subheader size to approximately 50 ft (15 m).

3. To find the longest allowable heat tracing pipe run, use Table 5.23, entering the table with the available steam pressure and the line size. Another factor in the

TABLE 5.21 Subheader Size Using 30 to 50 psig (210–350 kPa) Steam Pressure

Maximum number of tracers ⅜-in (12 mm) O.D.	Maximum number of tracers ½-in (15 mm) O.D.	Subheader pipe size, in	DN
1–4	1–2	¾	20
5–9	3–5	1	25
10–22	6–16	1½	40

TABLE 5.22 Subheader Size Using 100 to 150 psig (700–1000 kPa) Steam Pressure

Maximum number of tracers ⅜-in (12 mm) O.D.	Maximum number of tracers ½-in (15 mm) O.D.	Subheader pipe size, in	DN
1–5	1–3	¾	20
7–12	4–7	1	25
13–30	8–24	1½	40

TABLE 5.23 Heat Tracer Length
Tracing design: ½-in O.D. tubing—parallel to pipe maximum tracing run per trap (ft)[1]

Line size, in	DN	Steam pressure, kPag					
		10 70	50 350	100 700	150 1050	200 1400	250 1750
Single tracer							
1	25	230	270	290	360	430	450
1½	40	190	230	250	310	360	390
2	50	170	210	220	270	320	350
3	80	140	170	180	240	260	280
4	100	130	150	160	210	220	230
6	150	100	120	130	160	170	200
Double tracer							
8	200	50	60	70	80	90	100
10*	250	100	120	130	160	170	200
12*	300	100	120	130	160	170	200
14*	350	50	60	70	80	90	100

1 ft × 0.305 = meters
*Use ¾-in O.D. tubing for tracer.

design of the tracer line is the sharp vertical rise and drop of the pipe (a gradual pitched line is not considered). It is recommended that friction loss from the combined sharp vertical rise and drop not exceed 45 percent of the steam gauge pressure, and that any one vertical dimension not exceed 20 ft (6.2 m). If it is not possible to stay within these requirements, a second tracer line should be used.

4. To size the condensate header pipe, use Table 5.24. Enter the table with the number of tracer line traps (one for each tracer line) and the steam pressure. Ac-

TABLE 5.24 Condensate Header Size

Maximum number of ⅜-in and ½-in (12 and 15 DN) traps			
30–50 psi (210–350 kPa) STM	100–150 psi (700 to 1000 kPa) STM	Condensate header pipe size, in	DN
1–3	1–2	¾	20
4	3	1	25
5–11	4–8	1½	40
12–22	9–15	2	50
23–50	16–40	3	80

cepted practice limits length of header run to approximately 60 ft (18 m), and header pressure to 30 percent of the lowest inlet trap pressure.

5. If the installation requires maximum heat transfer between the tracer and the pipe, a heat-conducting paste can be used to fill any gaps along the length of the tracer. Care must be taken to adequately clean both pipe surfaces before applying the paste.

6. If the installation has pipe or product that may be sensitive to the high temperature resulting from direct contact with the tracer, a strip of insulating material, such as mineral wool or fiberglass, could be installed between the tracer and the pipe.

7. To calculate the heat lost in Btu through common insulation materials, refer to Table 5.25.

Expansion

The tracer line will expand at a different rate than the pipe being protected if they are made from different materials. This difference must be provided for. When flanged and screwed pipe is being protected, it is common practice to provide an expansion loop at each joint. For long runs of straight welded pipe, expansion loops are provided every 50 ft, usually as loops in the tracing line. Expansion loops are not required on vertical piping where spiral tracing is used.

TABLE 5.25 Heat Loss in Btus Through Common Insulation Materials

	100°F 37°C	200°F 92°C	300°F 150°C	400°F 200°C	500°F 260°C	600°F 310°C
Fiberglass	0.26	0.30	0.34			
Polyurethane	0.16	0.16	0.16			
Calcium silicate	0.33	0.37	0.41	0.46	0.57	0.60
Cellular glass	0.39	0.47	0.55	0.64	0.74	0.85

Note: These are representative values per inch thickness for one square foot of area. Exact values should be confirmed by the insulation manufacturer.

Special Installation Considerations

Large pumps, instruments, and other irregularly shaped pieces of equipment must also be protected. These pieces of equipment generally require that the tracer be either directly in contact with the object being protected or, in cases where overheating cannot be tolerated, isolated from that equipment by spacers between the tracer and equipment or by tape wound around the tracer to reduce the surface temperature of the tracing pipe. Special design details for tracing methods must be custom made for specific pieces of equipment.

Because it is common to find dirt and debris in the tracer line, it is important that it be blown out with steam before being placed in service.

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