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

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

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

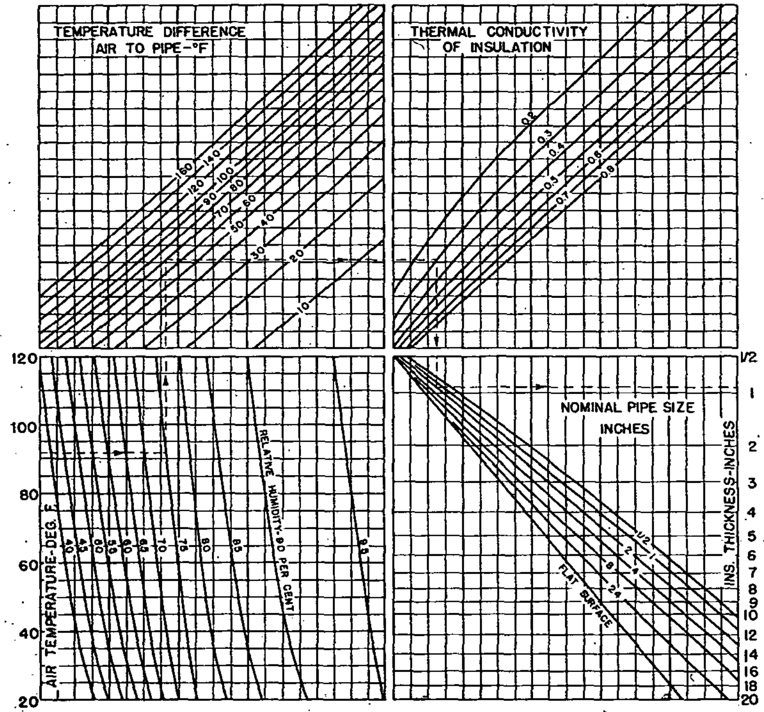
$$C_p = \text{Capacity of pipe, lb water/lin. ft} = \frac{\pi r_o^2}{144} \times 62.4$$

$$q_o = \frac{k\left[\left(\frac{t_1 + 32}{2}\right) - t_2\right]}{r_2 \log_e \frac{r_2}{r_1}} \tag{4}$$

where

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

When water must remain stationary longer than the times designated in Table 9, the only safe way to insure against freezing is to install a steam or hot water pipe parallel to the cold water pipe or to place an electric resistance heater along the side of the exposed water line. The heating system and the water line are then insulated so that the heat losses from the heating system are not excessive, and the heating effect is concentrated against the water pipe where it is needed. For this form of protection 2 in. of an efficient insulation may be applied.



* Solve problems as indicated by dotted line, entering chart at lower left-hand scale.

Fig. 7 . . . . Thickness of Pipe Insulation to Prevent Condensation on Outer Surface*

APPLICATION OF INDUSTRIAL INSULATION

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

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

The application of insulation to air-conditioning ducts is accomplished in a variety of ways depending largely on ambient conditions and temperature differentials between the air in the room and conditioned air. Boards or blankets are normally used in a single layer 1 in. thick. Boards are fastened to the duct surfaces with spot or solid application of adhesive, and further reinforced with wires, bands, spindle anchors, or sheet-metal screws. Although, where the service is not too severe, it is permissible merely to point the joints with a mastic compound, in most cases the insulations should be protected against water-vapor permeation. Where blankets are used the insulation can be wrapped around the duct, and held in place with tape over all joints or with spirally wrapped twine. Again in most cases the insulation should be provided with an outer vapor barrier protection.

UNDERGROUND PIPE INSULATION

Underground steam distribution pipes may be installed in tunnels or in protective structures of various types, sizes, and shapes. Conduits for piping are described in Chapter 27.

Pipes in tunnels are covered with sectional insulation to provide maximum thermal efficiency, and are also finished with good mechanical protection in the form of metal or waterproofing membrane outer jackets. In some instances, where actual submersion of hot lines may occur, it has been found good practice to fasten the covering securely with corrosion-resistant wire, and then sew on a wire-inserted asbestos fabric jacket with wire. This jacket is porous. The principle of withstanding submersion is that water may enter as water, then actually boil at the pipe surfaces and escape as steam without rupturing the insulation or jacket. Conduit systems are in more general use than tunnels. Pipes carried in conduits may be insulated with sectional insulation; however, the more usual practice is to fill the entire section of the conduit around the pipes with high quality, loose insulating material. The insulation must be kept dry at all times, and for this purpose effective waterproofing membranes enclose the insulation. A drainage system is also provided to divert water which may tend to enter the conduit.

Table 10 . . . . Thickness of Loose Insulation for Use as Fill in Underground Conduit Systems

Steam Pressure Psig or Condition	Steam Temperature Fahrenheit Degrees	Minimum Thickness of Insulation in Inches: Steam Lines, Pipes Less than 4 In.	Steam Lines, Pipes 4 In. to 10 In.	Steam Lines, Pipes Larger than 12 In.	Return Lines, Pipes Less than 4 In.	Return Lines, Pipes 4 In. and Larger	Minimum Distance Between Steam and Return
Hot water, or 0 to 25	212 to 267	1½	2	2½	1¼	1½	1
25 to 125	267 to 352	2	2½	3	1¼	1½	1¼
Above 125, or superheat	352 to 500	2½	3	3½	1¼	1½	1½

The economical thickness of insulation for underground work is difficult to determine accurately due to the many variables which have to be considered. As a result of theories[4] previously developed, together with other experimental data which have been presented, the usual endeavor is to secure not less than 90 percent efficiency for underground piping. A comparison of heat loss under actual conditions vs. calculated values has been published by the National District Heating Association.[5] Table 10 can be used as a guide in arriving at the minimum thickness of loose insulation fills to use for laying out conduit systems. Other factors such as the number of pipes and their combination of sizes, as well as the standard conduit sizes, are primary controlling factors in the amount and thickness of insulation for use.

When sectional insulation is applied to pipes in tunnels or conduits, usual practice is to apply the most efficient materials ½ in. less in thickness than that determined by the use of Fig. 6. The data in Fig. 6 are based on conditions of insulation exposed to the air, whereas normal ground temperature is substituted for air temperature in determining the temperature difference for use with the chart when applying it for underground pipe system estimates.

REFERENCES

[1] R. H. Heilman: Heat loss from copper piping (*Heating, Piping and Air Conditioning*, September 1933, p. 458).

[2] *Technical Data Sheet* (Johns-Manville Corp., August 1955).

[3] U. W. Smith: Rapid method of determining the economical thickness of pipe insulation (ASHVE JOURNAL SECTION, *Heating, Piping and Air Conditioning*, October 1947, p. 118).

[4] J. R. Allen: Theory of heat losses from pipes buried in the ground (ASHVE TRANSACTIONS, Vol. 26, 1920, p. 335).

[5] *District Heating Handbook* (National District Heating Association, 1951, 3rd ed., pp. 193–194).