protection in the form of metal or waterproofing membrane outer jackets. 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.

The economical thickness of insulation for underground work is difficult of accurate determination due to the many variables which have to be considered. As a result of theories developed by J. R. Allen[3], together with experimental data presented by others, the usual endeavor is to secure not less than 90 per cent efficiency for underground piping. Table 13 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 lines 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. 3. Fig. 3 is 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 line estimates.

TABLE 13. THICKNESS OF LOOSE INSULATION FOR USE AS FILL IN UNDERGROUND CONDUIT SYSTEMS

Steam Pressures (Lb Gage) or Conditions	Steam Temperatures Degrees Fahrenheit	Minimum Thickness of Insulation in Inches					Minimum Distance Between Steam and Return
		Steam Lines			Return Lines		
		Pipes Less than 4 In.	Pipes 4 In. to 10 In.	Pipes Larger than 12 In.	Pipes Less than 4 In.	Pipes 4 In. and Larger	
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

[3]Theory of Heat Losses from Pipes Buried in the Ground, by J. R. Allen (A.S.H.V.E. TRANSACTIONS, Vol. 26, 1920).

PROBLEMS IN PRACTICE

1 ● Compute the total annual heat loss from 165 ft of 2-in. bare pipe in service 4000 hours per year. The pipe is carrying steam at 10 lb pressure and is exposed to an average air temperature of 70 F.

The pipe temperature is taken as the steam temperature, which is 239.4 F, obtained from Table 7, Chapter 1. The temperature difference between the pipe and air = 239.4 − 70 = 169.4 deg. By interpolation of Table 1 between temperature differences of 157.1 F and 227.7 F, the heat loss from a 2-in. pipe at a temperature difference of 169.4 deg is found to be 1.677 Btu per hour per linear foot per degree temperature difference. The total annual heat loss from the entire = 1.677 × 169.4 × 165 (linear feet) × 4000 (hours) = 188,000,000 Btu.

2 ● Coal costing $11.50 per ton and having a calorific value of 13,000 Btu per pound is being burned in the furnace supplying steam to the pipe line given in Question 1. If the system is operating at an over-all efficiency of 55 per cent determine the monetary value of the annual heat loss from the line.

The cost of heat per 1 million Btu supplied to the system = 1,000,000 × 11.5 (dollars) ÷ 13,000 (Btu) × 2000 (lb) × 0.55 (efficiency) = $0.804. The total cost of heat lost per year = 0.804 × 188 (million Btu) = $151.15.[4]

3 ● If the steam line given in Question 1 is covered with 1-in. thick 85 per cent magnesia, determine the resulting total annual heat loss through the insulation. Also compute the monetary value of the annual saving and the percentage of saving over the heat loss from the bare pipe.

By interpolation of Table 5 between temperature differences of 157.1 F and 227.7 F, the coefficient of transmission for 1-in. magnesia on a 2-in. pipe is found to be 0.525 Btu per hour per square foot of pipe surface per degree temperature difference at a temperature difference of 169.4 deg. The total hourly loss per square foot of insulated pipe will then be 0.525 × 169.4 = 89.04 Btu. From Table 2 the area per linear foot of 2-in. pipe is found to be 0.622 sq ft. The total annual loss through the insulation = 89.04 × 0.622 × 165 (linear feet) × 4000 (hours) = 36,550,000 Btu. The annual bare pipe loss as determined in the solution of Question 1 was found to be 188,000,000 Btu. The saving due to insulation is then 188,000,000 − 36,550,000 = 151,350,000 Btu per year.

From the solution of Question 2 it was found that the heat supplied to the system cost $0.804 per million Btu; therefore, the monetary value of the saving = 0.804 (dollars) × 151.35 (million Btu) = $121.69, or 81.2 per cent of the cost when using uninsulated pipe.

4 ● The manufacturer's list price for 85 per cent magnesia insulation is $0.36 per linear foot for 1-in. (standard thick) material to cover a 2-in. pipe. Determine the period of time required for the saving found in Question 3 to pay for the cost of the insulation if it can be purchased and applied at 80 per cent of list price (20 per cent discount).

The applied cost of insulation = 165 (linear feet) × 0.36 (dollars) × 0.80 (net) = 47.52. Since the annual saving as found in Question 3 amounts to $121.69, the insulation will pay for its cost in 47.52 ÷ 121.69 = 0.3905 years; in other words, the cost will be repaid 2.56 times by the saving obtained in one heating season.

5 ● The conductivity of magnesia insulation is 0.455 at the mean temperature which will result under the conditions of Question 3. Estimate the most economical thickness of magnesia for application on the pipe when operating under the conditions which are given in the foregoing problems and when a 20 per cent return is required on the investment for insulation.

Use chart given in Fig. 3. Begin at the left bottom margin and proceed successively as shown by the dotted line example to the following essential data which are collected from the problems previously given:

4000 hours operation per year.
$0.804 value of heat, dollars per million Btu.
169.4 deg temperature difference.
0.455 conductivity of insulation.
20 per cent discount from list, cost of insulation.
20 per cent fixed charges, return on investment.
2-in. pipe size.

Solution of the problem by use of Fig. 3 results in a required thickness of approximately

[4]A closely approximate solution of this problem may be quickly made by use of the estimating chart given in Fig. 1.