

300 Choosing Economical Insulation Thickness

Abstract

This section will guide you in selecting the most economical thickness of insulation for hot equipment. It has a manual procedure for determining heat loss and doing an economic analysis. It includes selection charts based on different payout periods and energy values to help the engineer quickly determine economical thickness for various sizes of pipe and small-diameter vessels. It also includes instructions for using the VM and PC versions of the computer program INSUL for more detailed studies. Figures are grouped at the end of the section.

This section assumes that insulation thickness is strictly driven by economics (i.e., the price of fuel). However, as discussed in Sections 100 and 200, other reasons for insulating, such as process considerations and personnel protection, may also affect choice of insulation thickness. Personnel protection is addressed in this section, but decisions based on process considerations are not addressed. Process-based decisions about insulation thickness must be made on a case-by-case basis.

The selection charts in this section only apply to the economics of insulating hot equipment. The same principles can be used for cold equipment with cost of refrigeration substituted for fuel cost. Section 200 includes some quick selection charts for insulation of cold equipment.

The *Tank Manual* contains a procedure for determining economical thickness for tank insulation.

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310 Insulation Selection Charts

Economical thickness is determined primarily by the value of heat, installed cost of insulation, payout period and to a lesser extent by ambient temperature, thermal conductivity and operating factor. Other factors to consider are: the thickness needed to protect personnel from hot surfaces and what thicknesses are commercially available.

311 For Piping, Vessels

Figures 300-3 through 300-19 (located in Section 340) are selection charts for insulating base surfaces. They were prepared by using the computer program INSUL (see Section 330), which was given the data bulleted below. **If values in your insulation project vary greatly from these data, you may want to use INSUL and specify new values instead of using the charts.** INSUL can also calculate insulation thickness to be added to a pre-existing layer of insulation with its own conductivity, emissivity and thickness for retrofit projects.

- Installed costs [11] are based on the use of calcium silicate insulation with aluminum weatherjacketing. These costs can vary widely due to differences in 1) labor rates between geographic areas and 2) the cost of different insulation materials.
- Prices are based on projects having \$30,000 of insulation. (Small projects may have unit prices up to 33% more than indicated in these charts and therefore slightly thinner insulation may be called for.)
- Economic bases for determining thickness:
 - Payout is either 2 or 4 years, before taxes.
 - Operating factor is 0.9.
 - Wind speed is 7 miles per hour.
 - Ambient air temperature is 60°F.
 - Energy value ranges from \$3.00 to \$7.50 per MMBtu.

The charts are plotted for varying values of heat and payout. In reading the charts, note that payout period is inversely proportional to energy cost; i.e., the required insulation thickness is the same for a project with an energy value of \$6/MMBtu and a 2-year payout as for a project with an energy value of \$3/MMBtu and a 4-year payout.

The value of heat is the cost of 1 million Btu's in the process, which is obtained by dividing the cost of fuel by the average furnace efficiency, typically 85 to 90% for furnaces with flue gas heat recovery.

Personnel Protection Chart. In the case of high temperature lines, the most economical thickness may not protect people from hot surfaces. If the insulated surface will be hotter than 140°F, additional insulation may need to be added to surfaces that people might touch. Figure 300-10 shows the required insulation thickness for personnel protection based on 80°F ambient temperature and no wind. You

can use INSUL to calculate the thickness required to limit surface temperature to a selected value.

For work involving significant amounts of insulation, we suggest you use INSUL, with current cost data, to plot new charts on Standard Form IRM-EF-823, which is in this manual.

312 For Valves, Flanges, Manway Covers, and Pumps

Flexible removable insulation covers are used for non-symmetrical shapes. Figures 300-11 through 300-13 allow you to estimate within 10 percent, for removable covers:

- Payback period for insulating at various energy costs
- Maximum cover cost to achieve a given payout
- Minimum life temperature that provides a given payout

Each figure shows a typical cost for flexible removable covers. Users should substitute their location costs (in the lower left chart of each figure) when known.

The arrowheads in Figures 300-11 through 300-13 show examples of how to use the charts. The heat savings presented assume a 60°F ambient temperature and average winds of 7 mph. The cost savings do not include an operating factor or energy loss through the insulation cover since these factors normally would not significantly impact the results. Covers with 2 inches of either ceramic fiber or fiber-glass will be between 95 and 99 percent efficient at reducing energy loss. These simple charts do not show differences between 150-pound and 300-pound class valves and fittings, nor are the specific valve types (plug, gate, etc.) shown. Covers for 300-pound class valves and fittings can be up to 15 percent more expensive than covers for 150-pound class valves and fittings, particularly in sizes over 10 inches.

320 Calculating Economical Thickness

This section gives the method for determining economical thickness and an example problem. It provides the background and the calculation procedure used in INSUL and in the preparation of Figures 300-3 through 300-10. This section also tells how to:

- Determine the break-point temperature between two insulation thicknesses,
- Calculate the outside surface temperature of the insulation, and
- Determine the heat loss from hot surfaces.

321 Determining Economical Thickness

Basic Principle. Minimize the total of all the costs involved. Each increment of greater initial expenditure must reduce heat loss during the specified payout period by a dollar amount equal to or greater than the additional expenditure. The same principle applies to the first justification of insulation. However, the heat loss from

bare surfaces (Figure 300-14) is so great compared to the loss through the minimum available insulation thickness (1 inch) that in general insulation is justified on surfaces over about 100°F for all normal ranges of the value of heat and cost of insulation.

Assumption. This calculation method assumes that the insulation offers the major resistance to heat transfer. The only other significant resistance is the air film and it will nearly always be less than 10% of the total resistance for average weather conditions anywhere. A factor of 7%, the average air film resistance over a range of pipe sizes and insulation thicknesses, is included as a constant to simplify the calculation procedure.

Procedure. Five steps are given below. These are the same steps INSUL uses.

- Step 1.** Gather the information needed (see below). This includes the most up-to-date installed costs per lineal foot or square foot of insulation available.
- Step 2.** Calculate the heat loss for various insulation thicknesses for the payout period specified.
- Step 3.** Calculate the value of heat loss for the various insulation thicknesses.
- Step 4.** Calculate the value of heat saved by the incremental insulation.
- Step 5.** Compare the results of Step 4 to the incremental insulation cost. The most economical thicknesses are those at which the incremental insulation cost equals the incremental value of heat saved.

Step 1, Information Needed. Selecting the most economical thickness of insulation requires the following information:

- A = Area of insulation, log mean for pipe, sq ft/lineal ft (Refer to Figure 300-15)
- A_o = Outside surface area of insulation, sq ft/lineal ft
- C = Installed cost of insulation, (\$/lineal ft) for pipe, (\$/sq ft) for flat surfaces (vessels and tanks) - from bids or cost estimating data.
- H = Heat value, \$/MMBtu—from the operating company
- h = Air film coefficient = $0.0058 (T_2 - T_3) + 1.5$ for still air and $1.9 [0.0058 (T_2 - T_3) + 1.5]$ for 7 mph wind speed. Both expressions are in units of Btu/(sq ft)(hr)(°F).
- k = Conductivity of insulating materials being considered, (Btu) (in)/(sq ft) (hr) (°F). (Refer to Figure 300-16)
- L = Insulation thickness (actual)—inches
- O = Operating factor or fraction of time that insulated equipment is hot (usually about 0.90)
- P = Payout period before taxes, shown on design data sheet for project (usually 2 or 4 years)
- Q = Heat loss over the payout period, Btu/lineal ft (See Equation 300-3)
- q = Heat loss per lineal foot of pipe, Btu/(hr)(lineal ft) (See Equation 300-1)
- q_1 = Heat loss through insulation, Btu/(hr)(sq ft) (See Figure 300-17.)

T_1 = Average hot temperature inside pipe/vessel, °F

T_2 = Average temperature—outside surface of insulation, °F

T_3 = Average air temperature, °F

Steps 2 through 5. The heat loss calculation example shown in the chart in Figure 300-1 shows how to complete steps 2 through 5.

Fig. 300-1 Heat Loss Calculation Example (1 of 2)

Given:

8-inch piping system, operating at 400°F with a 60°F ambient temperature and insulated with calcium silicate.

Assume:

H = \$6.00/MMBtu = heat value

O = 0.9 = operating factor

P = 2 years = payout period before taxes

Use:

$A_{1\frac{1}{2}''}$ = 2.65 sq ft/lineal ft, from Figure 300-15

$A_{2''}$ = 2.76 sq ft/lineal ft, from Figure 300-15

$A_{2-1\frac{1}{2}''}$ = 2.87 sq ft/lineal ft, from Figure 300-15

$C_{1\frac{1}{2}''}$ = \$15.07/lineal ft for 1½" insulation

$C_{2''}$ = \$18.40/lineal ft for 2" insulation

$C_{2\frac{1}{2}''}$ = \$22.43/lineal ft for 2½" insulation

L = Use nominal insulation thickness, inches

T_1 = 400°F

T_3 = 60°F

k = 0.46 (Btu)(in)/(sq ft)(hr)(°F), from Figure 300-16 for a mean temperature of:

$$\frac{400 + 130^{(1)}}{2} = 265^\circ\text{F}$$

(1) Estimated outside surface temperature of the insulation.

Steps 2 and 3. Calculate two-year heat loss quantity and value of heat loss using the following relationships:

Heat Loss Q in MMBtu/lineal foot =

$$0.93 \frac{kA}{L} (T_1 - T_3) \text{ OP } \frac{8760}{10^6}$$

Value of heat loss = H (Q) \$/lineal ft

Fig. 300-1 Heat Loss Calculation Example (2 of 2)

Steps 4 and 5. Tabulate the results of the example problem and the economic analyses:			
	Insulation Thickness		
	1½"	2"	2½"
Heat Loss Quantity - Q (Btu/lineal ft)	4.05	3.16	2.63
Value of Heat Loss - HQ (\$/lineal ft)	24.3	18.9	15.7
	0	6	8
Value of heat saved by incremental insulation – ΔHQ (\$/lineal ft)		5.34	3.18
Insulation cost - C (\$/lineal ft)	15.0	18.4	22.4
	7	0	3
Incremental insulation cost - ΔC (\$/lineal ft)		3.33	4.03

Heat Loss Calculation Procedure

For one lineal foot of insulated pipe:

$$q = \frac{T_1 - T_3}{L/kA + 1/hA_o} \quad (\text{Eq. 300-1})$$

Since this equation contains two unknowns, “q” and “h”, and “h” in turn is a function of T_2 which is unknown, it requires a trial and error solution. Also “A” is log mean area, whereas A_o is outside surface area, adding further complications. This makes comparison of 2 or 3 alternative insulation thicknesses awkward and time-consuming.

However, it is possible to simplify the equation for use in economic comparisons while retaining accuracy commensurate with the other data in the problem.

We have selected 7 mph wind speed and 60°F ambient air temperature as reasonable average conditions for equipment located out of doors. Also, we wish to limit T_2 , the temperature of the outside surface of the insulation, to 140°F for personnel protection.

Setting these two conditions, we can compute a representative value for “h” using the relationship in our list of “Information Needed.” It is 3.8.

If values of L/kA are now computed for various pipe sizes and insulation thicknesses, it is found that $1/hA_o$ is only 3 to 11% of the corresponding value of L/kA . By taking a mean value of 7%, and introducing it as a constant, the basic equation can be greatly simplified, without materially affecting over all accuracy:

$$q = \frac{T_1 - T_3}{L/kA + 0.07(L/kA)} \quad (\text{Eq. 300-2})$$

or, more conveniently rearranged:

$$q = 0.93 \frac{kA}{L} (T_1 - T_3)$$

The actual heat loss over the payout period in MMBtu per lineal foot is:

$$Q = 0.93 \frac{kA}{L} (T_1 - T_3) \text{ OP } \frac{8760}{10^6}$$

(Eq. 300-3)

322 Break-Point Temperature Between Two Thicknesses

The break-point temperature between two thicknesses is the process temperature at which the incremental value of heat saved equals incremental insulation cost. To determine this, use the relationships shown in the design example in Figure 300-2.

323 Surface Temperature of Insulation

The outside surface temperature of insulation under still air conditions can be determined from Figure 300-17. It applies directly for flat surfaces.

For insulation on pipe, a log mean thickness correction is made to the L/k value. The equivalent thickness L' to use in place of the actual thickness L is given in Figure 300-18.

No wind is assumed for designing personnel protection insulation, since this is the most conservative basis, i.e., gives the highest surface temperature. The effect of wind is to reduce the surface temperature. The amount of reduction depends on wind velocity and the size, shape, and emissivity of the surface.

Example (using the Heat Loss Calculation Example):

$$\begin{aligned} k &= 0.46 \text{ (Btu)(in)/(sq ft)(hr)(}^\circ\text{F)} \\ L &= 2 \text{ inches} \\ L' &= 2.444 \text{ inches for 8-inch pipe, from Figure 300-18} \\ L'/k &= 5.31 \\ q_1 &= 57 \text{ Btu/(sq ft)(in), from Figure 300-17} \\ T_1 &= 400^\circ\text{F} \\ T_2 &= 33 + 60 = 93^\circ\text{F} \\ T_3 &= 60^\circ\text{F} \\ T_1 - T_3 &= 400 - 60 = 340^\circ\text{F} \\ T_2 - T_3 &= 33^\circ\text{F, from Figure 300-17} \end{aligned}$$

Fig. 300-2 Break-Point Temperature Design Example

Since:

$$Q = 0.93k \frac{A}{L} (T_1 - T_3) OP \frac{8760}{10^6} \quad (\text{from (Eq. 300-3)})$$

and:

$$HQ = H(0.93) k \frac{A}{L} (T_1 - T_3) OP \frac{8760}{10^6} \quad (\text{Eq. 300-4})$$

or for an increment:

$$\Delta(HQ) = H(0.93) k \Delta\left(\frac{A}{L}\right) (T_1 - T_3) OP \frac{8760}{10^6} \quad (\text{Eq. 300-5})$$

Solving for $T_1 - T_3$:

$$T_1 - T_3 = \frac{\Delta(HQ)(10^6)}{0.93 H k OP (8760) \Delta(A/L)} \quad (\text{Eq. 300-6})$$

Substituting: C for (HQ), $C_1 - C_2$ for ΔC , and $(A_1/L_1 - A_2/L_2)$ for $\Delta(A/L)$ where subscripts ₁ and ₂ note comparative insulation thicknesses:

Then:

$$T_1 - T_3 = \frac{(C_1 - C_2)(10^6)}{0.93 H k OP (8760) (A_1/L_1 - A_2/L_2)}$$

Example. Solve for T_1 using data from previous 8-inch pipe example, to find where 2-inch insulation is economical above T_1 and 1-inch insulation is economical below T_1 .

$$T_1 = 215^\circ\text{F} + 60^\circ\text{F} = 275^\circ\text{F}$$

$$T_1 - T_3 = \frac{(18.40 - 15.07)(10^6)}{(0.93)(6.0)(0.46)(0.9)(2)(8760)(2.65/1.5 - 2.76/2)} = 215^\circ\text{F}$$

Use 2-inch insulation above 275°F and 1-inch insulation below 275°F .

324 Heat Loss from Hot Surfaces to Air

The heat transfer coefficient for heat loss from hot surfaces to air can be determined from Figure 300-19 for varying wind velocities and surface emissivities.

330 User's Guide for Computer Program "INSUL"

331 Scope

The "user-oriented" computer program INSUL is available either on the VM system or as a PC program. INSUL simplifies the selection of economical insulation thicknesses for hot lines and vessels. In response to computer interrogation, the user simply states the problem, provides cost information, and the type of analysis to be conducted. All calculations are then performed by the computer, yielding the required design information.

INSUL provides two major services:

1. It calculates specific economical insulation thicknesses, and
2. It determines the break-point temperatures between successive insulation sizes.

For each case, the user must identify the geometry of the problem and cost information for the range of insulation types and sizes being considered. All information is supplied in response to questions asked by the computer.

Within these services, two major options exist:

1. The user can limit the insulation surface temperature below a certain value, which typically is 140°F.
2. The user can analyze the economics of retrofitting. Here an option exists to specify an additional pre-existing layer of insulation with its own conductivity, emissivity, and thickness. There are no associated material costs assumed. When considering pipes, an analysis is conducted using the pipe size and nominal radius of the pre-existing insulation. The associated thermal resistance is then included in the heat transfer analysis. New insulation is added onto this effective pipe size and evaluated appropriately.

332 Limitations

A maximum of 9 separate problems and 9 different insulation types may be analyzed during an individual run. Pipe insulation thicknesses must conform to standard sizes and not exceed 5 inches, while block insulation may be any thickness up to 1 foot.

333 Calculation Procedure

INSUL uses the principles discussed in Sections 310 and 320.

334 Using the PC Version

A PC version of the INSUL program is on a disc at the back of the manual. This program is an exact duplicate of the VM program, with the following exceptions:

- This first release does not have the input options H, Q, S, R, P, D as discussed in Section 335.
- This program prompts you for input. You cannot import data files as you can with the VM program (see Section 337).

Future releases will correct these deficiencies.

System Requirements

The PC version of INSUL requires that your PC have a math coprocessor chip (floating-point coprocessor) installed in your PC. If you try to run INSUL on a PC that doesn't have a coprocessor (or whose coprocessor is not active), you will get the following message:

Error in MAIN Error number 4001.

Many Company PC's have a program (located in \DOS or \UTIL directories) that allows you to check your system configuration. To execute the program (from DOS), type:

PCSCLOGO

The SYSTEM CONFIGURATION box displayed on the screen will show if FP Coprocessor is active or not. If the message says not active, either no math coprocessor is installed, or the math coprocessor is not active.

Accessing the Program

To execute the INSUL program, place the 360K PC disc (at the back of this manual) in the B drive and from DOS type:

b:INSUL

Then follow the directions in Section 336.

335 VM Version: Log on Procedure and Input Options

Access the Engineering Technology Department's VM Computer program library as follows:

- Log on to your personal user ID - Consult your local CITC support group for help if necessary.
- Type "ATTACH T9ENGR" to call up the computer program library.
- Type "INSUL" to begin execution.

The program will now prompt you as follows:

ENTER "H" FOR INFORMATION

ENTER "Q" FOR QUIT

ENTER "S" FOR A SAMPLE FILE

ENTER "R" FOR RUN WITH SAMPLE DATA FILE

ENTER "P" TO BE PROMPTED FOR INPUT

ENTER "D" TO RUN WITH AN INPUT DATA FILE

"P" allows you to be prompted for information. This is time consuming, but it instructs the user on how to input data into the program. The example program which follows will use the "P" input mode.

"D" allows the user to set up a data file and attach it to the program. The procedure for doing this will be discussed in Section 337.

336 Example Problem

For this example, 5-foot diameter vertical vessels connected via 6-inch pipe will be analyzed using the following information:

Ambient Temperature	60°F
Maximum Allowable Surface Temperature	140°F
Fraction of Time System Is Hot	7 mph
Wind Velocity	0.9
Cost of Fuel	\$3.28/MMBtu
Pay-out Period	4 years

In addition, the vessels are initially bare, while the pipes are to be retrofitted. The pre-existing pipe insulation is 0.94 inch with a thermal conductivity of 0.60 Btu in./hr ft² °F. The following hypothetical cost information applies:

Insul. Thickness (in)	8-inch Pipe (\$/ft)	Block (\$/ft ²)
1½	11.70	4.95
2	13.59	5.70
2½	15.60	—
3	17.70	8.50
3½	20.37	—
4	22.35	11.80
4½	24.55	—
5	—	13.55

Note that due to pre-existing insulation, i.e., 1-inch nominal thickness on 6-inch pipe, the effective pipe size becomes 8 inches. Had the pipes been bare, 6-inch pipe insulation would have been appropriate.

Break-Point Temperature Calculation

The task at hand is to obtain break-point information for both pipes and vessels at the prescribed sizes. With this information available, temperature ranges in which specific insulation thickness should be employed, will be determined.

When execution commences, some information is initially printed.

SELECTION OF INSULATION FOR HOT LINES AND VESSELS

TWO CALCULATION SERVICES ARE PROVIDED:

1. THE MOST ECONOMICAL INSULATION THICKNESS IS DETERMINED FOR A GIVEN GEOMETRY, INSULATION, AND HOT PROCESS TEMPERATURE.
2. THE "BREAK-POINT" HOT PROCESS TEMPERATURE BETWEEN TWO INSULATION THICKNESSES IS DETERMINED FOR A GIVEN GEOMETRY AND INSUL. TYPE.

EITHER SERVICE CAN EVALUATE MULTIPLE CASES AND INSULATION TYPES DURING ONE RUN, WHILE PROVIDING BOTH NEW AND RETRO-FITTING SOLUTIONS.

PLEASE TYPE WHICH SERVICE IS REQUIRED: (1.) OR (2.)

Since the hot process or hot surface temperatures are not known and a table of transitional or "break-point" temperatures is desired, service 2 will be employed. (A cursor (>) in the left margin indicates a user response.)

>2.

2.0000

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0.

A USER DICTIONARY, WHICH DESCRIBES THIS PROGRAMS TERMINOLOGY, IS AVAILABLE. WOULD YOU LIKE THIS SERVICE PROVIDED?

PLEASE TYPE YES(0.) OR NO(1.): (0.) OR (1.)

Until you are more familiar with this program's terminology, refer to the User Dictionary.

>0.

0.0

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0.

TYPE VALUES FOR:

CASES, INSULATIONS, PAYOUT, OP. FAC., HEAT VALUE

For this problem, a particular pipe size and vessel length are to be insulated with the insulations having equivalent properties. Therefore, CASES = 2. and INSULATIONS = 1.

>2.,1.,4.,. 9,3.28

2.0000 1.0000 4.0000 0.9000 3.2800

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

If no number is typed in response to a computer question, it will be interpreted as a zero (0.). Hence, simply hitting the "Return" key when asked "IS YOUR RESPONSE OK? YES(0.) OR NO(1.)" will prompt the program to proceed to the next question.

>0

TYPE VALUES FOR:

COND(1), EMISS(1), NUM. OF THICK.

>.456,.9,8.

0.4560 0.9000 8.0000

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0

TYPE VALUES FOR:

INSUL THICKNESS, PIPE COST, BLOCK COST: FOR INSUL(1)

USER DICTIONARY	
CASE NUMBER	A THREE DIGIT NUMBER OR SMALLER REPRESENTING ONE OF THE VARIOUS PROBLEMS BEING SOLVED
CASES	TOTAL NUMBER OF PROBLEMS TO SOLVE DURING THIS RUN, WITH DIFFERENT GEOMETRY, TEMPERATURES & CONSTRAINTS
COND(I)	CONDUCTIVITY ASSOCIATED WITH INSULATION TYPE I, INSUL(I) (BTU*IN/(HR*FT*FT*F)) Conductivities of various insulation materials are listed in Figure 100-1 (Section 100 of the manual).
DIAMETER	ACTUAL DIAMETER FOR EXISTING CYLINDRICAL SURFACE, INCLUDING OLD INSULATION WHEN RETRO-FITTING (IN)
E	RADIATION EMISSIVITY FOR THE BARE HOT TEMPERATURE SURFACE This value would normally be 0.9 for weathered steel surfaces (see Figure 300-19).
EMISS(I)	RADIATION EMISSIVITY ASSOCIATED WITH INSULATION TYPE I, INSUL(I) This is the emissivity of the outside of the insulation or weather jacket. It would range from 0.9 for weathered steel surfaces to 0.2 for weathered aluminum or stainless steel surfaces.
EXTRA INSUL	NUMBER OF LAYERS OF PRE-EXISTING INSULATION; EITHER (0.) OR (1.)
EXTRA COND	CONDUCTIVITY ASSOCIATED WITH THE PRE-EXISTING LAYER OF INSULATION DURING RETRO-FITTING
EXTRA THICK	ACTUAL THICKNESS OF PRE-EXISTING LAYER OF INSULATION DURING RETRO-FITTING (IN)
EXTRA EMISS	RADIATION EMISSIVITY FOR THE BASE SURFACE OF PRE-EXISTING INSULATION DURING RETRO-FITTING Again, this is the emissivity of the outer surface of the existing insulation.
GEOMETRY	GEOMETRY AND ORIENTATION CODE: PIPE = 0., VERT PLATE = 1., HOR PLATE = 2.(HOT SIDE UP) OR 3.(DOWN)
HEAT VALUE	VALUE OF HEAT OR COST OF FUEL IN \$/MMBTU; AS OF SEPTEMBER 1978, THIS VALUE WAS \$3.28/MMBTU AT RICH. (For example, at \$25/EFO, Heat Value = \$25/EFO ÷ 6.25 MMBtu/EFO = \$4.0/MMBtu)
INSULATIONS	TOTAL NUMBER OF INSULATION TYPES ENCOUNTERED DURING THIS COMPUTER RUN WITH DIFFERENT CONDUCTIVITIES
INSUL(I)	REFERS TO A PARTICULAR INSULATION TYPE AMONGST THE TOTAL ASSORTMENT BEING INPUT
INSUL THICKNESS	THE STANDARD SIZE OR THICKNESS OF EITHER PIPE OR SHEET INSULATION; NOT NOM. THICK. FOR PIPES (IN)
NUM OF THICK	THE NUMBER OF STANDARD INSULATION THICKNESSES FOR A PARTICULAR INSULATION TYPE

OP FAC	FRACTION OF TIME WHICH SYSTEM SPENDS IN ACTUAL HOT OPERATING CONDITIONS
PAYOUT	Plant operators can give you an idea of how often equipment is in service. CURRENT PAYOUT PERIOD BEFORE TAXES DURING WHICH MARGINAL COSTS AND SAVINGS ARE EQUATED (4 YRS: 9/78)
PIPE COST	This would be based on the current rate of return hurdle rate. COST OF PIPE INSULATION FOR A SPECIFIC INSULATION THICKNESS AND INSULATION TYPE (\$)
PSIZE	NOMINAL PIPE SIZE FOR EXISTING CYLINDRICAL SURFACE, INCLUDING OLD INSULATION WHEN RETRO-FITTING
T1	EITHER THE HOT PROCESS TEMPERATURE OR HOT BARE SURFACE TEMPERATURE (FAHR)
T3	AVERAGE AMBIENT AIR TEMPERATURE EXPERIENCED DURING OPERATING CONDITIONS (FAHR)
TMAX	MAXIMUM ALLOWABLE SURFACE TEMPERATURE DURING AVERAGE OPERATING CONDITIONS (FAHR)
WIND	Enter 140° for personnel protection. AVERAGE WIND VELOCITY EXPERIENCED DURING OPERATING CONDITIONS (MPH)
X	Usually 7 MPH. CHARACTERISTIC LENGTH FOR A VESSEL USED IN A FLAT PLATE ANALYSIS (FT)

At this stage, all cost information is to be input. These should include basic material, weatherstripping and installation costs, as well as any other costs associated with the insulation. Note that zeroes are entered where gaps in cost information exist. This cost information can be obtained from the CTRC cost estimating books.

>1.5,11.7,4.95

1.5000 11.7000 4.9500

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0

TYPE VALUES FOR:

INSUL. THICKNESS, PIPE COST, BLOCK COST: FOR INSUL(1)

>2.,13.59,5.7

2.0000 13.5900 5.7000

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0

TYPE VALUES FOR:

INSUL. THICKNESS, PIPE COST, BLOCK COST: FOR INSUL(1)

>2.5,15.6,0

2.5000 15.6000 0.0

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0

TYPE VALUES FOR:
INSUL. THICKNESS, PIPE COST, BLOCK COST: FOR INSUL(1)

>3.,17.7,8.5
3.0000 17.7000 8.5000

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0

TYPE VALUES FOR:
INSUL. THICKNESS, PIPE COST, BLOCK COST: FOR INSUL(1)

>3.5,20.37,0.
3.5000 20.3700 0.0

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0

TYPE VALUES FOR:
INSUL. THICKNESS, PIPE COST, BLOCK COST: FOR INSUL(1)

>4.0,22.35,11.4
4.0000 22.3500 11.4000

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

In the last response, a typing error was committed. The mistake was noticed only after the input was printed. In order to change the 11.4 to 11.8, "1." is entered as the answer to the question "IS YOUR RESPONSE OK?" so that the previous request for input will be repeated.

>1.

TYPE VALUES FOR:
INSUL THICKNESS, PIPE COST, BLOCK COST: FOR INSUL(1)

>4.0,22.35,11.8
4.0000 22.3500 11.8000

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0

TYPE VALUES FOR:
INSUL. THICKNESS, PIPE COST, BLOCK COST: FOR INSUL(1)

>4.5,24.55,0.
4.5000 24.5500 0.0

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0

TYPE VALUES FOR:
INSUL. THICKNESS, PIPE COST, BLOCK COST: FOR INSUL(1)

>5.0,0.,13.55
5.0000 0.0 13.5500

IS YOUR RESPONSE OK? YES(0.) OR NO(1.)

>0

TYPE VALUES FOR:
CASE NUMBER, GEOMETRY

The case numbers are arbitrary. Here the vessel will be represented by the number 10 and the pipe by 15. The remaining input to the computer is as follows: Remember that the pipe ("GEOMETRY" = 0.) has pre-existing insulation ("EXTRA INSUL" = 1.).

```
>10.,1.
10.0000  1.0000
IS YOUR RESPONSE OK? YES(0.) OR NO(1.)
>
TYPE VALUES FOR:
T3, WIND, X
>60.,7.,10.
60.0000  7.0000  10.0000
IS YOUR RESPONSE OK? YES(0.) OR NO(1.)
>
TYPE VALUES FOR:
E, TMAX, EXTRA INSUL.
>0.9.,140.,0.
0.9000  140.0000  0.0
IS YOUR RESPONSE OK? YES(0.) OR NO(1.)
>
TYPE VALUES FOR:
CASE NUMBER, GEOMETRY
>15.,0.
15.0000  0.0
IS YOUR RESPONSE OK? YES(0.) OR NO(1.)
>
TYPE VALUES FOR:
T3, WIND, DIAMETER, PSIZE
>60.,7.,8.6,8.0
60.0000  7.0000  8.6000  8.0000
IS YOUR RESPONSE OK? YES(0.) OR NO(1.)
>
TYPE VALUES FOR:
E, TMAX, EXTRA INSUL.
>9,140.,1.
0.9000  140.0000  1.0000
IS YOUR RESPONSE OK? YES(0.) OR NO(1.)
>
TYPE VALUES FOR:
EXTRA COND, EXTRA THICK, EXTRA EMISS
>.6,.94,.9
0.6000  0.9400  0.9000
IS YOUR RESPONSE OK? YES(0.) OR NO(1.)
>
```

Once the input has been supplied, computation begins immediately and the required output is provided. Before printing results most input (including the cost information) is supplied for easier reference. This completes the entire computer run.

SELECTION OF INSULATION FOR HOT LINES AND VESSELS

PAYOUT = 4.0 YEARS, OP. FAC = 0.90, H,V, = 3.28 \$/MMBTU

COST INFORMATION

INSUL	THICK(IN)	PIPE(\$/FT)	BLOCK(\$/SQ FT)
1	1.5	11.70	4.95
1	2.0	13.59	5.70
1	2.5	15.60	0.0
1	3.0	17.70	8.50
1	3.5	20.37	0.0
1	4.0	22.35	11.80
1	4.5	24.55	0.0
1	5.0	0.0	13.55

CASE NUMBER 10

GEOM = 1, T3 = 60., TMAX = 140., LENGTH = 5.0, EXINS = 0.

FOR INSULATION TYPE 1, THE FOLLOWING BREAK-POINT TEMPERATURES APPLY,

BETWEEN 0.0 INCHES AND 1.5 INCHES: 78°F

BETWEEN 1.5 INCHES AND 2.0 INCHES: 173°F

BETWEEN 2.0 INCHES AND 3.0 INCHES: 462°F

BETWEEN 3.0 INCHES AND 4.0 INCHES: 973°F

BETWEEN 4.0 INCHES AND 5.0 INCHES: 853°F

CASE NUMBER 15

GEOM = 0, T3 = 60., TMAX = 140., LENGTH = 8.0, EXINS = 1.

FOR INSULATION TYPE 1, THE FOLLOWING BREAK-POINT TEMPERATURES APPLY, +

BETWEEN 0.0 INCHES AND 1.5 INCHES: 235°F

BETWEEN 1.5 INCHES AND 2.0 INCHES: 341°F

BETWEEN 2.0 INCHES AND 2.5 INCHES: 409°F

BETWEEN 2.5 INCHES AND 3.0 INCHES: 695°F

BETWEEN 3.0 INCHES AND 3.5 INCHES: 1091°F

BETWEEN 3.5 INCHES AND 4.0 INCHES: 1009°F

BETWEEN 4.0 INCHES AND 4.5 INCHES: 1339°F

An interpretation of these results is in order, with special regard to the break-point temperatures 973°F and 853°F in case 10 and similarly, 1091°F and 1009°F in case 15. It might seem strange that there are situations where the break-point temperature actually decreases with increasing insulation thickness. This is plausible and indicates that a particular thickness should never be used due to a cost discontinuity, critical radius of insulation, single layer/multi-layer transition, etc. To obtain cleaner results, rerun the program without inputting costs of undesirable thicknesses. Without showing any input here, the following results are obtained when 4-inch thick flat and 3.5-inch thick pipe insulation are not considered.

CASE NUMBER 10

GEOM = 1, T3 = 60., TMAX = 140., LENGTH = 5.0, EXINS = 0.

FOR INSULATION TYPE 1, THE FOLLOWING BREAK-POINT TEMPERATURES APPLY,

BETWEEN 0.0 INCHES AND 1.5 INCHES: 78°F

BETWEEN 1.5 INCHES AND 2.0 INCHES: 173°F

BETWEEN 2.0 INCHES AND 3.0 INCHES: 462°F

BETWEEN 3.0 INCHES AND 5.0 INCHES: 927°F

GEOM = 0, T3 = 60., TMAX = 140., LENGTH = 8.0, EXINS = 1.

FOR INSULATION TYPE 1, THE FOLLOWING BREAK-POINT TEMPERATURES APPLY,

BETWEEN 0.0 INCHES AND 1.5 INCHES: 235°F

BETWEEN 1.5 INCHES AND 2.0 INCHES: 341°F

BETWEEN 2.0 INCHES AND 2.5 INCHES: 409°F

BETWEEN 2.5 INCHES AND 3.0 INCHES: 695°F

BETWEEN 3.0 INCHES AND 4.0 INCHES: 1055°F

BETWEEN 4.0 INCHES AND 4.5 INCHES: 1339°F

Economical Thickness Calculation

The other service available, i.e., Service 1, has not been discussed in detail but works in a very similar fashion. The only extra requirement is that the hot process temperature must be known. If the values of 550°F for a vessel and 500°F for a pipe are assumed, the following results would be obtained.

Comparing Different Types of Insulation

Note that Service 1 also provides a total cost figure which includes the total material cost supplied and the expense associated with heat lost during the payout period. This is the actual figure which must be minimized and provides a basis of comparison for optimal thicknesses of different insulation types. The insulation with the lowest associated cost normally is used unless there are other reasons not to (i.e., durability).

SELECTION OF INSULATION FOR HOT LINES AND VESSELS			
PAYOUT = 4.0 YEARS, OP. FAC. = 0.90, H.V. = 3.28 \$/MMBTU			
COST INFORMATION			
INSUL	THICK(IN)	PIPE(\$/FT)	BLOCK(\$/SQ FT)
1	1.5	11.70	4.95
1	2.0	13.59	5.70
1	3.0	17.70	8.50
1	3.5	20.37	0.0
1	4.0	22.35	11.40
1	4.5	24.55	0.0
1	5.0	0.0	13.55
CASE NUMBER 10			
GEOM = 1, T1 = 550., T3 = 60., TMAX = 140., LENGTH = 2.5, EXINS = 0.			
FOR INSULATION TYPE 1, THE OPTIONAL THICKNESS IS: 3.00 INCHES			
THE TOTAL COST PER FT (SQ FT) IS: \$ 15.87			
THIS YIELDS A SURFACE TEMPERATURE OF 82°F			
CASE NUMBER 15			
GEOM = 0, T1 = 500., T3 = 60., TMAX = 140., LENGTH = 8.0, EXINS = 1.			
FOR INSULATION TYPE 1, THE OPTIONAL THICKNESS IS: 2.50 INCHES			
THE TOTAL COST PER FT (SQ FT) IS: \$ 31.51			
THIS YIELDS A SURFACE TEMPERATURE OF 72°F			
THE INTERMEDIATE INSULATION TEMPERATURE IS 379°F			

337 Setting Up a Data File

As discussed in Section 335, the user can set up a file without prompting. This is much faster than prompting, provided the data is entered correctly.

After INSUL is accessed, the program will prompt the user as follows:

```
ENTER "H" FOR INFORMATION
ENTER "Q" TO QUIT
ENTER "S" FOR A SAMPLE FILE
ENTER "R" TO RUN WITH SAMPLE DATA FILE
ENTER "P" TO BE PROMPTED FOR INPUT
ENTER "D" TO RUN WITH AN INPUT DATA FILE
```

Typing "D" will enable the user to establish a data file and attach it to the program.

```
>d
ENTER THE NAME, TYPE, AND MODE OF YOUR INSUL INPUT FILE?
```

"DATA" IS THE DEFAULT FILETYPE
 "A" IS THE DEFAULT FILEMODE.

>INSULB

In this case "insulb" is the file name. If this is a new file the program will ask you to start inputting line by line. If this name is an existing file, then the program will ask you if you want to edit it as follows:

ENTER A "E" TO EDIT INSULB DATA A OTHERWISE PRESS ENTER AND THE PROGRAM WILL PROCEED AS IS.

WHEN YOU ARE DONE EDITING YOUR FILE TYPE "FILE" SO THE CHANGES WILL BE SAVED OR "QUIT" TO LEAVE THE FILE IN ORIGINAL FORM.

>e

In this case the file will print on the screen and you can change any part of that file as needed. Note that the contents of each line was explained in the previous section. Also, every value must have an entry, even if that entry is 0. This also applies to the prompt mode.

The file for the example problem is as follows:

```

2.
0.
2.,      1.,      4. .9,    3.28
.456,    .9,      8.
1.5,     11.7,    4.95
2. ,     13.59,   5.7
2.5,     15.6,    0.
3.,      17.7,    8.5,
3.5,     20.37,   0.
4.0,     22.35,   11.8,
4.5,     24.55,   0.,
5.0,     0.,      13.55,
10.,     1.,
60.,     7.,      10.,
.9,      140.,    0.,
15.,     0.,
60.,     7.,      8.6, 8.
.9,      140.,    1.
.6,      .94,     .9

```

The program executes immediately after the file is completed.

340 Figures For Section 300

341 Notes to Figures 300-1 through 300-7

1. Economic basis for determining insulation thickness:
Payout (before taxes) = 2 to 4 years
Operating factor = 0.9
Average temperature = 60°F
Average wind speed = 7 mph
Energy value per MMBtu = \$3.00 to \$7.50
2. Insulation may be single layer below 650°F. Double layer shall be used above 650°F, except on piping 1½ inches and smaller.
3. Insulation costs, using Richardson's *Process Plant Construction Estimating Standards* [11], are based on the use of calcium silicate insulation and aluminum weather coat and on job costs greater than \$30,000. (Small projects may have unit prices up to 33% more than indicated in these charts, and therefore slightly thinner insulation may be called for.)
4. The value of heat is the cost of 1 million Btu's in the process, which is obtained by dividing the cost of fuel by the average furnace efficiency, typically 85 to 90% for furnaces with flue gas heat recovery.

342 List of Figures

- Figure 300-3, Insulation Selection Chart 1
- Figure 300-4, Insulation Selection Chart 2
- Figure 300-5, Insulation Selection Chart 3
- Figure 300-6, Insulation Selection Chart 4
- Figure 300-7, Insulation Selection Chart 5
- Figure 300-8, Insulation Selection Chart 6
- Figure 300-9, Insulation Selection Chart 7
- Figure 300-10, Insulation Selection Chart—Personal Protection
- Figure 300-11, Insulation Selection Chart—Valves
- Figure 300-12, Insulation Selection Chart—Flanges
- Figure 300-13, Insulation Selection Chart—Manways
- Figure 300-14, Heat Loss From Horizontal Bare Steel Pipes and Flat Surfaces
- Figure 300-15, Log Mean Insulation Area for Pipe
- Figure 300-16, Conductivity of Insulating Materials
- Figure 300-17, Heat Transfer Through Insulation
- Figure 300-18, Equivalent Thickness of Pipe Insulation, L' (inches)
- Figure 300-19, Heat Loss from Hot Surfaces to Air

Fig. 300-3 Insulation Selection Chart

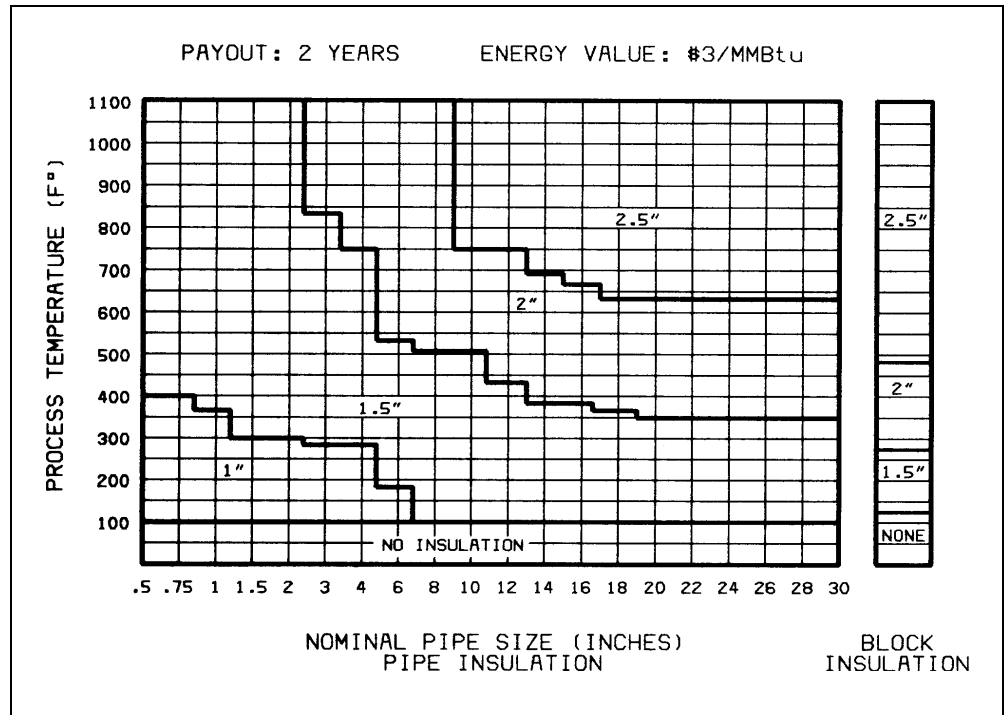


Fig. 300-4 Insulation Selection Chart 2

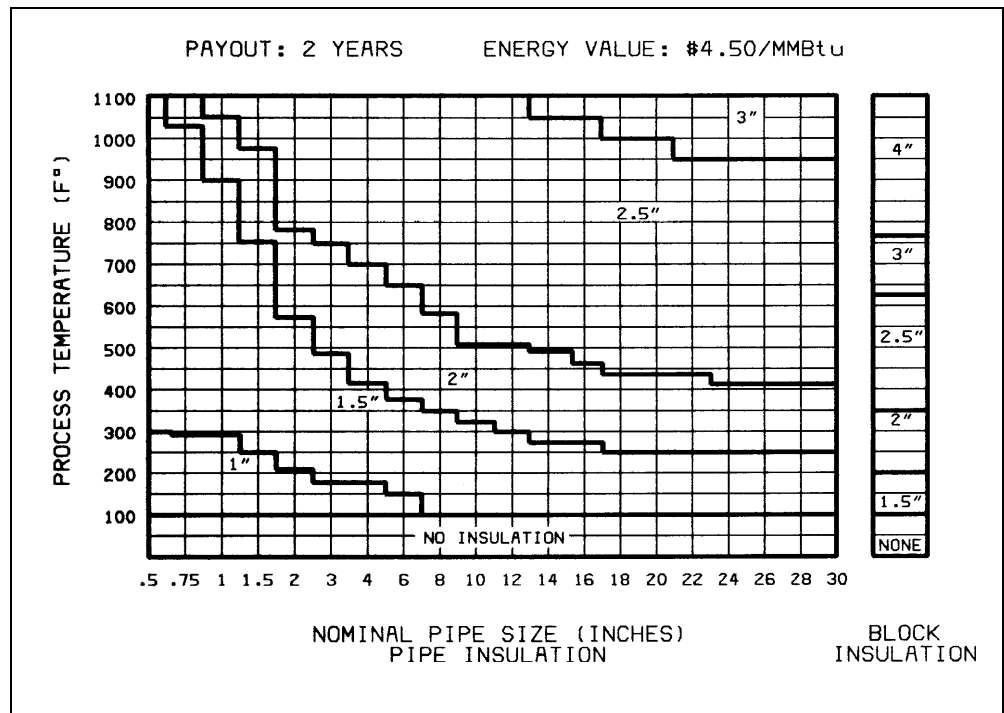


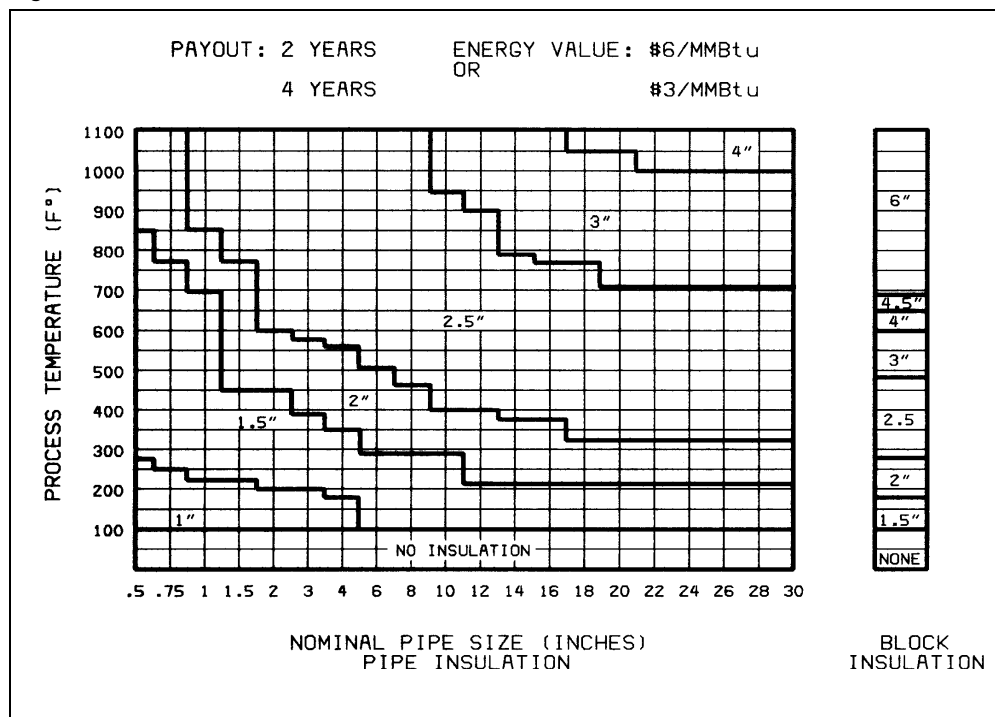
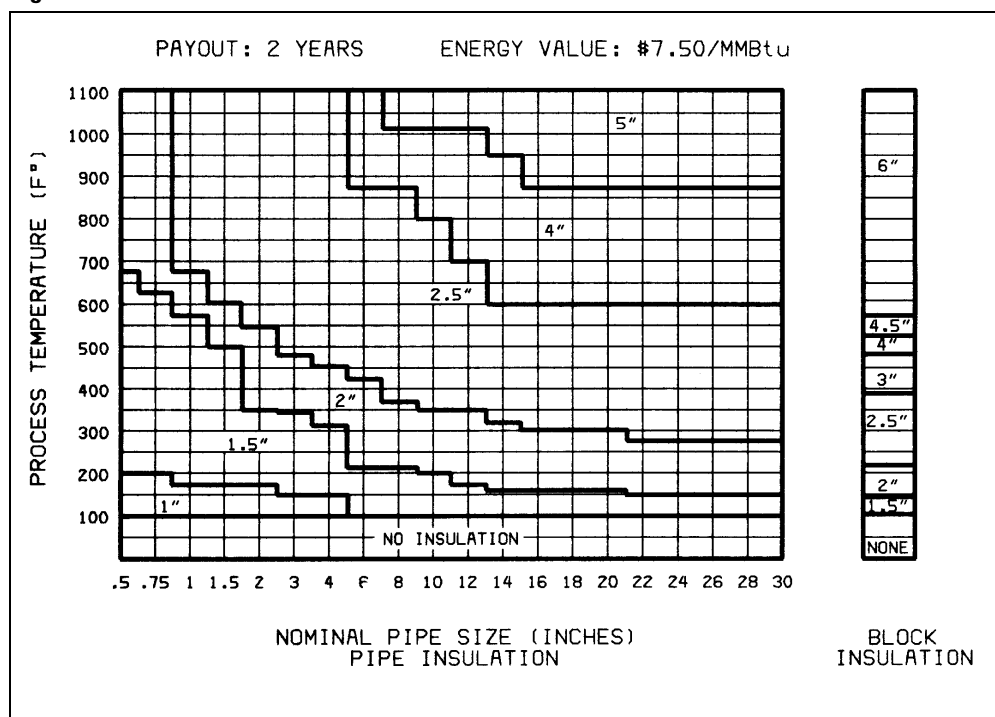
Fig. 300-5 Insulation Selection Chart 3**Fig. 300-6** Insulation Selection Chart 4

Fig. 300-7 Insulation Selection Chart 5

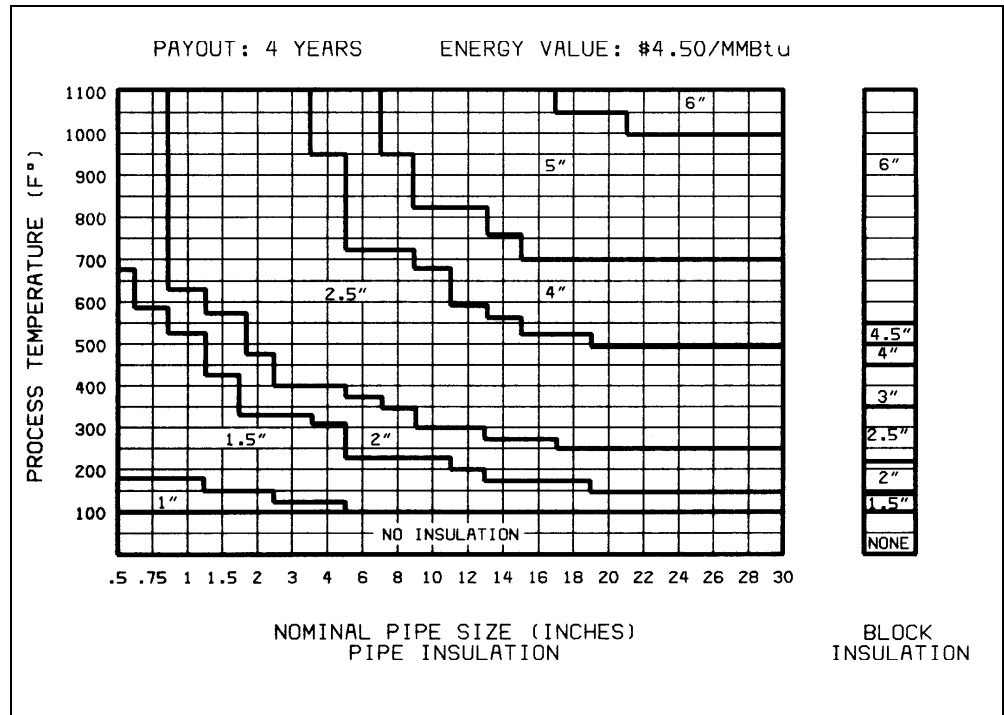


Fig. 300-8 Insulation Selection Chart 6

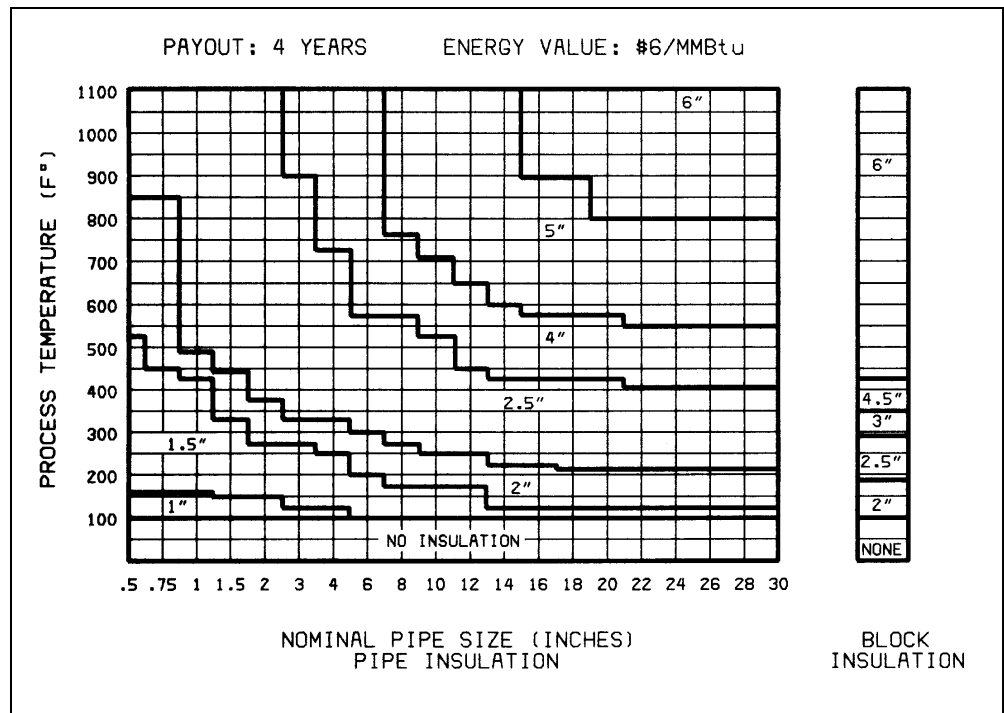


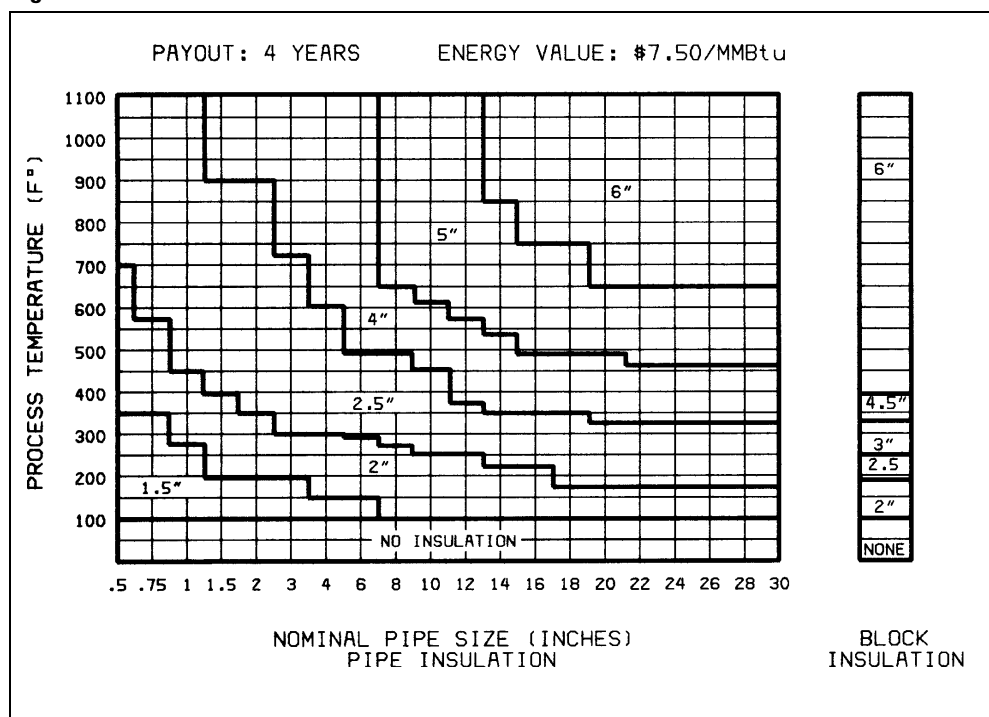
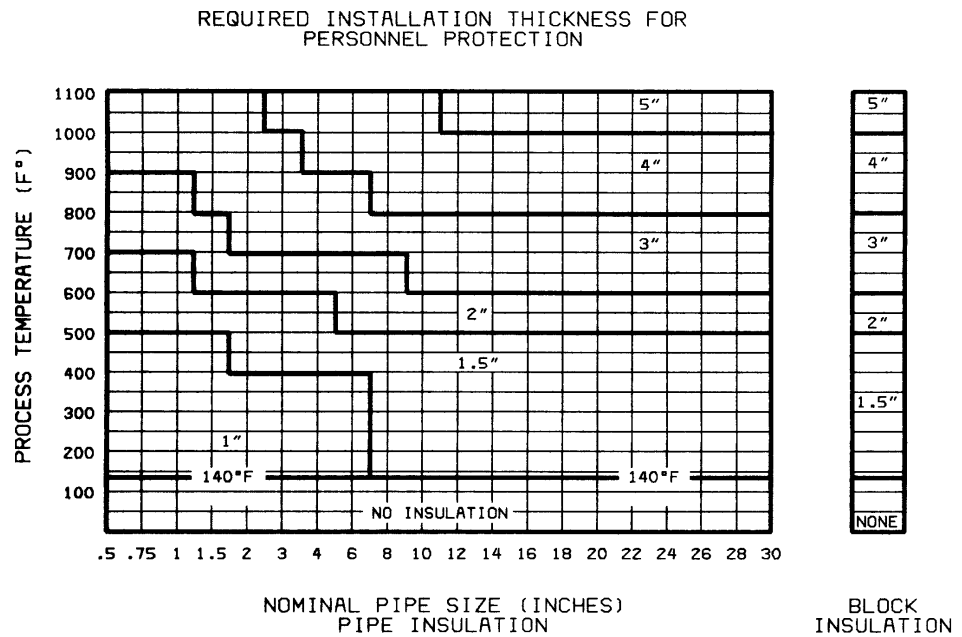
Fig. 300-9 Insulation Selection Chart 7

Fig. 300-10 Insulation Selection Chart for Personnel Protection

1. Required insulation thickness for personnel protection basis:
 Maximum surface temperature 140°F
 Ambient temperature 80°F and
 No wind
 Thermal conductivity—based on manufacturer's data for calcium silicate insulation
2. This chart was compiled from Figure 300-17, "Heat Transfer Through Insulation."
3. Where insulation thickness shown on this chart is greater than the economic thickness, insulation thickness shall be per this chart in areas where personnel protection is required.

Fig. 300-11 Insulation Selection Chart for Valves *Determine payback (\$6 MMBtu) on insulating a 400° F 4-inch valve. Answer: 0.5 years*

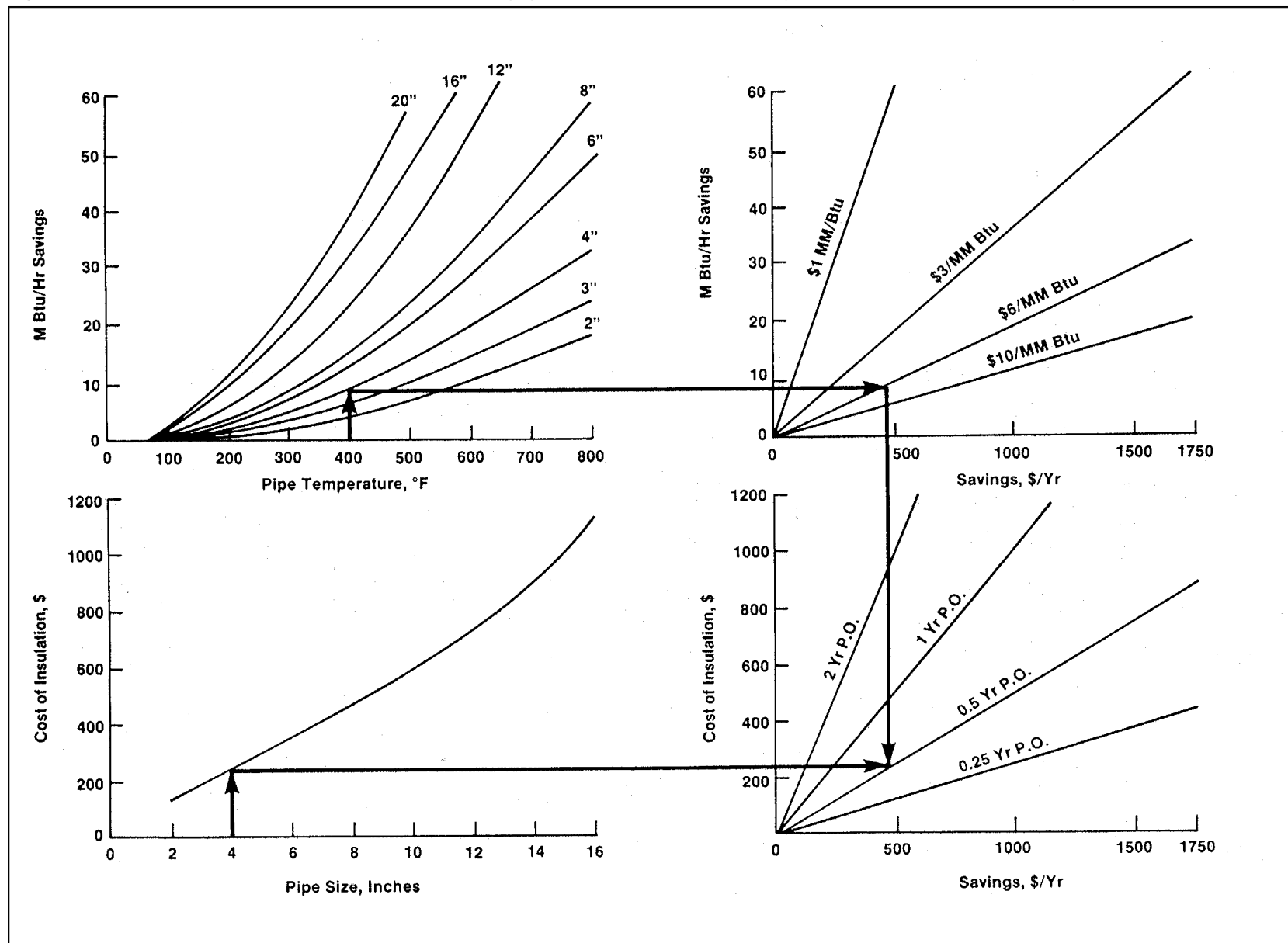


Fig. 300-12 Insulation Selection Chart for Flanges *Determine minimum temperature to achieve a one-year payout (\$6 MMBtu) or better on 10-in. flange covers. Answer: 200°F*

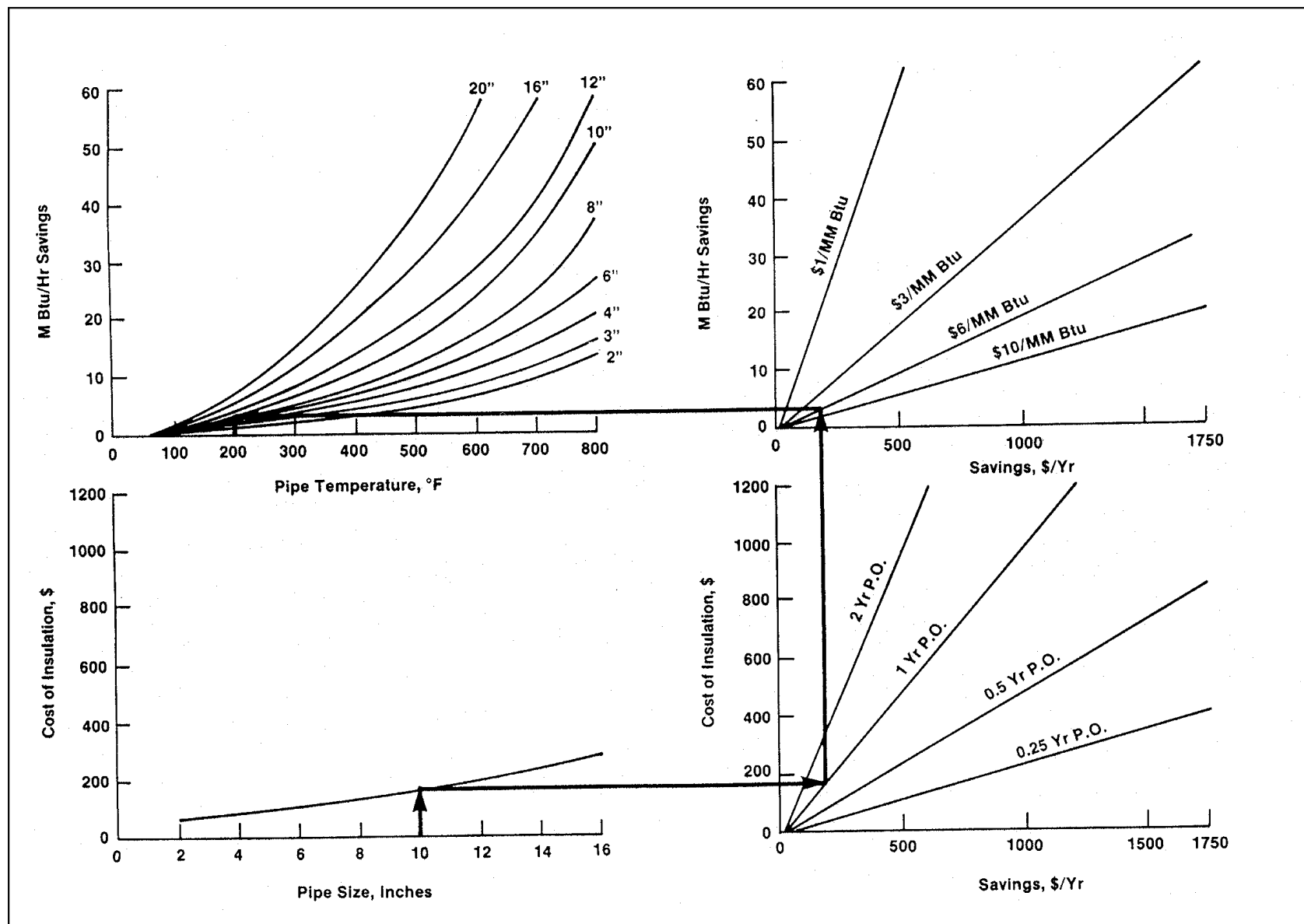


Fig. 300-13 Insulation Selection Chart for Manways *Determine cover cost that achieves a 0.25-year payout (\$6 MMBtu) for a 500° F 24-inch manway cover.*
Answer: \$280

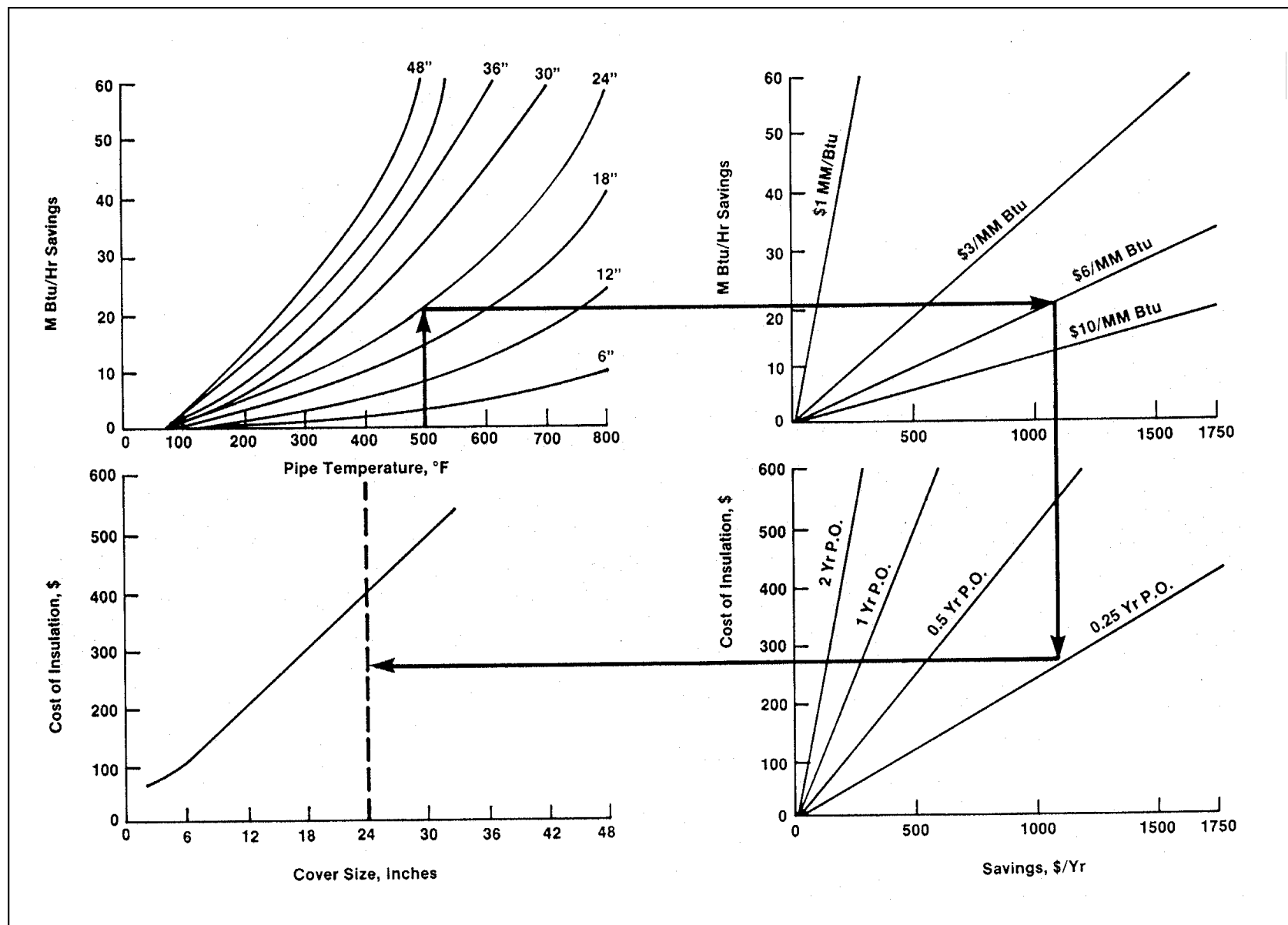


Fig. 300-14 Heat Loss from Horizontal Bare Steel Pipes and Flat Surfaces, in Btu per Sq Ft of Pipe Surface per Hour per °F Temperature Difference Between Pipe and Air

Pipe Size Inches	Linear Foot Factor *	Temperature Difference, °F Between Pipe Surface and Surrounding Air. Air at 80 °F.																			
		50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
1/2	0.220	2.12	2.48	2.80	3.10	3.42	3.74	4.07	4.47	4.86	5.28	5.72	6.19	6.69	7.22	7.79	8.39	9.03	9.70	10.42	11.18
3/4	0.275	2.08	2.43	2.74	3.04	3.35	3.67	4.00	4.40	4.79	5.21	5.65	6.12	6.61	7.15	7.71	8.31	8.95	9.62	10.34	11.09
1	0.344	2.04	2.38	2.69	2.99	3.30	3.61	3.94	4.33	4.72	5.14	5.58	6.05	6.54	7.07	7.64	8.23	8.87	9.55	10.26	11.02
1 1/4	0.435	2.00	2.34	2.64	2.93	3.24	3.55	3.88	4.27	4.66	5.07	5.51	5.97	6.47	7.00	7.56	8.16	8.79	9.47	10.18	10.94
1 1/2	0.497	1.98	2.31	2.61	2.90	3.20	3.52	3.84	4.23	4.62	5.03	5.47	5.93	6.43	6.96	7.52	8.12	8.75	9.43	10.14	10.89
2	0.622	1.95	2.27	2.56	2.85	3.15	3.46	3.78	4.17	4.56	4.97	5.41	5.87	6.37	6.89	7.45	8.05	8.68	9.36	10.07	10.82
2 1/2	0.753	1.92	2.23	2.52	2.81	3.11	3.42	3.74	4.12	4.51	4.92	5.36	5.82	6.31	6.84	7.40	7.99	8.63	9.30	10.01	10.77
3	0.916	1.89	2.20	2.49	2.77	3.07	3.37	3.69	4.08	4.46	4.87	5.31	5.77	6.26	6.79	7.35	7.94	8.57	9.25	9.96	10.71
3 1/2	1.047	1.87	2.18	2.46	2.74	3.04	3.34	3.66	4.05	4.43	4.84	5.27	5.73	6.23	6.75	7.31	7.91	8.54	9.21	9.92	10.67
4	1.178	1.85	2.16	2.44	2.72	3.01	3.32	3.64	4.02	4.40	4.81	5.25	5.71	6.20	6.72	7.28	7.87	8.51	9.18	9.89	10.64
4 1/2	1.309	1.84	2.14	2.42	2.70	2.99	3.30	3.61	4.00	4.38	4.79	5.22	5.68	6.17	6.69	7.25	7.85	8.48	9.15	9.86	10.61
5	1.456	1.83	2.13	2.40	2.68	2.97	3.28	3.59	3.97	4.35	4.76	5.20	5.65	6.15	6.68	7.23	7.82	8.45	9.12	9.83	10.58
6	1.734	1.80	2.10	2.37	2.65	2.94	3.24	3.55	3.94	4.32	4.72	5.16	5.61	6.10	6.63	7.19	7.78	8.41	9.08	9.79	10.54
7	1.996	1.79	2.08	2.35	2.63	2.91	3.21	3.53	3.91	4.29	4.69	5.13	5.58	6.07	6.60	7.15	7.75	8.38	9.05	9.76	10.51
8	2.258	1.77	2.06	2.33	2.60	2.89	3.19	3.50	3.88	4.26	4.67	5.10	5.56	6.05	6.57	7.12	7.72	8.35	9.02	9.73	10.48
9	2.520	1.76	2.05	2.31	2.59	2.87	3.17	3.48	3.86	4.24	4.65	5.08	5.53	6.02	6.54	7.10	7.69	8.32	8.99	9.70	10.45
10	2.814	1.75	2.03	2.30	2.57	2.85	3.15	3.46	3.84	4.22	4.62	5.05	5.51	6.00	6.52	7.08	7.67	8.30	8.97	9.68	10.43
12	3.338	1.73	2.01	2.27	2.54	2.83	3.12	3.43	3.81	4.19	4.59	5.02	5.48	5.96	6.48	7.04	7.63	8.26	8.93	9.64	10.39
14	3.665	1.72	2.00	2.26	2.53	2.81	3.11	3.41	3.79	4.17	4.57	5.00	5.46	5.94	6.47	7.02	7.61	8.24	8.91	9.62	10.37
16	4.189	1.70	1.98	2.24	2.51	2.79	3.08	3.39	3.77	4.14	4.55	4.98	5.43	5.92	6.44	6.99	7.59	8.21	8.88	9.59	10.34
18	4.717	1.69	1.96	2.22	2.49	2.77	3.07	3.37	3.75	4.12	4.53	4.96	5.41	5.90	6.42	6.97	7.56	8.19	8.86	9.57	10.32
20	5.236	1.68	1.95	2.21	2.47	2.75	3.05	3.36	3.73	4.11	4.51	4.94	5.39	5.88	6.40	6.95	7.54	8.17	8.84	9.55	10.29
24	6.283	1.66	1.93	2.19	2.45	2.73	3.02	3.33	3.70	4.07	4.48	4.90	5.36	5.84	6.36	6.92	7.51	8.14	8.80	9.51	10.26
Vertical Surface	1.84	2.14	2.42	2.70	3.00	3.30	3.62	4.00	4.38	4.79	5.22	5.68	6.17	6.70	7.26	7.85	8.48	9.15	9.86	10.62	
Horizontal Surface Facing Upward	2.03	2.37	2.67	2.97	3.28	3.59	3.92	4.31	4.70	5.12	5.56	6.02	6.52	7.05	7.61	8.21	8.85	9.52	10.24	10.99	
Horizontal Surface Facing Downward	1.61	1.86	2.11	2.36	2.64	2.93	3.23	3.60	3.97	4.37	4.80	5.25	5.73	6.25	6.80	7.39	8.02	8.69	9.39	10.14	

Values are for Flat Surfaces four square feet or more in area.

* To secure losses per linear foot, multiply sq ft losses in table by this factor. The losses per sq ft of pipe surface for pipes larger than 24 in. can be considered the same as the losses for the 24-in. pipe.

Fig. 300-15 Log Mean Insulation Area of Pipe (1 of 2)

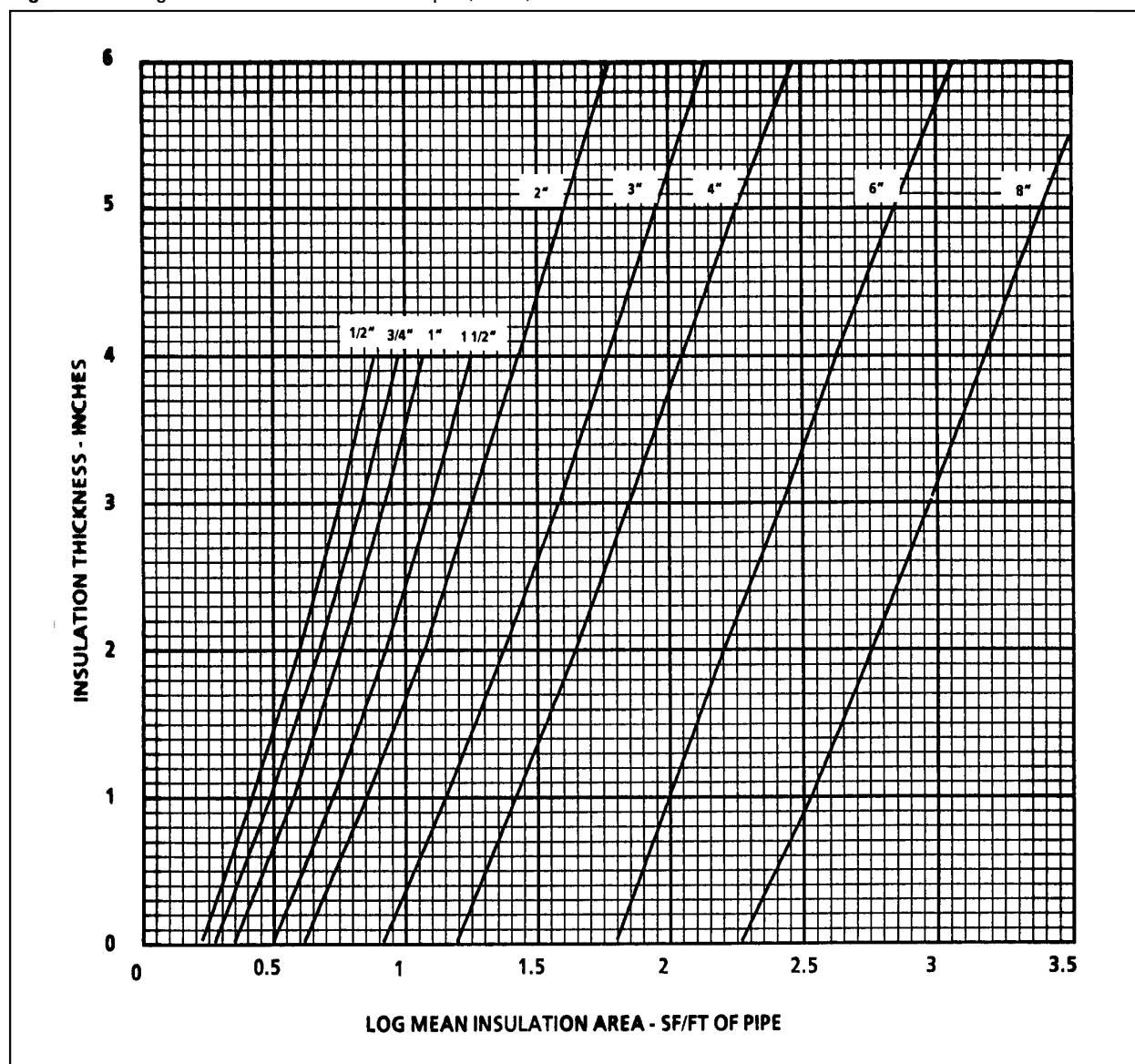


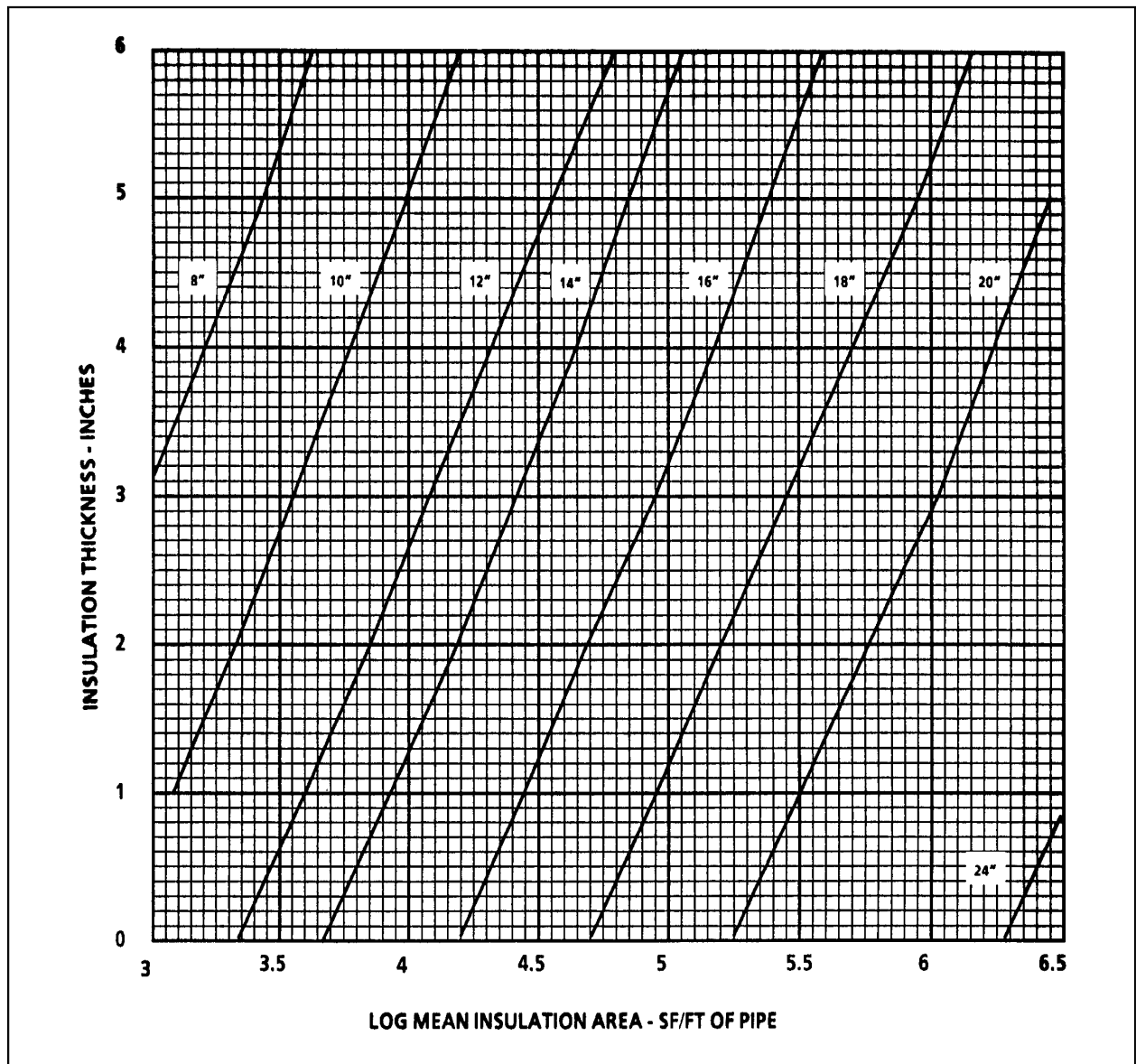
Fig. 300-15 Log Mean Insulation Area of Pipe (2 of 2)

Fig. 300-16 Conductivity of Insulating Materials

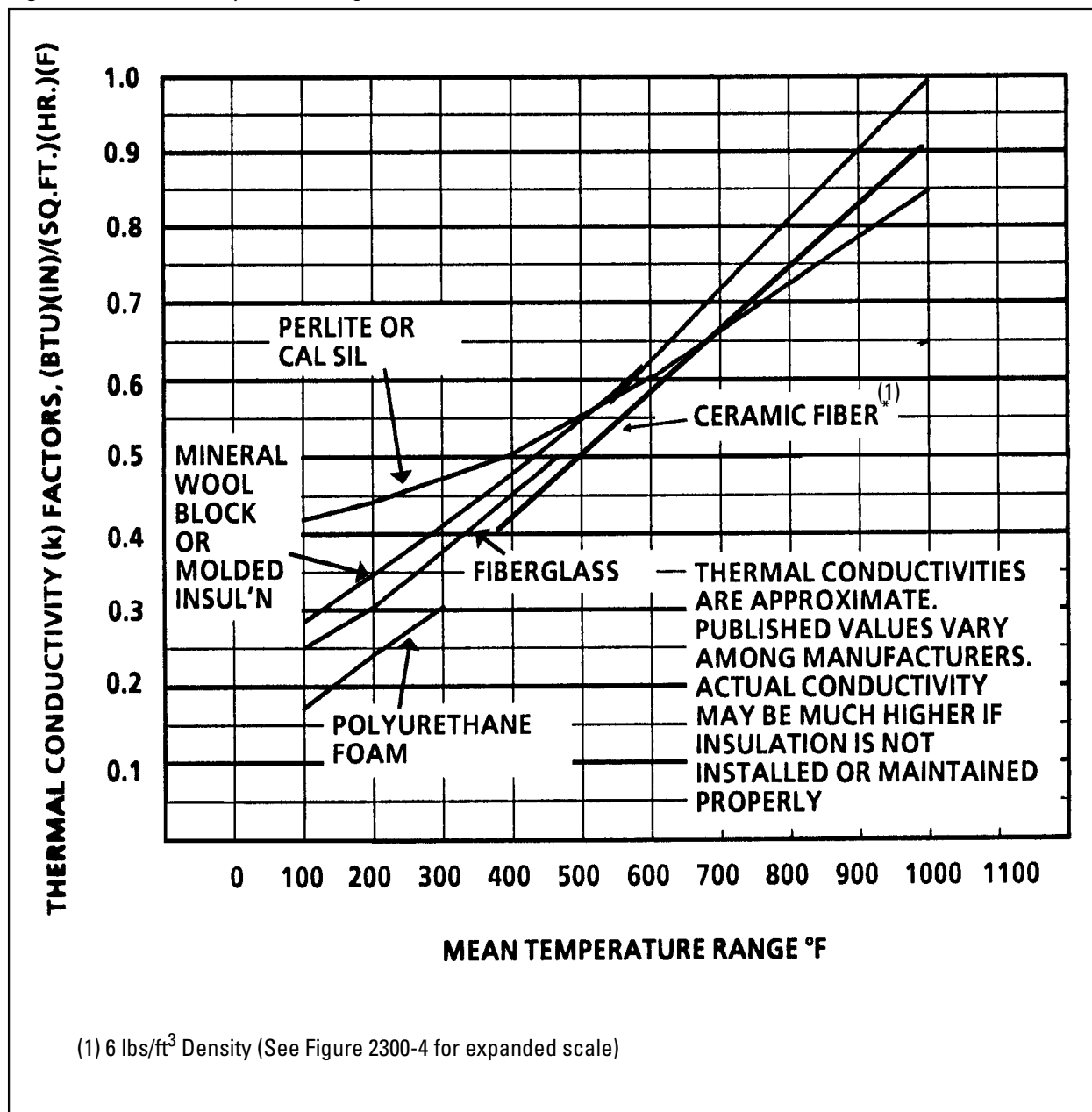
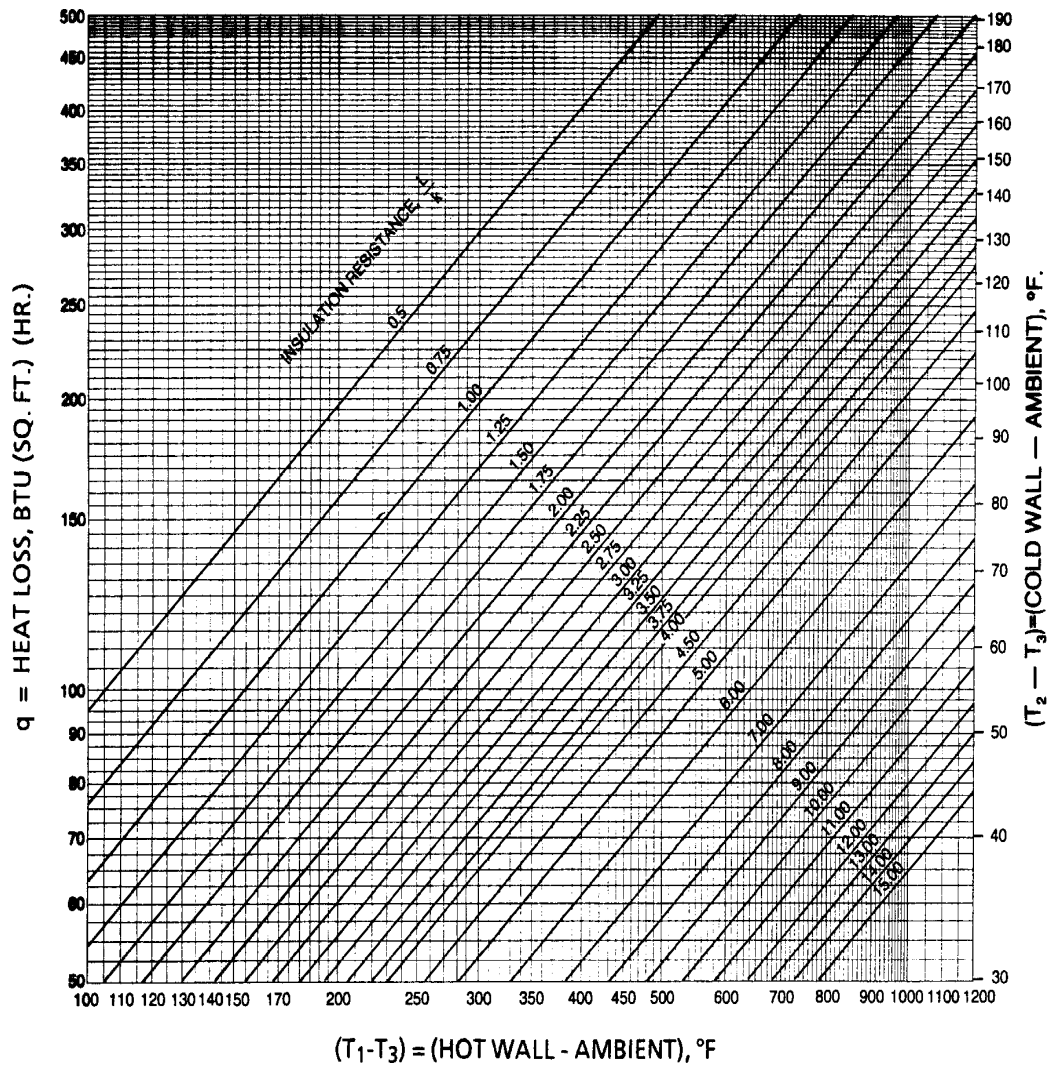


Fig. 300-17 Heat Transfer Through Insulation

**Equations and Symbols**

$$q_1 = h(T_2 - T_3); \quad \frac{T_1 - T_3}{T_2 - T_3} = \frac{Lh}{k} + 1$$

L = Insulation thickness in inches for flat surfaces. For pipe, the equivalent thickness as shown in Figure 300-15 should be used in place of actual thickness.

k = Insulation conductivity, Btu/(sq. ft.) (hr.) (F.) (in.)

h = Air film transfer coefficient (radiation and convection) = $h = 0.0058 (T_2 - T_3) + 1.5$ for common vertical surfaces except polished metal or new aluminum paint. (W. L. Nelson, Pet. Ref. Eng., 1st Ed., pg. 221)

T = Temperatures as shown on chart.

Other symbols as shown. Zero wind velocity assumed.

Fig. 300-18 Equivalent Thickness of Pipe Insulation, L' (inches)

NOMINAL INSULATION THICKNESS (INCHES)											
Nominal Pipe Size	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5	5-1/2	6
1/2	1.729	3.075	4.409	6.787	8.250	9.982	10.742	13.525	15.320	—	—
3/4	1.434	2.658	3.883	6.083	7.446	9.060	10.641	12.374	14.058	—	—
1	1.713	2.767	4.013	5.357	6.701	8.112	9.580	11.196	12.765	—	—
1-1/2	1.455	2.381	4.023	5.250	6.474	7.675	9.091	10.562	11.898	—	—
2	1.435	2.364	3.396	4.445	5.560	6.733	8.035	9.310	10.627	—	—
3	1.287	2.111	2.967	3.888	4.866	5.963	7.043	8.167	9.554	10.759	11.999
4	1.280	2.009	2.803	3.656	4.619	5.574	6.573	7.874	8.890	10.004	11.149
6	1.135	1.794	2.554	3.313	4.118	5.180	6.015	6.936	7.885	8.931	9.877
8		1.771	2.444	3.389	4.051	4.840	5.661	6.511	7.389	8.294	9.224
10		1.806	2.457	3.134	3.846	4.588	5.357	6.153	6.974	7.819	8.687
12		1.771	2.402	3.098	3.743	4.451	5.191	5.948	6.727	7.535	8.358
14		1.648	2.256	2.900	3.562	4.257	4.968	5.703	6.465	7.242	8.046
16		1.628	2.231	2.831	3.502	4.169	4.865	5.574	6.311	7.059	7.834
18		1.612	2.205	2.811	3.449	4.098	4.776	5.473	6.180	6.914	7.656
20		1.607	2.187	2.789	3.410	4.051	4.710	5.387	6.082	6.792	7.520
24		1.589	2.149	2.739	3.347	3.958	4.598	5.254	5.913	6.598	7.298
30		1.572	2.122	2.687	3.281	3.874	4.481	5.116	5.748	6.393	7.065

$$L' = r_1 \ln r_1/r_2 \text{ where}$$

 r_1 = radius outside of insulation

 r_2 = radius inside of insulation

Fig. 300-19 Heat Loss from Hot Surfaces to Air
