

Table 1.... Thermal Conductivity (*k*) of Industrial and Pipe Insulations
(For Mean Temperatures Indicated)
Expressed in Btu per (hour) (square foot) (Fahrenheit degree temperature difference per in.)

Form	Material (Composition)	Accepted Max. Temp. for Use, °F	Density lb./Cu Ft	Typical Conductivity <i>k</i> at Mean Temp. Fahr.							
				40	70	100	200	300	500	700	900
BLANKETS	MINERAL WOOL (Rock, Slag, or Glass)										
	Metal Reinforced	1200	8-15			0.29	0.35	0.42	0.56		
	Felt-Flexible Type	450	0.5-3	0.23	0.26	0.28	0.34	0.45			
	Felt-Semi-Rigid Type	450	2-8	0.24	0.25	0.27	0.35	0.44			
	VEGETABLE & ANIMAL FIBER Hair Felt or Hair Felt plus Jute	180	10	0.27	0.28	0.30					
BLOCKS AND BOARDS	ASBESTOS										
	Molded Amosite & Binder	1200	18			0.37	0.40	0.47	0.56	0.66	0.76
	Laminated Asbestos Paper	700	30			0.40	0.45	0.50	0.60		
	Corrugated & Laminated Asbestos Paper										
	4 ply	300	11-13		0.54	0.57	0.68	0.80			
	6 ply	300	15-17		0.49	0.51	0.59	0.69			
	8 ply	300	18-20		0.47	0.49	0.57	0.65			
	CALCIUM SILICATE	1200	11			0.33	0.38	0.43	0.53	0.64	0.75
	CELLULAR GLASS	800	9	0.37	0.39	0.41	0.48	0.55			
	CORKBOARD (Without Added Binder)	200	6.5-8	0.26	0.27	0.28			0.60	0.64	0.68
	DIATOMACEOUS SILICA	1500	22						0.70	0.75	0.80
	1900	25									
	85% MAGNESIA Mag. Carb. & Asbestos	600	11-14			0.35	0.38	0.42	0.46		
	MINERAL WOOL (Rock, Slag or Glass)										
	Low Temp. (Asphalt or Resin Bonded)	200	6-18	0.28	0.29	0.30					
	High Temp. (Resin Bonded)	600	6-10			0.28	0.35	0.43			
	(With Inorganic Binder)	1600	16-24			0.34	0.39	0.44	0.54	0.64	
PIPE IN- SULA- TION	PLASTICS (Foamed)	175	1.6	0.26	0.28	0.30					
	RUBBER (Foamed)	150	5	0.23	0.24	0.25					
	ASBESTOS										
	Molded Amosite & Binder	1200	16			0.33	0.38	0.43	0.53		
	Laminated Asbestos Paper	700	30			0.40	0.45	0.50	0.60		
	Corrugated & Laminated Asbestos Paper										
	4 Ply per in.	300	11-13		0.54	0.57	0.62	0.80			
	6 Ply per in.	300	15-17		0.49	0.51	0.59	0.69			
	8 Ply per in.	300	18-20		0.47	0.49	0.57	0.65			
	CALCIUM SILICATE	1200	11			0.36	0.40	0.44	0.55		
	Caic. Sil. & Asbestos	800	9	0.37	0.39	0.41	0.48	0.55			
	CELLULAR GLASS	200	7-10	0.27	0.28	0.29	0.30		0.64	0.66	0.71
	CORK (Without Added Binder)	1500	22						0.70	0.75	0.80
	DIATOMACEOUS SILICA	1900	25								
	85% MAGNESIA Mag. Carb. & Asbestos	600	11-14			0.39	0.42	0.45	0.51		
	MINERAL WOOL (Rock, Slag or Glass)										
	Low Temp. (Asphalt or Resin Bonded)	200	15	0.28	0.30	0.33	0.39				
	Low Temp. (Fine Fiber Resin Bonded)	450	3	0.22	0.23	0.24	0.27	0.31			
INSU- LAT- ING CE- MENT	High Temp. Blanket-Type (Metal Reinforced)	1200	6-15			0.29	0.36	0.42	0.56		
	PLASTICS (Foamed)	175	1.6	0.26	0.28	0.31					
	RUBBER (Foamed)	150	5	0.23	0.24	0.25					
	VEGETABLE & ANIMAL FIBER										
	Wool Felt	180	20	0.29	0.31	0.33					
	Hair Felt or Hair Felt plus Jute	180	10	0.27	0.28	0.30					
	85% MAGNESIA Mag. Carb. & Asbestos	600	18			0.46	0.52	0.58			
	MINERAL WOOL (Rock, Slag or Glass)										
	With Colloidal Clay Binder	1800	24-30			0.49		0.61	0.73	0.83	

* These temperatures are generally accepted as maximum. When operating temperature approaches these limits the Manufacturer's recommendations should be followed.

Industrial Insulation

material for a specific service becomes more critical and must be based on experience and factual performance data (see Table 1).

FORMS OF INSULATION

The physical form of industrial insulations varies from powders and loose fills which might be called *formless*, through materials with varying degrees of compressibility and flexibility, to completely rigid shapes often referred to as preformed insulation. After deciding that a material has the necessary insulating value, physical properties, and temperature resistance, the choice of the form desired will usually be governed by considerations of material and application cost. The application method and cost in turn will be greatly affected by the nature of the surface to be covered.

Loose fills such as powders and granules must be supported in place by retaining walls, coverings, etc. for application on vertical surfaces and on the under side of horizontal surfaces. Insulating cement is a loose material which when mixed with water to obtain plasticity and adhesion, may be trowelled on a surface and dried in place to serve as *insulation*. Both loose-fill and insulating cement are especially suited for covering uneven and irregular surfaces.

Flexible and nonrigid insulations are generally grouped as blanket insulation, and are available in many types and varieties, both organic and inorganic, with and without binders, and with reinforcing coverings on one or both sides. Such materials include hair, plastics, and rubber in the organic field, and asbestos and mineral wool in the inorganic field. Coverings and facings such as paper, aluminum, asbestos sheet, wire mesh, metal lath, may be used as reinforcing, vapor barriers, reflective surfaces, or surface finishes in general. Thicknesses and shapes may be of any dimension that can be handled although standard sizes are generally used. Some blanket insulations are prepared in roll form for economical shipping.

Rigid materials are preformed during manufacture to standard lengths, widths, and thicknesses of a size that can be handled readily. In the case of insulation for pipes and cylindrical surfaces the radius of curvature is varied to suit all standard sizes of pipe and tubing. Some materials are offered in shapes curved to fit greater radii up to several feet or more. Material in rectangular dimensions is usually called block, board, or sheets, the name varying with custom for particular uses.

BARE SURFACE HEAT LOSSES—FLAT SURFACES AND PIPE

Heat losses from or to uninsulated surfaces of pipes, ducts, vessels, or furnaces may be of considerable magnitude if the temperature of the surrounding medium differs appreciably from that of the surface. Losses are increased by motion of the surrounding air or by contact of the hot or cold surface with bodies of high conductivity. Good design, therefore, must include consideration of such heat losses and provision for adequate insulation wherever needed.

The basic principles of heat loss from surfaces are discussed in Chapter 5. In that chapter radiation and convection are treated separately.

Heat losses from horizontal bare steel pipes, based on tests at Mellon Institute and calculated from the fundamental radiation and convection equations (Chapter 5), are given in Table 2. This table also gives the heat losses or surface conductances for flat vertical and horizontal surfaces for surface

temperatures up to 1080 F with the surrounding air at 80 F. The surface per linear foot of pipe is given in the second column of Table 2.

Heat losses from tarnished copper pipe and tube are given in Table 3. The surface per linear foot of tube is given in Table 4. Table 3, Section A, of Chapter 9 also gives the surface conductances for flat surfaces of different emissivities and orientations in contact with still air. Table 5 gives the area in square feet of flanges and fittings for various standard pipe sizes. These tables can be used to advantage in estimating the amount of insulation required.

Examples 1 and 2 show how the annual heat loss from uncovered pipe and its dollar value may be computed from the data in Table 2.

Example 1: Compute the total annual heat loss from 165 ft of 2 in. bare pipe in service 4000 hr per year. The pipe is carrying steam at 10 psi pressure and is exposed to an average air temperature of 80 F.

Solution: The pipe temperature is taken as the steam temperature, which is 239.4 F, obtained by interpolation from Steam Tables. The temperature difference between the pipe and air = 239.4 - 80 = 159.4 F. By interpolation in Table 2 between temperature differences of 150 and 200 F, the heat loss from a 2-in. pipe at a temperature difference of 159.4 F is found to be 2.615 Btu per (hr) (sq ft) (F deg). The total annual heat loss from the entire line = 2.615 × 159.4 × 0.622 (linear ft factor) × 165 (linear ft) × 4000 (hr) = 171,100 Mb. (Mb = 1000 Btu.)

Example 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 the previous example. If the system is operating at an overall efficiency of 55 percent, determine the monetary value of the annual heat loss from the line.

Solution: The cost of heat per 1000 Mb 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 × 171.1 (thousand Mb) = \$137.56.

CONDUCTIVITY OF INDUSTRIAL INSULATIONS

The conductivities of various materials used for insulating steam and hot water systems are given in Table 1. They are given as functions of the mean temperatures or the arithmetic mean of the inner and outer surface temperatures of the insulations.

HEAT FLOW CALCULATIONS

The heat losses through 1, 1½, and 2-in. thick pipe insulation on various size pipes for various temperature differences between the pipe and the surrounding atmosphere up to 525 F, are shown in Figs. 1, 2, and 3.

The actual thickness of many molded pipe coverings is not exactly 1 in. However, the loss through any given thickness of insulation can be obtained by interpolation.

The heat losses through 1, 1½, and 2-in. thick block, blanket, or cement insulation when applied to a flat vertical surface is given in Fig. 4.

The losses through any of the insulations given in Table 1 can be obtained by multiplying the losses obtained from Figs. 1, 2, 3, or 4 by the factors given in Table 6.

Pipes operating at high temperatures are frequently insulated to the best advantage by combining a high temperature insulation near the pipe with a moderate or low temperature insulation around it as an outer layer. By this method an efficient material may be used for each of the two temperature ranges encountered. In calculating the heat loss through such a combination the mean temperature of each