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 non-rigid 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. Only inherently fibrous materials are generally suited for blanket insulation. Such materials are wood, cotton, and hair 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. Most common sizes of block insulation are 36 in. long, 6 in. or 12 in. wide, and in thicknesses ranging from 1 to 4 in. *Boards* in the building insulation field range up to 12 ft long by 4 ft wide with the thickness usually ½ to 1 in. but ranging up to 1½ in. Smaller *boards*, or sheets, are used on air conditioning ducts, equipment, and in the cold storage field.

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 4. 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.

TABLE 2. HEAT LOSSES FROM HORIZONTAL BARE STEEL PIPES AND FLAT SURFACES

In Btu per Sq Ft of Pipe Surface per Hour per F Deg Temperature Difference Between Pipe and Air

Pipe Size Inches	Linear Foot Factor[a]	Temperature Difference F Deg 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
½	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
¾	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
1¼	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
1½	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
2½	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
3½	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
4½	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	2.91	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.

[a] 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.

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