r_2 = outer radius of insulation, inches.
k = thermal conductivity of insulation, Btu per (hour) (square foot) (Fahrenheit degree per inch).
t_1 = temperature of inner surface of insulation, Fahrenheit degrees.
t_2 = temperature of outer surface of insulation, Fahrenheit degrees.

It is convenient to work from the outer surface of the insulation, since the loss through the covering must be determined from the outer surface loss by means of surface loss curves such as given in Fig. 4. The curves were plotted from tests conducted at the *Mellon Institute*.

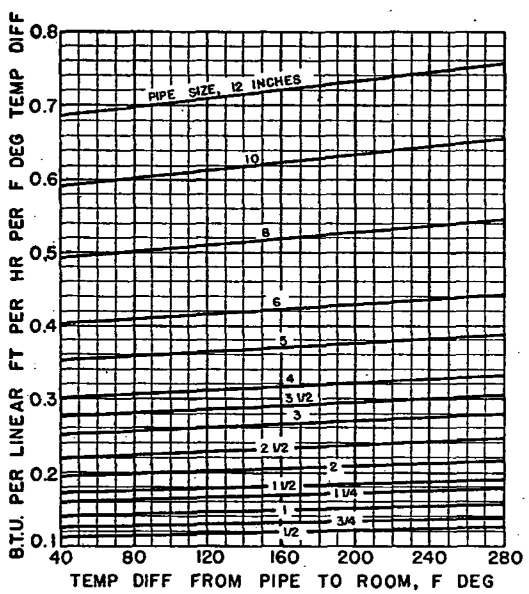

Fig. 3. Heat Loss Through 2 In. Thick 85 Percent Magnesia Type Covering

After the true heat loss is obtained, the loss per square foot of pipe surface can be calculated from the relationship:

$$q_i = q_o(r_2/r_1)$$

where

q_i = Btu per (hour) (square foot outer surface of pipe).

The heat loss through two or more thicknesses of insulation applied to a pipe can be calculated by means of the equation:

$$q_o = \frac{t_1 - t_2}{\dfrac{r_s \log_e \dfrac{r_2}{r_1}}{k_1} + \dfrac{r_s \log_e \dfrac{r_3}{r_2}}{k_2} + \cdots} \quad (2)$$

where

r_3 = outer radius of second layer of insulation, inches.
r_s = outer radius of last layer of insulation, inches.

The method of solving Equation 2, which is the most difficult of the two, is given in *Example 3*.

Example 3: Compute the heat loss per linear foot of pipe surface per hour from a 6-in. pipe, insulated with a 3-in. thickness of diatomaceous silica, 1900 F maximum type, and a 2-in. thickness of 85 percent magnesia. The pipe is operating at a temperature of 1200 F and is exposed to a room temperature of 80 F.

Solution: In figuring the heat loss from Equation 2, it is necessary to first make an assumption for the outer surface temperature t_2 and the temperature between the diatomaceous silica and 85 percent magnesia insulation, so that the mean temperature of each material can be obtained and the thermal conductivity corresponding to the mean temperature of each material substituted in the formula. First assume an outer surface temperature of 140 F and a temperature of 570 F between the two materials corresponding to a mean temperature of (1200 + 570) ÷ 2 or 885 F for the diatomaceous silica and (570 + 140) ÷ 2 or 355 F for the 85 percent magnesia insulation. The conductivities of these two materials at mean temperatures of 885 and 355 F, interpolated from Table 6, are 0.796 and 0.467 Btu, respectively.

Table 7. Pipe Covering Factors to be Applied to Figs. 1, 2 and 3

Type of Pipe Insulation	Mean Temperature, Fahrenheit							
	40	70	100	200	300	500	700	900
85% MAGNESIA	1.05	1.05	1.05	1.05	1.05	1.05		
MOULDED AMOSITE AND BINDER	—	—	0.89	0.95	1.01	1.09	—	—
LAMINATED ASBESTOS PAPER (35–40 Per In.)	—	—	1.08	1.13	1.07	1.24	—	—
CORRUGATED AND LAMINATED ASBESTOS PAPER								
4 Ply Per In.	—	1.49	1.54	1.70	1.87	—	—	—
6 Ply Per In.	—	1.35	1.37	1.48	1.62	—	—	—
8 Ply Per In.	—	1.30	1.32	1.43	1.52	—	—	—
CALCIUM SILICATE	—	—	0.97	1.00	1.03	1.13	—	—
CELLULAR GLASS	1.05	1.08	1.10	1.20	1.29	—	—	—
DIATOMACEOUS SILICA (22 lb 1 cu ft)	—	—	—	—	—	1.24	1.18	1.14
DIATOMACEOUS SILICA (25 lb 1 cu ft)	—	—	—	—	—	1.44	1.39	1.34
MINERAL WOOL (Rock, Slag or Glass)								
Low Temp. (Asphalt or Resin Bonded)	0.80	0.83	0.89	0.98	—	—	—	—
Low Temp. (Fine Fiber Resin Bonded)	0.63	0.64	0.65	0.68	0.73	—	—	—
High Temp. (Blanket, Metal Reinforced)	—	—	0.78	0.90	0.98	1.05	—	—
PLASTICS (Foamed)	0.74	0.78	0.84	—	—	—	—	—
RUBBER (Foamed)	0.66	0.72	0.68	—	—	—	—	—
WOOL FELT	0.83	0.86	0.89	—	—	—	—	—
HAIR FELT OR HAIR FELT PLUS JUTE	0.77	0.78	0.81	—	—	—	—	—

These values are substituted in Equation 2 and a trial calculation made. For a nominal 6-in. steel pipe: r_1 = 3.312, r_2 = 6.312, and r_3 = 8.312. Then,

$$q_o = \frac{1200 - 140}{\dfrac{8.312 \log_e \dfrac{6.312}{3.312}}{0.796} + \dfrac{8.312 \log_e \dfrac{8.312}{6.312}}{0.467}} = \frac{1060}{6.74 + 4.89} = 91.1 \text{ Btu.}$$

The temperature drop from the outer surface of the insulation to the surrounding air for a heat loss of 91.1 Btu is found from Fig. 4 to be 55 deg for a 16-in. O.D. cylindrical surface, or 55 + 80 F room temperature = 135 F surface temperature. Since a surface temperature of 140 F was assumed, it is evident that a temperature closer to 135 F, or, for instance, 136 F should be used for recalculation:

$$q_o = \frac{1200 - 136}{6.74 + 4.89} = 91.5 \text{ Btu.}$$

Since the temperature drop through each material is equal to the heat flow times the actual resistance of each material, the temperature drop through the diatomaceous silica is 91.5 × 6.74 = 617 F, or the temperature between the two insulating materials is (1200 − 617) = 583 F. Since a temperature of 570 F between the two materials was