Table 26 .... Simplified Thicknesses (L) for Rigid Pipe Insulations

Iron Pipe			Nominal Thickness, Inches								
Size, in.	O.D., in.	r_o, in.	1	1½	2	2½	3	3½	4	4½	5
½	0.84	0.42	1.00	1.56	2.06	2.88	3.38	3.88	4.38	4.94	5.44
¾	1.05	0.52	0.88	1.44	1.94	2.75	3.25	3.75	4.25	4.81	5.31
1	1.32	0.66	1.06	1.56	2.09	2.63	3.13	3.63	4.13	4.69	5.19
1¼	1.66	0.83	0.88	1.63	1.91	2.44	2.94	3.44	3.94	4.53	5.03
1½	1.90	0.95	1.00	1.50	2.31	2.81	3.31	3.81	4.38	4.91	5.41
2	2.38	1.19	1.03	1.56	2.09	2.59	3.09	3.59	4.16	4.66	5.16
2½	2.88	1.44	1.03	1.84	2.34	2.84	3.34	3.91	4.41	4.91	5.53
3	3.50	1.75	1.00	1.53	2.03	2.53	3.03	3.59	4.09	4.59	5.22
3½	4.00	2.00	1.28	1.78	2.28	2.78	3.34	3.84	4.34	4.34	4.97
4	4.50	2.25	1.03	1.53	2.03	2.53	3.09	3.59	4.09	4.72	5.22
4½	5.00	2.50	1.28	1.78	2.28	2.84	3.34	3.84	4.47	4.47	4.97
5	5.56	2.78	1.00	1.50	2.00	2.56	3.06	3.56	4.19	4.69	5.19
6	6.63	3.31	0.97	1.47	2.03	2.53	3.03	3.66	4.16	4.66	5.22
7	7.63	3.81	—	1.53	2.03	2.53	3.16	3.66	4.16	4.66	5.16
8	8.63	4.31	—	1.53	2.03	2.66	3.16	3.66	4.16	4.66	5.16
9	9.63	4.81	—	1.53	2.16	2.66	3.16	3.66	4.16	4.66	5.16
10	10.75	5.37	—	1.59	2.09	2.59	3.09	3.59	4.09	4.59	5.09
11	11.75	5.87	—	1.59	2.09	2.59	3.09	3.59	4.09	4.59	5.09
12	12.75	6.37	—	1.56	2.06	2.56	3.06	3.56	4.06	4.59	5.09
14	14.00	7.00	—	1.44	1.94	2.44	2.94	3.44	3.94	4.44	4.94
Over 14 up to and including 33			—	1.44	1.94	2.44	2.94	3.44	3.94	4.44	4.94

k = thermal conductivity of insulation at mean temperature, Btu per (hour) (square foot) (Fahrenheit degree per inch thickness).
L = thickness of insulation, inches.
t_a = temperature of ambient air, Fahrenheit.
t_o = temperature of inner surface of insulation, Fahrenheit.
t_s = temperature of outer surface of insulation, Fahrenheit.
$t_1, t_2, \cdots$ = intermediate surface temperatures of layers of insulation, Fahrenheit.
r_o = inner radius of insulation, inches.
r_s = outer radius of insulation, inches.
$r_1, r_2, \cdots$ = outer radius of intermediate layers of insulation, inches.
R_s = surface resistance = $1/h$, (hour) (square foot) (Fahrenheit degree) per Btu.
h = surface conductance coefficient, Btu per (hour) (square foot) (Fahrenheit degree).
$\log_e$ = natural or Naperian logarithm.

To calculate the heat flow per square foot of pipe surface, Equation 12 can be used.

$$q_o = q_s\, r_s/r_o \tag{12}$$

where

q_o = rate of heat transfer per square foot of pipe surface, Btu per (hour) (square foot).

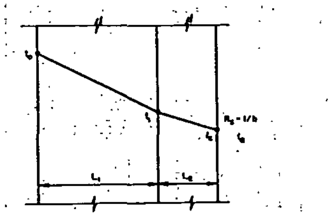

Fig. 5 .... Heat Flow Through Flat Surfaces

For steady state conditions, the heat flow through each successive material is the same. However, the temperature drop through each material is proportional to its thermal resistance. The terms which appear in the denominators of Equations 10 and 11 represent the resistances to heat flow.

The heat transferred is inversely proportional to the sum of the resistances ($R_1 + R_2 + \cdots + R_s$) of the system. The various temperature drops in the system are proportional to the resistances.

The assumptions used for calculations of heat loss are usually:

t_o = temperature at inner surface of insulation equal to the temperature of fluid in the pipe or container.
t_a = still air ambient temperature = 80 F.
r_o = inner radius of insulation = outside radius of iron pipe.
r_s = outer radius of insulation = $r_o + L$.

Example 13: Compute the heat loss from a boiler wall if the interior insulation surface temperature is 1100 F and the ambient still air temperature is 80 F. The wall is insulated with 4½ in. of mineral fiber block and ½ in. of mineral fiber insulating and finishing cement.

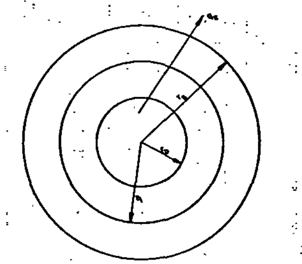

Fig. 6 .... Heat Flow Through Cylindrical Surfaces

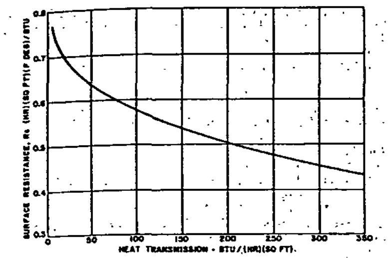

Fig. 7 .... Heat Transmission vs Surface Resistance for Flat and Cylindrical Surfaces

Solution: Assume that the mean temperature of the mineral fiber block is 700 F, the mean temperature of the insulating cement is 200 F, and $R_s = 0.60$.

From Table 21, $k_1 = 0.64$ and $k_2 = 0.80$. Then,

$$q_s = \frac{1100 - 80}{\frac{4.5}{0.64} + \frac{0.5}{0.80} + 0.60} = \frac{1020}{8.26} = 123.5 \text{ Btu/(hr) (sq ft)}$$

As a check, from Fig. 7, at 123.5 Btu/(hr) (sq ft), $R_s = 0.55$.
The mean temperature of the mineral fiber block is:

$$1100 - (3.52/8.26)(1020) = 1100 - 435 = 665 \text{ F.}$$

The mean temperature of the insulating cement is:

$$1100 - (7.35/8.26)(1020) = 1100 - 908 = 192 \text{ F.}$$

From Table 21, at 665 F, $k_1 = 0.62$, and at 192 F, $k_2 = 0.80$.
Recalculating q_s with these adjusted values:

$$q_s = \frac{1020}{\frac{4.5}{0.62} + \frac{0.5}{0.80} + 0.55} = \frac{1020}{8.48} = 120.3 \text{ Btu/(hr) (sq ft).}$$

From Fig. 7, at 120.3 Btu/(hr) (sq ft), $R_s = 0.55$.
The mean temperature of the mineral fiber block is:

$$1100 - (3.65/8.48)(1020) = 1100 - 439 = 661 \text{ F.}$$

The mean temperature of the insulating cement is:

$$1100 - (7.62/8.48)(1020) = 1100 - 917 = 183 \text{ F.}$$

From Table 21, at 661 F, $k_1 = 0.62$, and at 183 F, $k_2 = 0.80$.
Since R_s, k_1 and k_2 do not change at these values, $q_s = 120.3$ Btu/(hr) (sq ft).

Example 14: Compute the heat loss per square foot of outer surface of insulation if the pipe temperature is 1200 F and the ambient still air temperature is 80 F. The pipe is a nominal 6 in. iron pipe and is insulated with a nominal 3 in. of diatomaceous silica as the inner layer and a nominal 2 in. of calcium silicate as the outer layer.

Solution: From Table 26, $r_o = 3.31$ in. A nominal 3-in. thick diatomaceous silica insulation to fit a nominal 6-in. iron pipe is 3.03 in. thick. A nominal 2-in. thick calcium silicate insulation to fit over the 3.03 in. diatomaceous silica is 2.06 in. thick. Therefore, $r_o = 3.31$ in.; $r_1 = 6.34$ in.; and $r_s = 8.40$ in.

Assume that the mean temperature of the diatomaceous silica is 600 F, the mean temperature of the calcium silicate is 250 F, and $R_s = 0.50$.

From Table 21, $k_1 = 0.68$ and $k_2 = 0.40$:

$$q_s = \frac{1200 - 80}{\frac{8.40 \log_e \frac{6.34}{3.31}}{0.68} + \frac{8.40 \log_e \frac{8.40}{6.34}}{0.40} + 0.50}$$

$$= \frac{1120}{\frac{5.45}{0.68} + \frac{2.35}{0.40} + 0.50} = 77.6 \text{ Btu/(hr) (sq ft)}$$

From Fig. 7, at 77.6 Btu (hr) (sq ft), $R_s = 0.59$.
The mean temperature of the diatomaceous silica is:

$$1200 - (4.00/14.40)(1120) = 1200 - 313 = 887 \text{ F.}$$

The mean temperature of the calcium silicate is:

$$1200 - (10.97/14.40)(1120) = 1200 - 853 = 347 \text{ F.}$$

From Table 21, $k_1 = 0.74$ and $k_2 = 0.44$.
Recalculating:

$$q_s = \frac{1120}{\frac{5.45}{0.74} + \frac{2.35}{0.44} + 0.59} = 84.1 \text{ Btu/(hr) (sq ft)}$$

From Fig. 7, at 84.1 Btu (hr) (sq ft), $R_s = 0.58$.
The mean temperature of the calcium silicate is:

$$1200 - (10.04/13.30)(1120) = 1200 - 846 = 354 \text{ F.}$$

From Table 21, $k_1 = 0.74$ and $k_2 = 0.44$.

$$q_s = \frac{1120}{\frac{5.45}{0.74} + \frac{2.35}{0.44} + 0.58} = 84.2 \text{ Btu/(hr)(sq ft)}$$

Since R_s, k_1, and k_2 will not change at 84.2 Btu/(hr) (sq ft), the heat loss is 84.2 Btu/(hr) (sq ft).

The heat loss per square foot of the inner surface of insulation would be:

$$q_o = q_s \frac{r_s}{r_o} = 84.2\left(\frac{8.40}{3.41}\right) = 214 \text{ Btu/(hr) (sq ft).}$$

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