Table 5 .... The Apparent Mean Thermal Conductivity k of Some Selected Multiple Layer Insulations

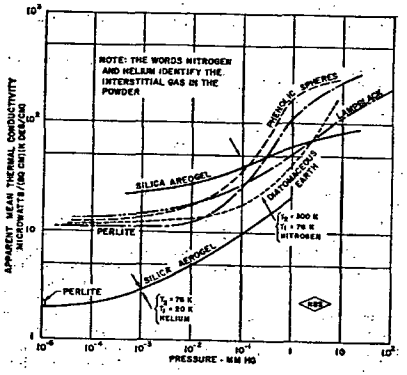
(For Insulators and Reflectors Described Below Table)

Insulator	Reflectors	t In.	Shields Number per in.	Density Lb per cu ft	Temp Cold Wall R	k*
A	2	1.3	55	7.5	137	0.32×10^{-4}
					36	0.23×10^{-4}
B	1	1.5	50	7.0	137	0.30×10^{-4}
					36	0.24×10^{-4}
B	1	1.0	50	7.0	137	0.41×10^{-4}
					36	0.35×10^{-4}
A	1	1.2	52	—	137	0.75×10^{-4}
A	3	1.5	—	3.8	137	1.85×10^{-4}
					36	1.39×10^{-4}
A	1	1.4	37	6.9	137	0.43×10^{-4}
					36	0.30×10^{-4}
A	1	1.5	23	6.9	137	0.49×10^{-4}
C	1	1.2	29	6.9	137	0.41×10^{-4}
					36	0.29×10^{-4}
A	2	2.0	48	7.5	137	0.64×10^{-4}
D	1	1.2	52	—	137	1.33×10^{-4}
A	2	1.5	52	5.9	137	0.87×10^{-4}

* Btu/(hr) (sq ft) (R deg/ft).

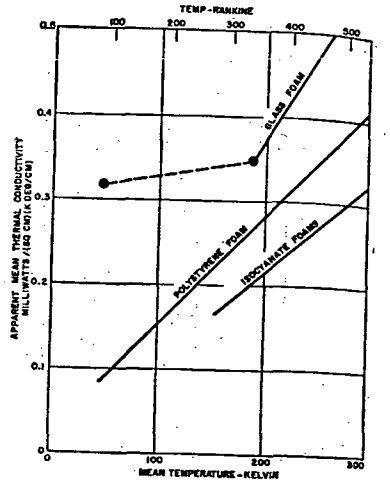
Code — Description

A Fiber glass paper, 0.008 in. thick, 90% *B* fiber; Dexter Paper Company.
B Fiber glass paper, 0.0045 in. thick, 90% *B* fiber; Dexter Paper Company.
C Fiberglas mat, styrene-bonded, 0.008 in. thick, AV. fiber dia. 0.0007 in., Owens-Corning Fiberglas Corporation.
D Nylon net, 0.006 in., 90% void.
1 Aluminum foil, 0.0005 in. thick; Alcoa Aluminum Corporation.
3 Aluminum foil, 0.00023 in. thick; Alcoa Aluminum Corporation.
S M Mylar, aluminized both sides, 1.5 to 2.0 ohms per square, Dobeckmun Company.



T_1 and T_2 were the respective boundary temperatures.
The densities in lb/cu ft were:
Silica aerogel 5, perlite 9, phenolic spheres 12, lampblack 12, diatomaceous earth 20. 1 *microwatt/cm/K* = 0.0000578 *Btu/hr/ft/R* = 0.000693 *Btu/in./hr/ft²/R.*

Fig. 16 .... Thermal Conductivities of Powders



(a) *Glass foam, density = 10 lb/cu ft*
(b) *Polystyrene foam, air-filled density = 2 lb/cu ft*
(c) *Isocyanate foams, CO_2-filled, density = 6 to 8 lb/cu ft.* 1 *milliwatt/(hr)(sq cm) (K deg/cm)* = 0.0578 *Btu/(hr) (sq ft) (R deg/ft)* = 0.693 *Btu/(hr) (sq ft) (R deg/in.).*

Fig. 15 .... Thermal Conductivities of Some Foams

Unevacuated Porous Insulations

These may consist of powders, fibers or foams. Heat conduction in such insulations is primarily due to the interstitial gas and is given to a rough approximation by the thermal conductivity of the gas. For example, the mean thermal conductivity in the range 76 to 300 K, was 1450 microwatts/(sq cm) (K deg per cm) for a perlite powder containing hydrogen gas at atmospheric pressure. The corresponding value for hydrogen itself is 1240. Similarly, *perlite* containing helium gave 1260, and a sample of *fiberglas* containing helium gave 1330, while the corresponding value for helium gas is 1100. Again, *perlite* containing nitrogen at atmospheric pressure gave 325, the *fiberglas* containing nitrogen gave 260 while nitrogen itself would be 170. In the same temperature range *Styrofoam* (air-filled) gave 260 while air is 170.

Thus it will be seen that an approximation to the conductivity of a gas-filled porous insulation can be obtained by taking a value somewhat larger than the conductivity of the gas itself in the same temperature range.

Data on foams are given in Fig. 15. Plastic foams are permeable to the common gases and if exposed to a foreign gas can show substantial changes in conductivity in a few days time due to exchange of the gas in the cells of the foam. Obviously exposure of such foams to hydrogen or helium should be avoided.

Among the powders, silica aerogel (*Santocel*) has superior insulating value unevacuated due to its extremely small effective pore size.

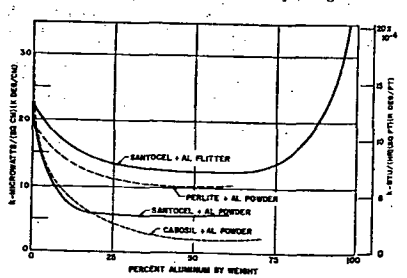


Fig. 17 .... Apparent Mean Thermal Conductivity Between 540 and 137 R of Some Evacuated Powders with Added Aluminum.

Table 6 .... The Apparent Mean Thermal Conductivity of Several Powders

(1 in. sample thickness; boundary temperatures of 540 and 137° R, and wall emissivities greater than 0.8)

Powder	Remarks	Density (lb/ft³)	Gas Pressure (mm Hg)	Interstitial Gas	Conductivity Btuh/(sq ft) (R deg/ft)
Silica aerogel	Chemically prepared 250A	6.2	10^{-4}	—	12×10^{-4}[a]
		6.2	628	Nitrogen	113×10^{-4}
		6.2	628	Helium	358×10^{-4}
		6.2	628	Hydrogen	462×10^{-4}
	+10% free silicon dust by weight	7.0	10^{-4}	—	10.5×10^{-4}
Silica	Flame prepared 150–200A	3.7	10^{-4}	—	12×10^{-4}
		3.7	630	Nitrogen	107×10^{-4}
Perlite, expanded	+30 mesh	3.7	10^{-4}	—	12×10^{-4}
	+30 mesh	6.2	10^{-4}	—	10.5×10^{-4}
	+30 mesh	6.2	628	Nitrogen	192×10^{-4}
	+30 mesh	6.2	628	Helium	735×10^{-4}
	+30 mesh	6.2	628	Hydrogen	845×10^{-4}
	−30+80 mesh	8.1	10^{-4}	—	7×10^{-4}
	−30+80 mesh	8.1	628	Nitrogen	188×10^{-4}
	−30+80 mesh	8.1	628	Helium	728×10^{-4}
	−30+80 mesh	8.1	628	Hydrogen	838×10^{-4}
	−80 mesh	8.7	10^{-4}	—	5.8×10^{-4}
	−80 mesh	8.7	628	Nitrogen	202×10^{-4}
	−80 mesh	8.7	628	Helium	780×10^{-4}
	−80 mesh	8.7	628	Hydrogen	840×10^{-4}
	−30 mesh	8.7	10^{-4}	—	5.8×10^{-4}[b,a,d]
Diatomaceous earth	1 – 100 microns	15.0	10^{-4}	—	9×10^{-4}
		15.6	10^{-4}	—	8×10^{-4}
		18.0	10^{-4}	—	5.8×10^{-4}
Alumina, fused	−50+100 mesh	125	10^{-4}	—	10.5×10^{-4}
Alumina, laminar	0.1–10 microns	4.4	10^{-4}	—	13.3×10^{-4}
Mica expanded	−20+30 mesh 30%	9.4	10^{-}	—	10.5×10^{-4}
	−30+15 mesh 70%	9.4	628	Nitrogen	290×10^{-4}
	−30+15 mesh 70%	9.4	628	Helium	867×10^{-4}
Lampblack	—	12.5	10^{-4}	—	7.2×10^{-4}
Charcoal peach pits	20–30 mesh	30	10^{-4}	—	10.5×10^{-4}
Carbon +7% Ash[f]	30% 44μ	12.5	10^{-4}	—	3.5×10^{-4}
Calcium silicate (synthetic)	0.02 microns	10.6	10^{-4}	—	4.3×10^{-4}
	0.02–0.07 microns	22.5	10^{-4}	—	3.2×10^{-4}
	0.02–0.07 microns	22.5	628	Nitrogen	263×10^{-4}

[a] 1.2×10^{-4} Btuh/(sq ft) (R deg/ft) for boundary temperatures of 137 and 36 R.
[b] 3.8×10^{-4} Btuh/(sq ft) (R deg/ft) for boundary temperatures of 540 and 36 R.
[c] 1.2×10^{-4} Btuh/(sq ft) (R deg/ft) for boundary temperatures of 137 and 36 R.
[d] 0.48×10^{-4} Btuh/(sq ft) (R deg/ft) for boundary temperatures of 137 and 7.6 R.
[e] Barometric Pressure at Boulder, Colorado.
[f] Mostly SiO_2 and Al_2O_3.

Evacuated Powders

The insulating value of powders is greatly increased by removing the interstitial gas. Fig. 16 shows the effect of in-