GENERAL RESEARCH DIVISION

HYDROUS CALCIUM SILICATES

PART V

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Physical and Chemical Properties of Kaylo Products

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HYDROUS CALCIUM SILICATES

FOREWARD

The science and technology of the hydrous calcium silicates were not advanced as far as desired when the broad potentialities of these products as structural and insulating materials were recognized by the Owens-Illinois Glass Company. The overall plans set-up by the Company to develop the kaylo products included a relatively large project having as objective the advancement of the basic knowledge.

This report, in the first three parts, summarizes in some detail the results of the planned research on the chemistry of kaylo. Part I deals largely with the nature of the solids forming in the ternary system lime-silica-water and represents the foundation of the basic science. Part II gives the fundamental and some practical information on xonotlite and lepisil kaylos, products which originated in the basic studies described in Part I. Part III, also based on the first part, gives the chemistry of the presently produced kaylo products and describes the important effect of alumina not previously recognized in these solids.

Parts IV and V include discussions on materials and processes, and physical and chemical properties of kaylo, respectively. The subject matter of these two parts was not amenable to detailed description because changes are being made currently in both formulations and processes. Alos currently, some of the test methods for determining the properties of kaylo products are being revised to keep pace with other developments. It was for this reason that this report was prepared in five separate parts, each of which may be amended or rewritten without calling for revision in the others.

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I. INTRODUCTION

Description of kaylo products in sales literature centers in large part around the terms: light density, high strength, low thermal conductivity, volume stability, incombustibility and others. These terms denote properties responsible for the position kaylo has gained in wide markets as an accepted new structural and insulating material. This portion of the report defines the properties and the methods of measuring them, and the units in which they are expressed. Considerations are also given to the implications these properties have on the usefulness of the kaylo products.

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II. DENSITY

Density simply means the weight of a solid per unit of volume. It is understood in using the term density in connection with kaylo that apparent density is implied. The density of the constituent solid parts of kaylo, approximately 150 pcf, is many times greater than of the overall density of the highly porous kaylo products. The density is obtained by measuring the dimensions of a trimmed sample, weighing it and computing the weight in pounds per cubic foot. The sample is weighed while still hot after being oven dried at 300°F, generally overnight.[a]

Kaylo products are currently made in two densities, nominally 10-11 and 20-22 pcf. Density indirectly expresses the thermal conductivity, and the lighter the weight the better is the heat insulation. Strength and other factors, particularly of processing, established the basis for the choice of the given densities. Strength is less important for products of low densities used primarily as heat insulation than for the 20 pcf products, except from the standpoint of breakage losses.

[a] Details of tests and limitation are given in Company's specifications.

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III. STRENGTHS

1. Modulus of Rupture in Bending

The strength most descriptive of this property of kaylo is the modulus of rupture in bending, commonly referred to as flexural or bending strength. The modulus of rupture in bending is the computed ultimate strength, and is defined as the fictitious tensile (or compressive) stress in the extreme fiber of a beam computed by the flexure equation,

$$S = Mc/I$$

where S, is the fiber stress,

M, the bending moment,

c, $\frac{1}{2}$d (depth of beam),

and I, the moment of inertia.

For a square or rectangular cross section the equation reduces to the following form, for single point loading at midspan,

$$S = 3/2 \frac{Wl}{bd^2}$$

where W, is the total load at failure,

l, the distance between supports,

b, the width,

d, the depth.

Obviously, the kaylo products loaded as a beam in service such as the roof tile must carry a total load at midspan considerably smaller than that represented by the total load at failure, W in the above equation. In practice the tensile stress developed by kaylo without reinforcement is insufficient to carry the ultimate potential load, allowance being made for an appropriate factor of safety. For this reason roof tile is reinforced with a wire basket located approximately 1/2 of an inch from the bottom side of the tile as placed in the roof. The modulus of rupture of the non-reinforced kaylo is not of itself a criteria of the strength of the roof tile. Present specification is based on the ultimate load applied to a full size slab. With a 34 inch span between supports, with the load applied at midspan, the reinforcement taking the load is in tension. The specified minimum ultimate load is 900 pounds. This corresponds to an overall fiber stress of 355 psi for roof tile having a thickness of 2-5/8 inches. The specifications also require that the modulus of rupture of non-reinforced kaylo of the roof tile shall be 150 psi or higher. This value is obtained by loading the roof tile in inverted position, the wire basket being in the top position. The same tile is then turned over and tested for the ultimate load. This double use of a tile for test purposes is possible because structurally the face containing the reinforcement is not damaged during the first loading. The failure occurs in tension. The modulus of the kaylo itself

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in a roof tile might appear to be a superfluous result, but in practice it serves as a check on the quality of the kaylo.

The modulus of rupture of the core material is obtained in the same manner as that of the roof tile during the first loading. The computed stress is a measure of the quality of the product. The minimum allowable modulus of rupture is 160 psi.

The light density ware at Sayreville is tested the same as the core material. Tests at the Berlin plant are made on specimens 1½ by 3 by 12 inches in size. The minimum allowable modulus of rupture is 35 psi. This requirement is easy to fulfill but experience has shown that a higher modulus is desirable in decreasing losses due to breakage. The present 10-11 pcf density kaylo shows a modulus of 60 to 80 psi.

Standard testing machines are used for strength determination. The Sayreville plant is equipped with a 50,000 lb. Baldwin-Southwark Universal testing machine, the Berlin plant with a Scott flexure tester and the General Research Laboratory with a Tinius Olson Universal Testing machine.

The bending strengths of kaylo-cement asbestos (KCA) laminates and others are, of course, much higher than of un-reinforced kaylo. The increase in strength is proportional to the strength of the surfacing material. Cement asbestos increases the modulus up to about an 800 psi fiber stress. Recent experimentation in the laboratory with the direct application of specially-prepared portland cement slurries to kaylo is showing promise as a method for making laminates according to a comparatively simple method. The modulus of these products ranges from 600 to 800 psi.

2. Compressive Strength

The compressive strength of kaylo does not represent the ultimate strength in compression at failure as in the case of concrete. Because of its highly porous nature kaylo undergoes an inelastic deformation at a certain load and continues to deform as the load is increased. The 10 pcf product shows a compressive strength of about 150 psi at a deformation of 5 percent. For so light a material, this is a relatively high strength which is desirable during application and maintenance as workmen moving about on the kaylo do not cause any structural damage to the insulation in place.

The compressive strength of the 20 pcf material has no real physical significance in any present applications. Only a few data have been obtained and these indicate that the strength in compression is about 400 to 500 psi for small deformation of the test specimen.

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IV. HANDLEABILITY

Kaylo, due to its very nature of being light weight, is subject to abuse in handling which a heavier material would be spared. Because of this the susceptibility to loss by breakage at the plant, during transit and installation requires evaluation by tests which would measure the quality of the ware in this respect. The resistance to breakage is not easily measured or expressed as a number of factors are involved. The modulus of rupture gives a rough indication of potential losses due to fracturing of full size specimens, but is not a measure of resistance to chippage. Brittleness is an important factor in chippage and that is measureable in terms of resistance to shear and impact stresses. Mechanical abrasion is another potential cause of loss of wear and can be evaluated in abrasion tests.

The term handleability has been introduced by ASTM Committee C-16 Sub-Committee S-1 for designating the resistance to breakage of such materials as kaylo. As indicated by the preceding paragraph, the number of factors involved does not permit the derivation of any simple definition. The definitions proposed by the sub-group for handleability and some comments are as follows:

1. Handleability is that group of physical properties of a block of preformed insulation, wherein each property is expressed as a numerical value, which can be used as a measure for evaluating the block's ability to withstand the rigors of reasonable mechanical stresses upon it without suffering undue damage. These stresses may be encountered by the dry block in the manufacturer's finishing processes, in transferring the individual blocks, in shipping the cartons of blocks, in applying the block to the job and in its ultimate service on the job. They may consist of: static flexural stresses; compressive stresses; impact stresses and abrasive stresses.

2. The handleability of an insulation block (or pipe covering) might be understood to be the ease and effectiveness with which it can be transported, manipulated and applied to a job with a minimum of breakage and labor.

3. Handleability is that property of a material which enables it to be shipped and installed without undue breakage when handled with ordinary roughness.

4. Handleability is defined as the measure (or index) of that combination of physical characteristics which enables the preformed insulation to be handled without excessive damage due to breaking, cracking, crushing or other structural failure, under the conditions of normal severity of loading or stress to which it will be subject as a result of handling before and during installation.

5. Handleability of preformed thermal insulation blocks is the ability of the material to be processed, packed, shipped, stored, transferred to job site, shaped where necessary and installed with a minimum of breakage or other damage; it is a combination of strength, resiliency, hardness and abrasion resistance and is affected by density and unit dimensions.

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- Comments -

It seems improbable that an index value obtained by summing or multiplying factors assigned to the test results of individual measurements of various properties such as outlined in the definition above will give a quantitative figure indicating handleability. A single poor factor - such as poor resilience - with other factors good, could result in poor handleability - example: long, narrow, thin glass plates.

Low strength and hardness, but good abrasion resistance and excellent resiliency could produce a very handleable product - example: rubber mats.

With equal resiliency, strength, hardness and abrasion resistance, long, narrow, flat sheets could not be handled as well as shorter, wider, thicker sheets. All other factors being equal, high-density products will be harder to handle than low-density products.

Of interest in connection with handleability are hardness and abrasion tests described in Navy Department specifications for Thermal Block Insulation No. 32-I-3, Dec. 1, 1943. The hardness test consists in the measurement of the penetration of a 1/8 inch diameter ball point under a load of 1 kg into the material mounted in a commercial apparatus called a plastometer. The maximum allowable penetrations are 1.15, 0.95 and 0.75 mm. for densities of 15, 23, 27 pcf. Kaylo of 11 pcf density showed a penetration of 1.00 mm. which is well within allowable limits of the test.

The abrasion test involves the determination of material abraded from twelve 1-inch cube specimens by twenty four 3/4-inch oak tubes during 10- and 20-minute periods of tumbling in a special machine built for this purpose. The percentage by weight of the cubes dusted or broken off during this period is obtained. The maximum loss in weights for 15 pcf density ware were 40 and 70 percent for the 10- and 20-minute tests. Light density kaylo showed a loss of only 17 to 13 percent at the end of the 20-minute test, which is well within the allowable limits.

Kaylo insulation block containing a fracture is still usable providing the pieces do not separate at the point of fracture. Long-fiber asbestos imparts the desired hinging strength discussed in another part of the report concerned with properties of asbestos.

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V. THERMAL CONDUCTIVITY

It is a well-known fact that heat may be transferred between two surfaces at different temperatures by radiation, convection and conduction. A heat insulation material for highest efficiency should offer resistance to heat flow by each type of transfer. The proportionate amount of total heat transferred by any one of these type depends on a number of factors. Flow by radiation increases as the fourth power of the absolute temperatures. Air is a very poor conductor of heat and, if immobile, so that heat is not transferred by convection, it is a good insulator.

Kaylo contains pores of exceedingly small sizes and this very fact accounts for small radiational losses. Although kaylo is a continuous-air type insulator the resistance to air flow is relatively high and heat loss by convection is relatively small. The heat is transferred primarily by conduction at the relatively small temperature differences as would obtain for roof tile or KCA panel in service. At high temperatures, the heat losses by radiation are of course greater, and convection losses may also be significant, especially for thin insulation application.

Thermal conductivity of a substance is defined as the amount of heat that will flow in unit time between opposite faces of unit area and unit thickness having a temperature difference of 1 degree. In the English system the unit for thermal conductivity, designated as K, is B.t.u./hour/sq. ft./°F/inch of thickness. K is expressed in many units. Seven of the more common ones are as follows:

No.	Unit	Used By
1.	Joules, sec^{-1}, cm^{-2}, $°C^{-1}$, cm	Electr. Eng. & ICT
2.	Gm cal, sec^{-1}, cm^{-2}, $°C^{-1}$, cm	Physicists
3.	Kg cal, hr^{-1}, M^{-2}, $°C^{-1}$, M	Foreign Engineers
4.	Btu, hr^{-1}, ft^{-2}, $°F^{-1}$, in.	Mech. & Refrig. Eng.
5.	Btu, hr^{-1}, ft^{-2}, $°F^{-1}$, ft.	Chem. Eng.
6.	Btu, hr^{-1}, $in.^{-2}$, $°F^{-1}$, in.	-
7.	Watts, M^{-2}, $°C^{-1}$, M	Mks system

It will be noted that unit No. 4 in this table is used in kaylo technology. For facilitating conversion from one unit to another the following table is presented.

Joules, $sec.^{-1}$ $cm.^{-2}$ $°C.^{-1}$ cm.	Gm. cal, $sec.^{-1}$ $cm.^{-2}$ $°C.^{-1}$ cm.	Kg. cal, $hr.^{-1}$ $m.^{-2}$ $°C.^{-1}$ m.	Btu,* $hr.^{-1}$ $ft.^{-2}$ $°F.^{-1}$ in.	Btu, $hr.^{-1}$ $ft.^{-2}$ $°F.^{-1}$ ft.	Btu, $hr.^{-1}$ $in.^{-2}$ $°F.^{-1}$ in.	Watts m^{-2} $°C.^{-1}$ m.
1.000	0.239	86.1	693	57.7	4.81	100
4.185	1.000	360	2903	242	20.2	419
0.0116	0.00278	1.000	8.06	0.672	0.0560	1.16
0.00144	0.000345	0.124	1.000	0.0835	0.00695	0.144
0.0173	0.00414	1.49	12.0	1.000	0.0835	1.73
0.208	0.0497	17.9	144	12.0	1.000	20.8
0.0100	0.00239	0.861	6.93	0.577	0.0481	1.000

*Unit used in kaylo publication.

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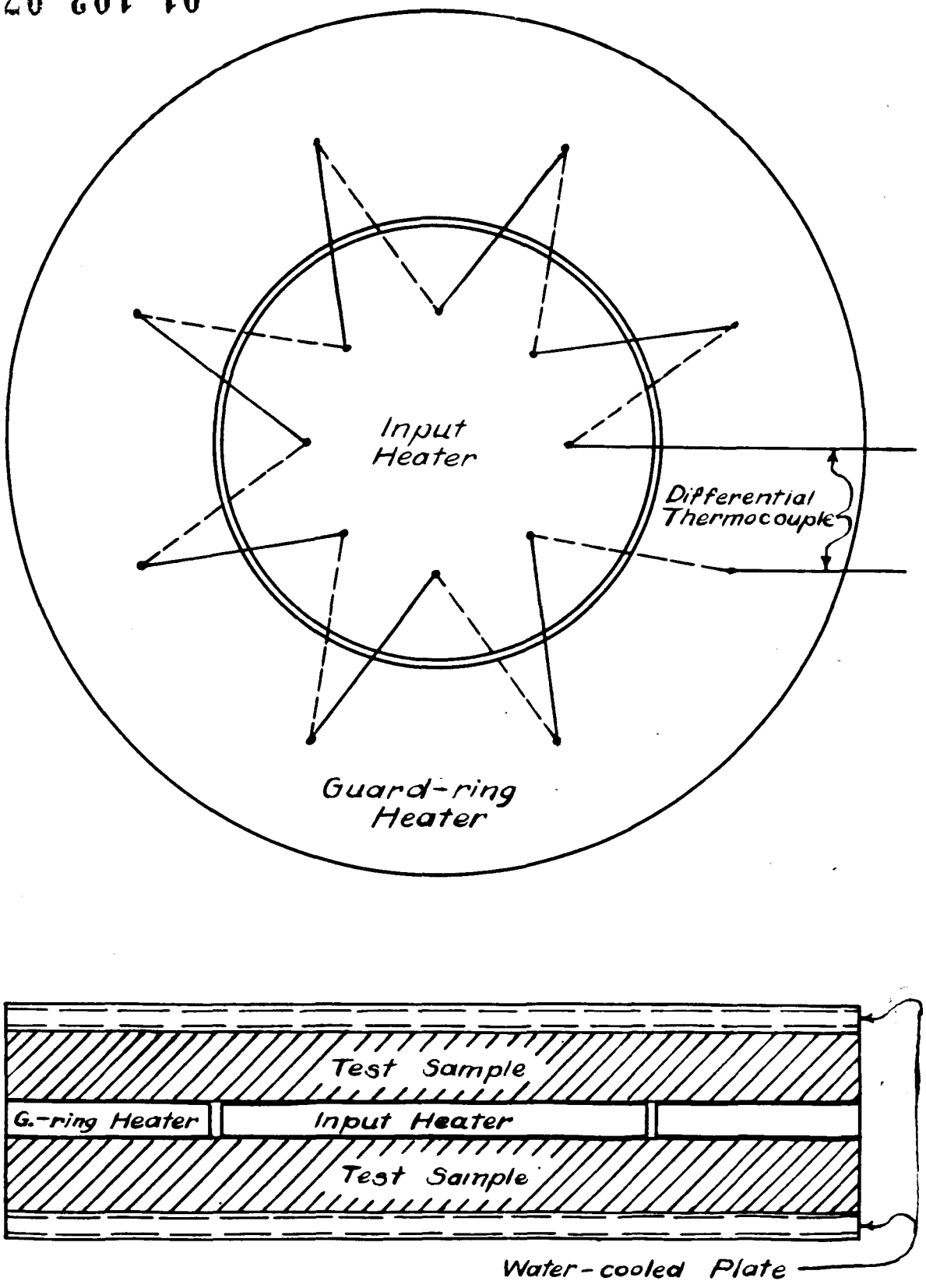

Figure V. 1

Drawing of principal parts of guard-ring equipment for measuring heat conductance of insulating materials.

Use of table, example

The K factor for an insulating material of a foreign manufacturer is given as 0.041 Kg.Cal./hr./m²/°C/m. To convert this value to other units, run down the column headed, Kg.Cal, hr.$^{-1}$ m^{-2} °C,$^{-1}$ m, until the value of 1.000 is found, then move horizontally to the column headed by the desired unit and multiply the original K factor by the factor found. Thus a K factor of 0.041 Kg.Cal./hr./m²/°C/m is equal to 0.041 x 8.06 = .330 Btu/hr/ft²/°F/in.

The methods of test for determining the K factor are not as precise or highly standardized as would be desired. Many factors are involved in the design of test equipment. The guarded-plate method is generally accepted as the most precise and has been standardized by the American Society for Testing Materials. It is described in ASTM specifications C177-45. Although this method is not used currently in our laboratory (its adoption being delayed by obtaining the heat input heater units) it will become the standard method. A comparative method embodying most of the principles of the standard test method is being used. The equipment is checked against either kaylo or cork specimens of known K factor and the factor so obtained is then applied in computation of the K factor of the test specimen.

The principle of the guarded-plate method is the measurement of the amount of heat transmitted through a sample of known area and thickness, and the temperature difference established between the hot and cold sides. The heat-input unit is placed between two specimens of a given kind and size. The important factor to control is the possible movement of heat laterally from the heater. Such heat obviously would not be transmitted through the test samples. The corrective against this difficulty is the use of a guard ring heater placed around the heat-input unit and covered with the material under test. This ring heater is built in the same manner and of the same materials as the heat-input unit. In use, it is maintained at identically the same temperature as the input heater by a separate control and heater system. The control of temperature is affected by an electrical controller activated by a multi-junction thermocouple, equal number of junctions being placed in contact with the guard ring heater and the principal heater. Only the guard ring heater is in circuit with the controller. The heat input into the principal heater, which of course, equals the heat transferred through the test specimens after equilibrium conditions are obtained, is measured with a wattmeter.

The general arrangement of the guard ring, principal heater, samples, and the external plates maintained at constant temperature is illustrated by the cut-out section in Figure V. 1. This cut shows the method of using water at constant temperature flowing through the steel plates comprising the outside covering of the sample. This method of maintaining constant temperature of the cold side is suitable, of course, for temperatures in the range between 32 and 212°F. At temperatures below 32 or above 212°F other methods are used. At elevated temperatures the outside plates may be maintained at a selected temperature by electric heaters in conjunction with a suitable controller. Another method generally used is that of increasing the thickness of the insulation on the cold side, the water coil plate forming the outside surface of the composite set of specimens.

The temperature of the cold and hot sides are measured with thermocouples and the electrical input is measured with a wattmeter. These and other data required for the determination of the K factor are:

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l = thickness of the sample in inches.

A = area of sample through which the heat flows in square feet.

t_2 = average temperature of warmer surface in °F.

t_1 = average temperature of cooler surface in °F.

q = corrected watt input to heater x 3.412 in Btu/hr.

The equation for computing the K factor is:

$$K = \frac{ql}{A(t_2 - t_1)} \quad \text{Btu, hr}^{-1}, \text{ft}^{-2}, \text{in}^{-1}, {}^\circ\text{F}^{-1}$$

The overall coefficient of heat transmittance, air to air temperatures, is designated U. It is the measured factor for built-up wall sections. The heat may be transmitted by conduction, convection, and radiation in a wall and therefore the factor U is used correctly only if this condition obtains. The factor C is the coefficient of thermal conductance computed for the surface temperature of the unit under test. Strictly speaking, the factor U for air to air temperature is correct for expressing the heat conductance through a wall or roof exposed to the sky. The outside surface temperature in winter of a built-up wall or roof will be 1 to 2°F lower than the air due to heat lost by radiation to the sky. Therefore, the factor U as determined in the laboratory, by a method to be described, would be somewhat in error if used in computations for the stated service conditions. The factor U is obtained using the guarded box method in which a wall is mounted as a partition in a constant temperature room and an area in the middle region on one side is covered with a box containing heaters in circuit with a wattmeter. The air immediately outside the heater box is maintained at exactly the same temperature as within the box. The air on the cooler side is maintained at a fixed and constant temperature. Baffles are inserted between the heaters and the test wall as a precaution against radiation from the heaters. The overall air-to-air coefficient of heat transmittance, U, can be computed from the equation,

$$U = \frac{\text{Watts x } 3.412}{(t_2 - t_1) \text{ x Area}} \quad \text{Btu, hr}^{-1}, \text{ft}^{-2}, {}^\circ\text{F}^{-1}$$

The preceding discussions and formula for calculating the factors apply to parallel flat surfaces. In computations involving curved surfaces such as pipe covering it is required that the proper effective area is known. In a cylindrical shell the area across which heat is flowing becomes greater as the thickness is increased. This area can be computed from a formula obtained by calculus. This formula is:

$$A = \frac{2(r_2 - r_1)}{\ln (r_2/r_1)} \quad \text{(per unit length)}$$

where A is the log mean area,
r_2, the outside diameter,
and r_1, the inside diameter.

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For large diameter and relatively small thickness value, the arithmetic mean area $(r_2 + r_1)/2$ may be used. Considerable error is made, however, using the arithmetic mean area when the ratio of r_2/r_1 is large.

Representative values of K are given in Table V. 1. for regular plant kaylo and nonetlite slabs made in the pilot plant.

The subject of heat diffusivity is of interest in connection with the time requirements for heating or cooling and also for explaining why hot kaylo may be handled without causing burns. Thermal diffusivity expresses the rate at which an insulating material is heated or cooled. Computations of time required to heat a furnace, for example, to some desired temperature are based on the thermal conductivity, heat capacity and density of the insulation material. The thermal diffusivity is expressed as K/cd where K is the conductivity factor, c the specific heat, and d the density. The lower the value of K/cd, the longer is the time required to heat to a specific temperature, or conversely, to cool.

It is of interest to reproduce an example from Wilkes' book on "Heat Insulation" (p. 133-134) comparing 3 insulation materials set up as walls of ovens of equal U factor (.042), namely, 4 inches of 85 percent magnesia block, 4 inches of glass wool, and 4 inches of crumpled aluminum foil. At a constant temperature of 500°F all three ovens lose the same amount of heat per unit of time. In this computation it is first required to compute the heat input to elevate the temperature of the insulation. This is simply the product of average minimum temperature, specific heat and density. These data are given on the following table:

Insulation	c, Btu/lb/°F	d, (Bulk) pcf	Btu/ft^3
Magnesia	0.234	15	3235
Glass wool	.234	3	204
Al. foil	.24	0.19	13

The next step is the computation of the ratios of heat requirements and these are 1:15:93 for the aluminum foil: glass wool: magnesia. This ratio also represents the relative times to heat the oven since the U factor is the same for all three (.042).

The same result is obtained by substituting in the formula, K/cd, for heat diffusivity. The values for heat diffusivities are 0.0099, 0.060 and 0.92 ft^2/hr. for the magnesia, glass wool and aluminum foil, respectively.

Since the time required for heating or cooling is inversely proportional to the diffusivity, it follows that the larger the thermal diffusivity the shorter the time required to effect the change in temperature. The ratios between the K/cd values are 1:15:93 for magnesia block: glass wool: aluminum foil. This means that the magnesia block will take 93 times as long as the aluminum to heat up to a steady state.

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VI. VOLUME STABILITY AT ELEVATED TEMPERATURES

A high degree of volume stability of light density insulation block and pipe covering is desirable for certain installations at elevated temperatures. Navy Department Specifications 32P8d Aug. 2, 1948 for pipe insulation require that linear shrinkage of pipe covering shall not exceed 2.0 percent for compounded insulation of 12 and 15 pcf density at temperatures of 750 and 1000°F, respectively. Kaylo easily meets these specifications, showing shrinkages of 0.8 and 0.9 percent (or less) at the stated temperatures. In practice this shrinkage is somewhat too high, as the kaylo pipe covering exposed to high temperatures on the hot side (500-900°F) undergoes a shrinkage while the outside surface at a markedly lower temperature does not. The insulation tends to warp and if restrained from movement, as it generally is in service, it may undergo cracking. These cracks in no way impair the thermal efficiency but are a cause of loss in oil refineries where the pipe insulation is removed periodically for inspection of the pipes. In the stripping operations and subsequent re-application of the some ware, some pieces break in two and are discarded.

The drying shrinkage of the gel-like hydrous calcium silicates may be eliminated in large part by previous drying at elevated temperature, the gel-like solid becoming partially irreversible. This treatment preshrinks the insulation but is a costly operation. A considerable amount of work on formulations and processing has been carried out with the objective of preventing the drying shrinkage without increasing the cost or altering the present processes. Some interesting results have been obtained, occasionally certain products showing no shrinkage-cracking. These results are not always readily duplicated. Among other observations holding promise were those using $CaCl_2$ as an additive. Addition of this salt to regular plant slurry produced in an experimental autoclave was effective. However, duplicate products made in the plant did not perform satisfactorily, the specimens showing about the same degree of cracking as those without treatment. It appears that our operations are on a borderline and the products obtained at certain stages of the reaction or under different initial processing may vary due to slight unknown alterations in the process.

Xonotlite kaylo would perform satisfactorily as a pipe insulation, but the slurries can be handled only with difficulty in present equipment. Xonotlite-lepisil combinations relatively low in lepisil should prove satisfactory also and possibly, if made from cement formulation, present process equipment would be suitable.

The method of test for evaluating the drying shrinkage of kaylo may be one of three used to date. The exposure of a full section of pipe insulation on a pipe heated to the temperature of service is the most direct. Cracking, if it is to develop, will be evident in one day or less. Another method permitting the simultaneous testing of a number of specimen, cut from slabs or pipe insulations, is heat soaking overnight of previously-measured specimens at a selected temperature. The length can be measured to a sufficient degree of accuracy using micrometer calipers and specimens about 10 to 15 inches long. The allowable shrinkage will have to be predetermined and data are now being gathered which will give the maximum permissible shrinkage. The third method involves the use of a furnace designed for measuring thermal coefficient

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Fig. V.3

Figure V. 3

Ranges in shrinkage of different types of plant and laboratory kaylo upon heating.

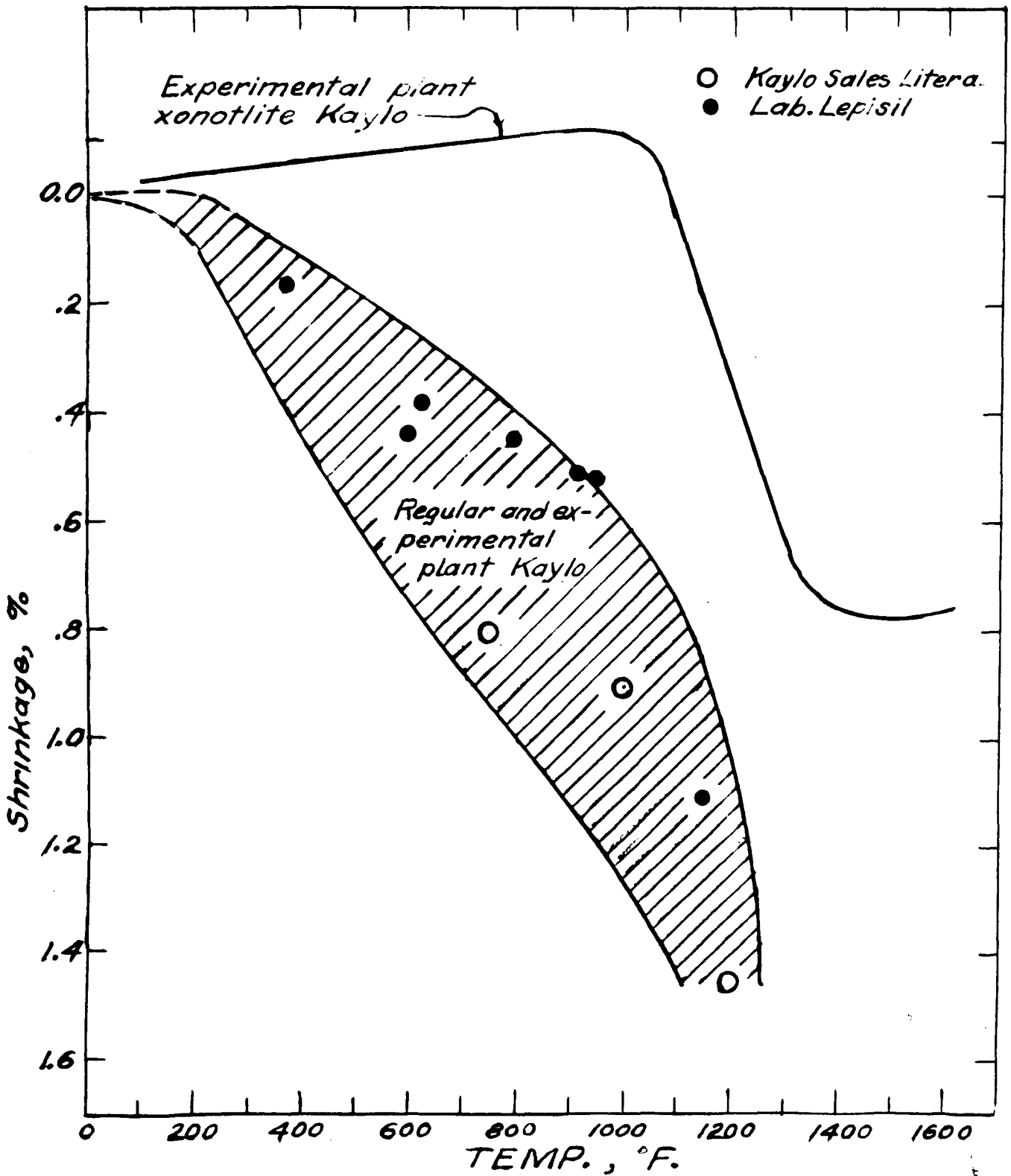

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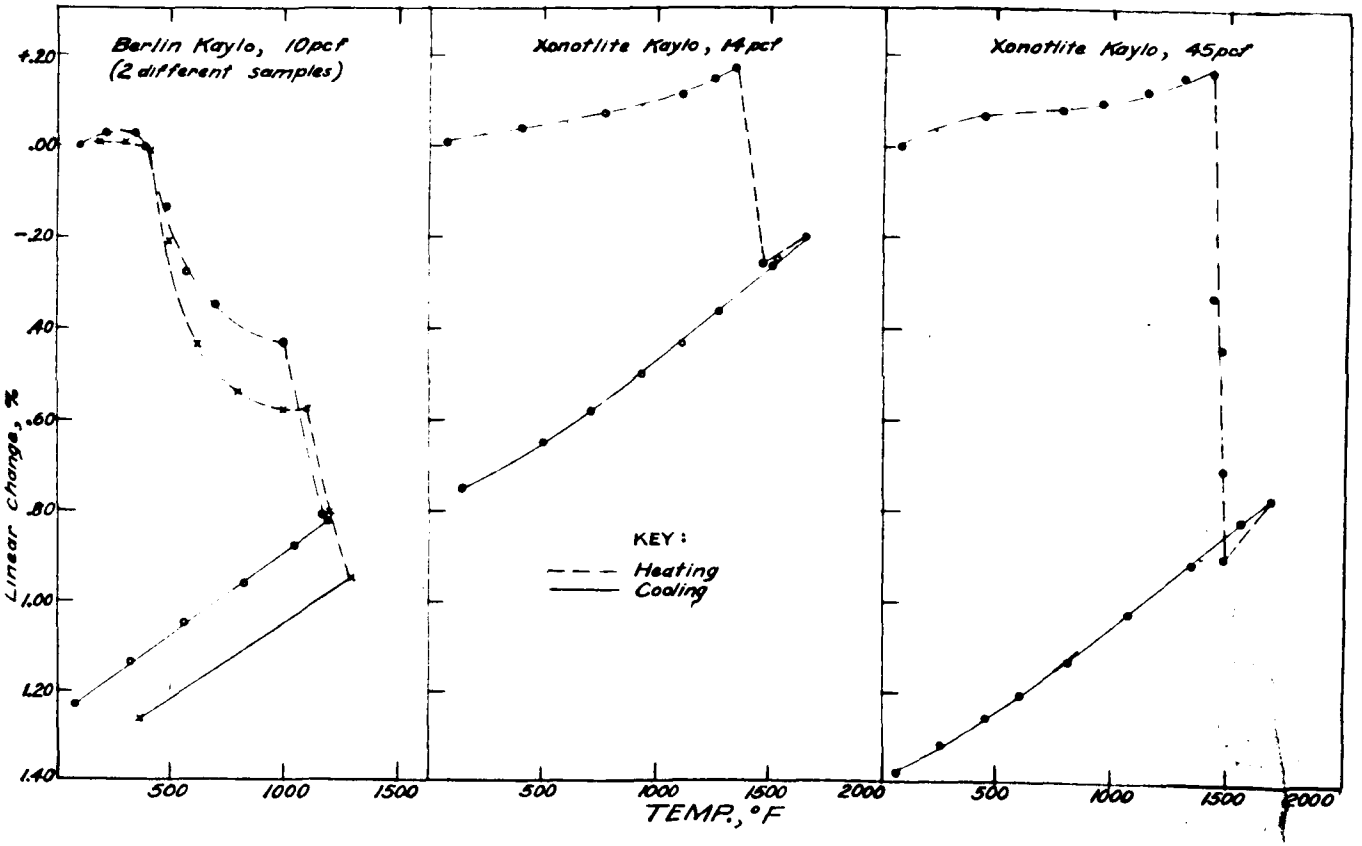
Figure V. 2

Linear changes of 10 pcf Berlin and 14 and 45 pcf xonotlite kaylo during heating and cooling.



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[illegible] of [illegible] This method permits the deter- [illegible] different [illegible] data giving the relation [illegible] temperature [illegible] shrinkage. [illegible] requires several days for com- [illegible] day appears [illegible] for the attainment of [illegible] stability [illegible] each temperature.

The results of tests on Berlin [illegible] xonotlite kaylos obtained with the thermal coefficient equipment are presented in Figure V. 2. The xonotlite kaylo contained 6 percent chrysotile asbestos. The individual points of the curve in Figure V. [illegible] were obtained after heat soaking periods of approximately a half-hour duration. Shortly after the micrometer dial indicated no further linear change at a given temperature for about 10-15 minutes the temperature was increased (or decreased in returning to room temperature). This procedure was repeated at each temperature.

Figure V. 2. shows that the 10 pcf Berlin kaylo started to shrink significantly [illegible] temperatures above 400°F. The shrinkages of the two sam- [illegible] 0.9 and 1.0 percent at about 1200 and 1300°F respectively. The [illegible] was then decreased stepwise to room temperature. The linear [illegible] during cooling is due simply to the thermal change of the [illegible]

[illegible] lite samples expanded about 0.2 percent over the temperature [illegible] 1400°F, due to the thermal change alone. At about 1400°F an [illegible] age occurred amounting to about 0.5 and 1.0 percent for the 14 [illegible] densities, respectively. This shrinkage is caused by the transformation of xonotlite to wollastonite ($CaO \cdot SiO_2$). This change is [illegible] the wollastonite as such does not form a hydrate. After this [illegible] is complete the wollastonite upon subsequent increase in [illegible] pands thermally. The linear shrinkage represents a thermal [illegible] was found to be reversible during alternate heating and cooling.

[illegible] 1 by 6 inches in size, cut from a set of 12 different [illegible] ulation, representing different formulations and processing [illegible] measured for shrinkage after heat soaking at temperature [illegible] 300 to 1225°F. These products were made with C/S ratios of [illegible] indurated for periods of 1 to 4 hours at 225 psi in the [illegible] cylinder and dried at 460 to 5[illegible]°F for periods of 1 to 4 hours. The [illegible] presented as a band in Figure [illegible] 3. indicating the spread in shrinkage [illegible] the best and worst performance. No correlation obtained between [illegible] and any of the mentioned variables. Two samples indurated for [illegible] for 1 hour represent the upper boundary of the area in Figure [illegible] two pieces of insulation [illegible] also the only ones in the [illegible] crack when exposed on a pipe [illegible] up to 1000°F. The [illegible] duced and the reason [illegible] excellent performance remains [illegible]

[illegible] inclined results [illegible] plant produced specimens of [illegible] mens were heat-soaked for 24 hours prior to [illegible] with a micrometer caliper, while still hot [illegible] higher temperature. The samples underwent the [illegible] starting [illegible] temperature of about 1200°F. The transformation [illegible] up to a temperature of 1900°F at which point the [illegible] terminated.

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Insulation block may be tested similarly as the pipe insulation. A hot box suitable for temperatures up to about 2500°F has been built for such tests. The exposure of one surface of insulation to high temperatures has caused warpage. If the hot side shrinks, as it does for regular plant kaylo over nearly the entire temperature range, the warpage of the hot surface is concave. Xonotlite kaylo, however, shows slight convex warpage of the hot surface up to temperatures of about 1200-1400°F, and at temperature higher than this the warpage becomes concave due to the resulting shrinkage.

If the slab is restrained from warping, the stresses due to the linear changes are relieved by cracking. In a permanent installation such cracking is not a problem, as the cracks are relatively small and shallow. Because of this the thermal efficiency of the block is not altered.

Regular kaylo insulation block warps and cracks badly when the temperature of the hot side is in excess of 1300°F. The xonotlite kaylo performed satisfactorily up to about 2000-2100°F, but at the latter temperature the cracks were relatively large. In one test of 3 weeks, the cold-side temperature of a 2½ inch thick slab of 10 pcf xonotlite remained constant at about 210°F throughout the test with the hot side at 2100°F. At these high temperatures the kaylo becomes relatively weak and soft.

01 102 0761

VII. PERMEABILITY TO GASES

One-dry kaylo of 20 pcf density consists of about 85 percent air and 15 percent solids by volume. The air spaces within the solid are both extremely numerous and very small. Because the solid consists of a network of minute fibers, the air spaces are continuous from boundary to boundary. Flow of gases through such a solid can occur. The amount that might pass under normal operating conditions exclusive of high-temperature insulation would be very small. The possible passage of air through kaylo is of no particular significance except in insulation block in service at high temperatures. The latter conditions would lead to the transfer of a part of the heat by convection with the effect of increasing the K factor.

The most undesirable feature of the pervious nature of kaylo is that water vapor can pass into the insulation. If the passage is from the warm to the cold side as is normally the situation, the vapor condenses if the dew point is reached in the cold side temperature. The water so condensed aggravates the condition further as the K factor increases and a lower temperature zone extends farther into the insulation going from the cold side.

The only preventative against condensation is the application of a vapor seal on the warm side of the insulation so that water vapor cannot enter the insulation. The effectiveness of such seal is determined by a measure of the amount of water that passes into the insulation with and without the seal. A complete seal is difficult to obtain.

Water vapor is a gas and obeys the laws governing the behavior of gases. The pressure exerted by a gas is dependent on the amount or concentration of it present. Water vapor in the atmosphere contributes a small portion of the total atmosphere (barometric) pressure. The amounts of water vapor in the air may very over relatively broad ranges at a given temperature. At each temperature the air has a certain saturation value which is expressed as 100 percent relative humidity. The amounts smaller than those of saturation are expressed on the relative scale as percentages of the saturation value. As the temperature is increased the saturation values become higher, and equal percentage relative humidities at two temperatures represent different amounts of water in the air. The partial pressures are, therefore, also different. Water vapor flows from the higher to lower pressures and in nearly all cases the lower temperature represents the lower vapor pressure. Accordingly, vapor barriers are applied to the face of the insulation in contact with the higher temperature to prevent such migration of moisture.

The unit expressing the amount of water in 1 cubic foot of air is the grain. One pound equals 7000 grains. The amount of water vapor flowing (the permeance) through a barrier is expressed as the number of grains of water per unit time per unit area under a unit vapor pressure differential. Different units are used and in comparing the results from different sources it is necessary to be certain of the unit used. The unit "perm" (abbreviated form of permeance) has been adopted by some writers and it means the flow of one grain of water vapor per hour per square foot under a pressure differential of one inch of mercury.

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The permeance of a material is measured by using it as a barrier between two chambers at different water vapor pressures. These chambers generally are also maintained at different temperatures, the more humid side being at the higher temperature. The simplest equipment consists of two air-tight compartments separated by a wall with provisions for holding the test specimen sealed in such manner as to prevent leakage around the edges. One compartment (on the humid side) is provided with an atmosphere of constant humidity such as that obtaining over a saturated solution of NaCl. This chamber may also be provided with a fan for circulating the air to facilitate the maintenance of the desired humidity. The temperature is measured by appropriately-placed thermometers and the humidity with a psychrometer, the wet bulb thermometer being placed in the air stream of the fan. The air on the dry side in the other chamber, if the temperature is above the freezing point of water, is maintained at low humidity approaching zero by the use of a desiccant such as anhydrone. The desiccant also serves as the collector of the water vapor passing through the specimen. The difference in weight of the desiccant before and after test gives the amount of water vapor that passed through the sample.

At temperatures below freezing the water vapor freezes on the walls of the sealed refrigeration unit. The ice carefully collected and weighed represents the amount of water passing through the sample under test.

The above-described equipment can be made up for different size specimens. Two models were used in the General Research Laboratories, one designed for 6 by 6 inch specimens and the other for full size roof tile. Data obtained on a roof tile at the Engineering Experiment Station, Pennsylvania State College, are given in a report by E. R. Queer covering the period of March 1, 1949 to August 31, 1950.

Simple laboratory methods are also available for measuring the permeance and one of these known as the water or wet-cup method has been proposed as a tentative ASTM standard (ASTM designation D697-42T (1946)). In this method the sample is sealed in a small glass cylinder one inch above the level of water placed in the bottom of the assembly. This unit is placed in a constant-humidity chamber and weighed periodically. After the water loss attains a constant rate, the test is continued until an amount of water is lost that is measurable to a desired degree of accuracy. The time required for attaining such a steady condition will vary with the permeance of the material.

Another relatively simple method known as the dry-cup method has been used in the General Research Laboratories. In this method the specimen is sealed in a glass tube or cylinder just above the top of anhydrone which is also sealed in the assembly. The unit is placed into a chamber of high constant humidity and the gain in weight, similarly as the loss in weight with the wet-cup method, gives a measure of the permeance of the test sample.

The simple laboratory methods give results subject to errors arising from the presence of air films at the surface of the specimens having the effect of decreasing the permeance. Forced circulation of the atmosphere above the sample is required to eliminate this difficulty and data reported on dry-cup and wet-cup determinations were for tests with such convection of air.

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Inasmuch as permeance decreases with increase in thickness, it is required that in presenting the data the effect of thickness be indicated. This is done by designating the exponent of the thickness. For products of definite thickness, such as roof tile or KCA board, the permeance is expressed for the fixed thickness. On the other hand, it has been found that permeance increases linearly with increase in the pressure differential, the straight line passing through the origin.

In Table V. 2. are given representative data obtained on roof tile, KCA board and xonotlite kaylo by the dry-cup and wet-cup methods. In comparing the xonotlite kaylo with the Sayreville core material tested at Penn State College it is seen that the permeance of the xonotlite is double that of the core material at comparable densities for a thickness of 1 inch. As one would expect, the permeance can be decreased markedly by a vapor barrier (Harrington CLO rubber). The wet-cup method leads to a higher value of permeance (14.2 perms) than the dry-cup (12.2 perms) method in the text on roof tile.

One of the errors of tests on specimens of a single thickness is that of the combined resistance of the air paths on the two sides of the specimens. It has been found that a plot of the reciprocal of the values of permeance (1/ permeance) against the thickness, this property being designated as the resistivity, gave a straight line. Such a line did not intersect the origin of the chart, a small resistance value being indicated at zero thickness. Accordingly in evaluating the permeance of kaylo products the surface resistance (at theoretical zero thickness of specimen) has to be evaluated by measurements on a number of specimens of different thicknesses. The resulting plot of 1/permeance, having the unit of $ft^2/hr/inch\ Hg/grain$, against the thickness and extrapolation to zero thickness gives the surface resistance.

The passage of water vapor into kaylo is of interest if the temperature conditions and humidities are of such values that the moisture condenses in the kaylo. For installations where such conditions may arise, the desirability of sealing the warm side against passage of vapor is indicated.

The permeance of air through core material was determined. The results were computed as air rates for different pressure differentials and are as follows for a thickness of 2.61 inches:

P, inches Hg	Air rate/$in.^3$/min./$ft.^2$
1	1.8
3	6.6
5	11.0

The permeance was computed to be 38.5 gr. of air/hr/ft^2/inch Hg for 2.61 inches of thickness. The comparable permeance of water vapor for the same conditions was 5.2 gr.

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