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# HEAT INSULATION

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The present-day high-pressure steam plants, with temperatures in excess of 500 degrees F., have created a new problem in heat insulation. The old standby for many years, 85 per cent hydrated magnesia carbonate insulation, is not suitable as it calcines and decomposes at temperatures in excess of 500 degrees F. An extensive amount of research has been conducted by various manufacturers in an effort to develop and produce insulating materials for the higher temperatures, which will meet the Navy Department requirements as to conductivity, structural strength, weight, etc. In general no single material will meet all of the requirements, with the result that different types are being used.

This paper discusses heat-insulating materials from the standpoint of the requirements of the naval service, service experience and the results of tests conducted at the U. S. Naval Engineering Experiment Station.

## General

Heat-insulating material may be defined as that substance which prevents or minimizes heat losses. Its use on the external surfaces of main and auxiliary machinery, boilers, evaporators, heaters, connecting piping, etc., under operating conditions, is necessary for several reasons:

(a) To promote efficiency of plant operation by minimizing heat losses;

(b) To prevent abnormal or unduly uncomfortable temperatures in the machinery spaces, especially in the closely confined spaces on board ship;

(c) To prevent injury to personnel through contact with hot surfaces; and

(d) To prevent or minimize fire hazards.

The various types of heat-insulating materials mentioned in this paper are discussed relative to the requirements of the naval service as specified by the various Navy Department specifications. The data presented were obtained primarily from the results of tests conducted at the U. S. Naval Engineering Experiment Station. These tests are conducted to determine the suitability of the materials for use on ships of the United States Navy. The test apparatus and procedure were developed with the view of simulating service conditions. The mere fact that a material satisfactorily passes all of the tests cannot, in itself, be accepted as conclusive evidence that it will be satisfactory under actual service conditions. This is especially true of the new types or brands. It is believed, however, that the tests do show which materials are unsuitable and which materials give promise of being suitable.

The tests are conducted to determine the following characteristics:

(a) Conductivity.

(b) Durability.

(c) Ease of application.

(d) Density.

Conductivity is of primary importance. It is a measure of the effectiveness of the material to prevent heat losses. The lower the conductivity the better the insulating value.

Next in importance is durability—a quality or characteristic denoting ability of the material to withstand the operating conditions of heat, shock, vibration, abrasion, moisture, etc. Operating conditions on board ship, as regards shock, vibration and moisture, are considered to be more severe than in shore plants. Such conditions require materials of greater durability.

Ease of application, for both the initial installation and for repairs, involves cost, time and degree of skill required of the workmen

Density is of importance especially on shipboard installations where space and weight are at a premium.

## Test Methods

The tests conducted at the Experiment Station may be summarized briefly as follows:

*Conductivity Test.* For pipe covering it is determined on the pipe test apparatus (Fig. 1) which consists of a 36-inch section of 3-inch

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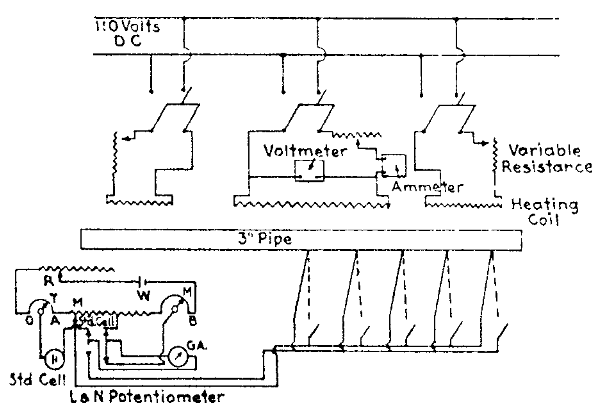
standard wrought-iron pipe. The covering under test is applied to this pipe. Inside of this pipe there is an electrically insulated 2-inch iron pipe around which are wound three heating coils. The center coil covers the 30-inch middle section—each end coil covers a 3-inch end section. The 2-inch pipe is centered in the 3-inch pipe and the ends are closed with insulating disks.

The heat supplied to each coil is regulated by means of a variable resistance. The input to each coil is adjusted until the temperature of the pipe over the end coils is the same as over the central coil. Under these conditions, corrections for end losses are eliminated, and the heat supplied the central coil is dissipated radially through the central 30-inch section of the covering. The temperatures of the inner and outer surfaces of the covering are measured by means of iron constantan thermo-couples. The input to the central coil is computed from voltmeter and ammeter readings. Runs are made at several different pipe temperatures. The resultant heat loss curve represents the British thermal units lost through the cover, per square foot of pipe surface, per hour, per degree F. temperature difference (pipe to room) for the particular thickness of the material under



Wiring Diagram of Testing Apparatus

test. The conductivity of the pipe covering material is calculated from the following formula:

$$k = \frac{H\left(r_1 \log_e \frac{r_2}{r_1}\right)}{(T_1 - T_2)}$$

where $H$ = heat loss, British thermal units, per square foot of pipe surface (30-inch central section only considered) per hour.

$k$ = heat conductivity of material.

$T_1$ = inner surface temperature of material, degrees F.

$T_2$ = outer surface temperature of material, degrees F.

$r_1$ = inside radius of material, inches.

$r_2$ = outside radius of material, inches.

Using this conductivity, the losses to be expected from all sizes of pipes and all thicknesses of material at any pipe temperature may be calculated.

For flat sections, such as blocks and insulating cements, the conductivity is determined in the flat plate testing apparatus shown in Fig. 2. The apparatus consists of a round heater plate, 8 inches in diameter, to each side of which is applied a 1-inch thick, 8-inch diameter disk of the material to be tested. Additional insulation is supplied as shown in Fig. 2. The entire assemblage is surrounded with pulverized diatomaceous earth. Electrical energy is supplied the heater plate by two coils—one coil heats the central 6-inch diameter area and the other coil the 1-inch rim. Thermocouples are installed to indicate the temperatures at different points across the face of the plate and at the outer face of the test disks. When the temperature across the face of the heater plate is constant at all points, it is assumed that all of the heat supplied to the central heating coil is being dissipated through the test disks. However, in order to minimize the effect of losses through the edges of the test disks themselves, only the central 4-inch area of the test disks and plate are considered in calculating the conductivity.

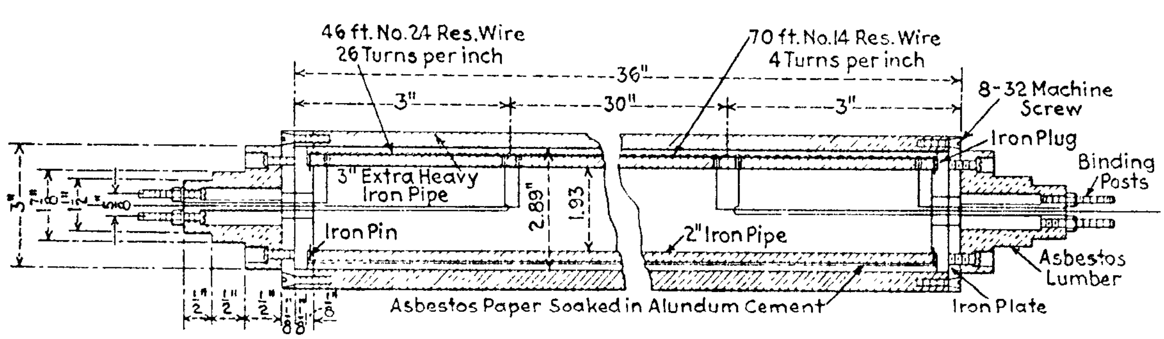


FIG. 1.—PIPE COVERING CONDUCTIVITY TESTING APPARATUS

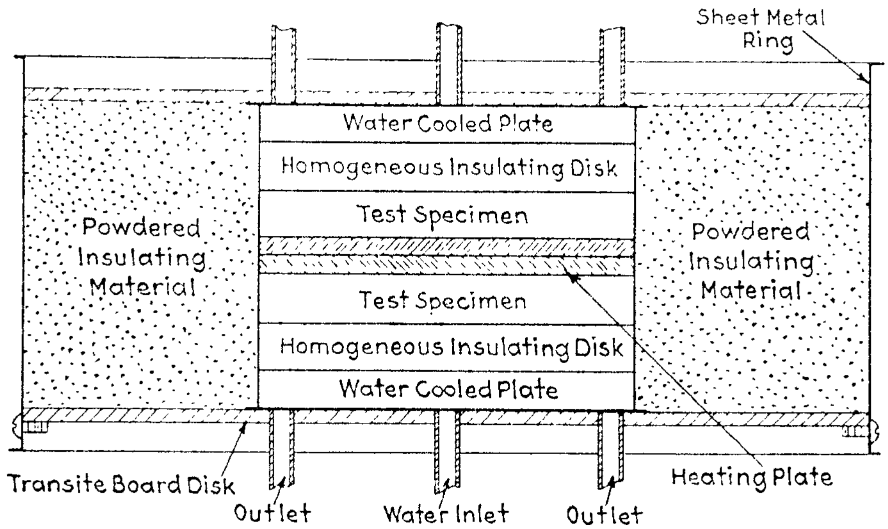



FIG. 2.—FLAT PLATE CONDUCTIVITY APPARATUS

The conductivity is calculated from the following formula:

$$k = \frac{H x}{T_1 - T_2}$$

where $H$ = heat loss, British thermal units per square foot of surface (central 4-inch section only considered) per hour.

$k$=heat conductivity of material.
$T_1$=inner surface temperature of material, degrees F.
$T_2$=outer surface temperature of material, degrees F.
$x$=thickness of material inches.

Conductivity values are obtained for different temperatures. Conductivity is plotted against the mean temperature of the high and low-temperature faces of the material.

As a general rule numerical limiting values as to conductivity are not specified. To be acceptable in this respect, the conductivity must compare favorably with other approved types.

*Shock and Vibration Test.* A section, in pipe covering form, is mounted on the test apparatus (Fig. 3). The pipe, with the material applied, is installed in a horizontal position on the vibration machine. In this position the material is subjected to 700 vibrations per minute through an arc of 15 minutes with a radius of 30 inches, for a period of at least 96 hours. The material is weighed before and after the test. Excessive loss of weight (about 5 per cent), sagging, looseness, crumbling, etc., are causes for rejection.

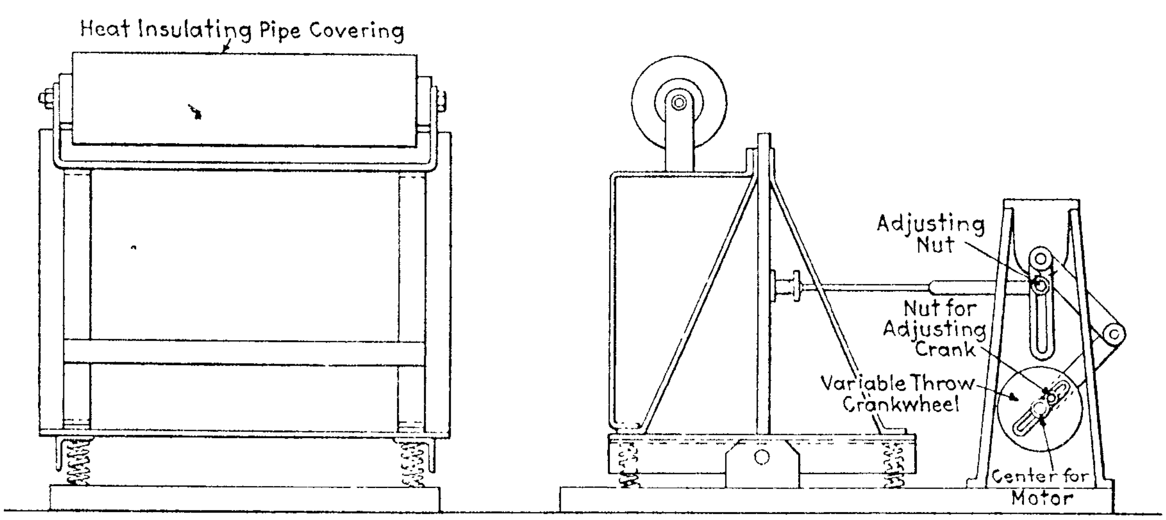



FIG. 3.—SHOCK AND VIBRATION MACHINE FOR TESTING HEAT-INSULATING PIPE COVERING

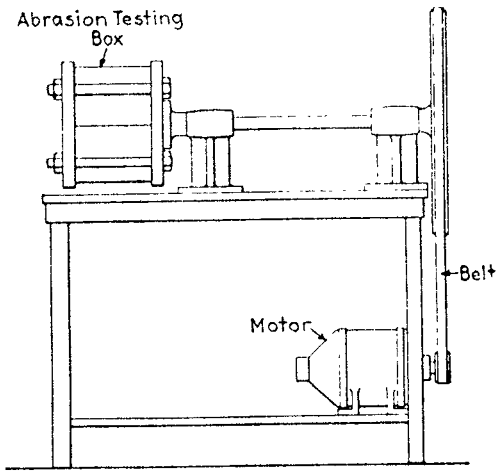



FIG. 4.—ABRASION TESTING APPARATUS FOR HEAT-INSULATING MATERIAL

*Hardness.* Hardness is determined by a plastometer. The degrees of hardness of the various insulating materials, in 1/100 millimeter using a ⅛-inch ball, are specified by the Navy Department specifications.

*Resistance to Abrasion.* The structural strength is determined by an abrasion test (Fig. 4). In this test twelve 1-inch cube specimens of the material and twenty-four ¾-inch oak cubes (specific gravity of wood 0.65), are placed in an oak box having inside dimensions 7½ inches by 7¾ inches by 7¾ inches. The oak box is then closed and it is rotated about its own axis at a speed of 60 revolutions per minute for two 10-minute periods. At the end of each 10-minute period, the cubes of the material under test are removed from the box and the per cent loss in weight, due to pulverization and breakage, is determined. The maximum allowable loss in weight is 40 per cent after the first 10-minute run and 60 per cent after the second 10-minute run.

*Physical Changes Under Heat.* Specimens of the material are subjected to a soaking heat, at various temperatures, in an electrically heated oven for a period of six hours. Changes in hardness, loss of weight, and linear shrinkage, are recorded. The size of the test specimens, oven temperature and allowable limits of change, are specified by the applicable specifications.

*Moisture Absorption.* Specimens are subjected to an atmosphere of 90 per cent relative humidity at 120 degrees F. dry bulb for six hours. The increase in weight is noted and the per cent absorbed by volume is calculated. Moisture absorption is limited to 3 per cent by volume.

*Water Absorption.* This test is not required by the specifications, but is conducted to obtain information which might be of future value. Specimens similar to those employed in the moisture absorption test are immersed in water at 80 degrees F. for six hours. The increase in weight is recorded.

*Chemical Analysis.* A complete chemical analysis is made in accordance with accepted laboratory methods.

*Weight.* Expressed in pounds per cubic foot. The applicable specifications limit the weight.

*Adhesion Test (Insulating Cements).* The adhesive properties of insulating cements are determined on the cement adhesion test apparatus (Fig. 5). This apparatus consist of a steel plate and a steel ring, each 10¼ inches in diameter and ⅜-inch thick, centered and held in parallel planes 2 inches apart by four studs set in the ring. The inside diameter of the steel ring is 6¼ inches. The material under test is held between the ring and the plate. A steel disk, 6 inches in diameter and ⅜-inch thick, completes the surface in the plane of the ring. The adhesion of the material to this disk is measured.

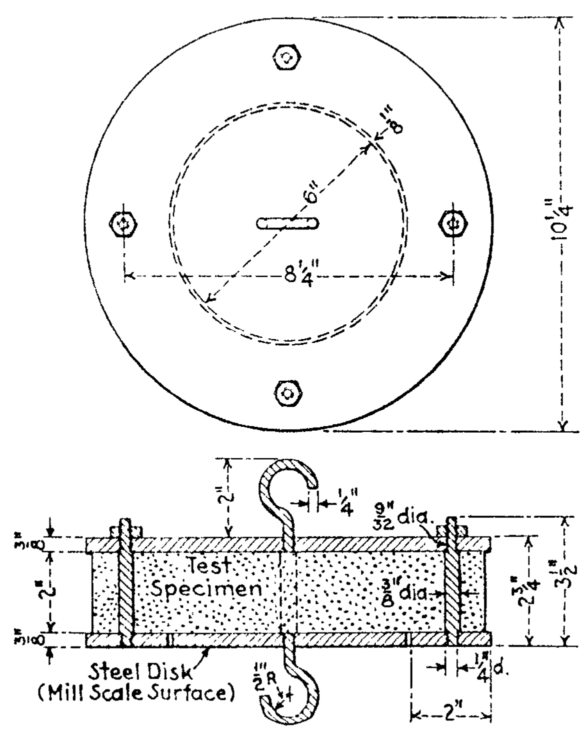



FIG. 5.—ADHESION TEST APPARATUS (INSULATING CEMENTS)

The insulating cement is applied to the apparatus as follows: The steel ring is laid on a flat, horizontal plate. The steel disk is laid in the center of the ring, its center concentric with that of the ring. The continuous flat surface thus presented is covered with a 2-inch troweled layer of the insulating cement. Ring, disk, supporting plate and cement are dried at 300 degrees F. to constant weight in an electric oven. The 10¼-inch steel plate is then secured in place by the four studs. Hooks are screwed into centered holes on the outside surface of plate and disk.

A measured load is applied to the hook in the steel disk while the specimen is suspended from the hook in the steel plate. Adhesive property is expressed in pounds of load (to cause rupture of bond) per square inch of sample. The average of three determinations is used.

In the cases of new type materials, of which no previous data or information are available, the test procedure is somewhat altered—the materials being subjected to test for a longer period of time. If any doubt still exists as to the suitability of the material, the approval is withheld until it has successfully withstood service conditions for a limited period.

## Classification

The Navy Department general specifications for machinery specify heat-insulating materials as follows:

(1) For insulating steam, hot water, and hot fuel-oil containing surfaces, and in general to prevent loss of heat by radiation, the standard insulating materials shall be "85 per cent magnesia" (Navy Department Specifications 32M2) wherever the temperature of the insulated surface will not exceed 500 degrees F.

(2) Where the temperature of the insulated surface will be above 500 degrees F. and will not exceed 850 degrees F., the insulating material shall be high-temperature insulation (Navy Department Specifications 32P3).

(3) For the insulation of combustion surfaces in general, where the normal full-power operating temperature will exceed 500 degrees F., and will not be in excess of 1500 degrees F., high-temperature insulation (Navy Department Specifications 32P3) shall be used.

(4) In lieu of the materials specified in paragraphs 1 and 2 above, "crinkled" aluminum foil (Navy Department Specifications 47A5, grade B) or rock wool (Navy Department Specifications 32P5) may be used, subject to all of the following conditions:

(a) Where weight saving is a consideration and where definite saving in weight will result.

(b) Where the temperature does not exceed 850 degrees F.

(c) When specifically approved by the Bureau.

(5) In addition to the optional materials listed in paragraph 4, preceding, where irregular surfaces are to be covered, asbestos cloth pads of convenient size may be used when specifically approved by the Bureau. The asbestos cloth shall be in accordance with Navy Department Specifications 32C11, type B. The pads shall be filled with magnesia asbestos cement or pulverized magnesia block (Navy Department Specifications 32M2) where the temperature will not exceed 500 degrees F. and asbestos fiber (Chrysotile) or (Amosite), or rock wool fiber (Navy Department Specifications 32P5) where the temperature will not exceed 750 degrees F. The pads shall be sewed and quilted with fine wire or with asbestos twine in such a manner as to provide a uniform thickness of insulation.

For many years 85 per cent magnesia insulation predominated the field of heat insulating materials. The ease with which this material could be applied in its various forms, its low conductivity, its relatively low cost, its comparative lightness in weight and durability, were factors for the retention of its use on board ship. The temperature range at which this material could be used, however, was limited. At temperatures in excess of 500 degrees F., it calcines and decomposes.

The use of high steam pressures and temperatures in excess of 500 degrees F. has presented a new problem in heat insulation. As 85 per cent magnesia is unsuitable, it became necessary to investigate, develop and employ other types of heat-insulating materials. These materials were required to have highly efficient insulating properties and physical properties which would not depreciate at the higher temperatures.

Extensive investigations and tests have been conducted on these materials. No one type has been found to possess all the required properties, hence this has resulted in adopting and employing a group of materials which may be classed as follows:

(a) Sectional and segmental molded insulation.

(b) Fabricated felted rock wool.

(c) Aluminum foil.
(d) Insulating cement.
(e) Asbestos pad and blanket.
(f) Asbestos tape.

### Discussion

*Sectional and segmental molded insulation* materials are generally composed of large percentages of diatomaceous earth and magnesium or calcium carbonate bonded together with small percentages of asbestos fibers. This class of material is generally more expensive, is heavier and does not have as high heat-insulating efficiencies as other types. It possesses, however, high heat-resisting properties and it is suitable for use at temperatures up to 1500 degrees F. Consequently it is employed for the insulation of pipe and combustion surfaces in general, where the normal full-power operating temperature will exceed 500 degrees F., but will not exceed 1500 degrees F.

Whenever practicable, especially in pipe-covering form, the material is furnished as an inner layer in combination with an outer layer of 85 per cent magnesia. Navy Department general specifications for machinery specify the thickness of the layers that are to be employed for different pipe sizes and temperatures. The double-layer type material reacts to the manufacturers' advantage because 85 per cent magnesia is cheaper than diatomaceous earth. It is advantageous to the Navy because the combination weighs less than a complete high-temperature material. The high-temperature materials in most cases are not as good heat insulators as 85 per cent magnesia, hence more heat protection is obtained from the combination than from a complete high-temperature material.

Manufacturers of the diatomaceous earth molded type high-temperature materials have strived to improve their product. Marked improvement has been obtained through the use of calcined diatomaceous earth. This has resulted in a more efficient lighter weight material, possessing adequate and ample physical properties.

*Fabricated rock wool* materials are composed of rock wool fibers, felted without the use of added binders and secured to inner and outer face metal supporting members. The rock wool fibers are made from natural stone, composed of calcium, magnesium and aluminum oxides and silica. The rock is melted and while in the molten state it is blown with a steam jet. A fibrous formation is obtained. The grade of fiber thus formed is dependent upon the process of manufacture. Drastic Navy Department leaflet specifications have been prepared in order to obtain a high quality material, with a low sulphur content and containing a minimum amount of undesirable shot or glassy globules.

The metal supporting members of the material on the outer face are screen wire or 1-inch mesh wire covering, and on the inner face are 1½-inch wide strips of screen wire, spaced 1½ to 2 inches apart and running longitudinally the length of the material. The securing and the fastening of metal members together and to the rock wool section of the material is performed by individual, small steel wires, fastened approximately 6 inches apart along the metal strips, passing vertically through the rock wool and fastened to the outer screen wire covering.

Rock wool fuses at about 1200 degrees F., hence it is not used for temperatures over 1000 degrees F. It ranks high as regards its heat-insulating properties. Its initial cost is lower than that of most of the other types. Its weight is approximately the same as 85 per cent magnesia.

When used on pipe surfaces it is wrapped around in a single layer and the abutting edges of the outer screen wire covering are secured by lacing or some type of clip. It is more difficult to apply to pipe surfaces than the molded type materials. A tight snug fit is imperative in order to prevent damage from vibration.

For the purpose of saving of weight, experiments and tests are now under way using this material as an inner layer in the combination type.

*Aluminum foil insulation* was used in Germany before it was introduced in this country. At first the idea of using a metal as an insulating material to retard the flow of heat seemed foolhardy. Nevertheless, very thin, pliable sheets of aluminum foil approximately 0.0003 inch thick, can be applied in such a manner as to form a rather efficient insulating material. The heat-insulating efficiency will vary widely with the manner of application of the foil and with the degree of expertness with which the applications are made. In its most effective form, it is applied plain, in successive layers made of individual sections of foil separated from each other by strips or frames made from heat-resisting materials, such as asbestos wood or built-up layers of asbestos paper. The cost of applying the material in this manner is too great for the material to be considered a practical insulation. Practical applications consist of built-up layers of crumpled foil in which no spacer or supporting sections are used. In this form the foil is first crumpled by hand and then applied in layers which are held apart approximately $^3\!/\!_8$-inch, solely by crumpling. For its insulating value in practical installations, it depends on the reluctance of a bright surface to absorb and radiate heat and, in part, on the opposition to convection current presented by the small air cells formed between adjoining layers of crumpled foil. Any number of layers of foil may be applied, depending on the heat protection desired and on the allowable bulk of installation. In view of the fragile nature of the foil, each application, whether on pipe or flat surfaces, must be protected with an outer metal sheathing. Special construction therefore must be provided to support the sheathing.

Aluminum foil installations using uncrumpled foil and spacer sections, as described in the preceding paragraph, are very efficient. As previously stated, the cost of application is prohibitive. It is, therefore, not considered practical and its properties should not be used for comparison with those of the practical type materials. Practical applications, employing layers of the crumpled foil, generally are found to have heat-insulating properties which are not as good as those of rock wool and only slightly better than those of the molded type materials.

The big advantage claimed for aluminum foil insulation over other types is its lightness in weight. This advantage is much reduced, if not entirely lost, by the added weight of the sheet metal protectors. With the aluminum foil-type of insulation higher outer surface temperatures are encountered than in the case of rock wool or molded type of insulation. This is due to the reluctance of the metal cover to radiate the heat transmitted to it. There have been some cases where the outer metal cover of the insulation on steam lines passing through confined areas was of such high temperature that it had to be covered with other types of insulating materials for protection of the personnel. Installations of the material in horizontal layers gave unsatisfactory service. The layers of the foil sagged or closed in to the lowest level.

The melting point of the foil is approximately 1200 degrees F. Hence, Navy Department general specifications for machinery limit the use of the material to temperatures not exceeding 850 degrees F.

The cost of aluminum foil itself is relatively low, but the labor cost of applying it and the patentee royalties are high. Hence, for corresponding thickness of insulation, the total initial cost of the material is higher than that of other type materials.

*Insulating cements* are composed of widely variant materials. As a result, they vary markedly in their heat-insulating and physical properties. In general they may be divided into the following groups, according to their basic constituents:

(a) Diatomaceous earth cements.

(b) Rock wool cements.

(c) Exfoliated mica cements.

All cements vary greatly among themselves as regards conductivity and weight, and in general are heavier and have a higher conductivity than other type insulating materials. They are principally used on uneven or irregularly shaped surfaces.

The primary characteristics to be considered in heat insulating cements are the following:

(a) Thermal conductivity.

(b) Ease of application and adhesive properties.

(c) Coverage capacity or cost per unit volume after applied.

(d) Refractoriness or the ability to withstand the action of heat at the temperature to which it is to be subjected.

(e) Shrinkage, wet to dry.

The diatomaceous earth type is composed of pulverulent diatomaceous earth, clay and asbestos fibers. This type, after applied, molded and dried, in general has the most efficient insulating properties. It is, however, difficult to apply and has poor adhesive properties. It will not adhere to hot surfaces nor readily adhere to lower or downward-facing cold surfaces, unless reinforcing wire is used. Its coverage capacity in general is lower than that of the other type insulating cements. After applied, molded and dried, its weight, structural strength and other physical properties approach those of the molded type insulating materials. The temperature range for which this type of material is suitable is in the realm of that of the molded type insulating materials.

The rock wool type is composed of nodulated rock wool fibers, clay and asbestos fibers. This type generally can be easily applied and will adhere to any clean, unheated or heated surface. It can be applied to the surface of piping without requiring the use of reinforcing wires. The adherence of this material to heated or hot surfaces is unique.

TABLE 1.—RANGE OF PHYSICAL CHARACTERISTICS

| Material | 85% Magnesia Molded Insulation (Pipe and Block) | Diatomaceous Earth Molded Insulation (Pipe and Block) | Rock Wool Blanket Insulation | Insulating Cements: Diatomaceous Earth | Insulating Cements: Rock Wool | Insulating Cements: Exfoliated Mica | Asbestos Blanket and Pad Insulation | Insulating Tape |
|---|---|---|---|---|---|---|---|---|
| Weight, lb. per cu. ft. | 15-18 | 18.6-27.5 | *15.0-19.0 | 28.6-36.6 | 29.1-36.0 | 17.0-18.0 | 13.0-14.2 | 13.8-21.0† |
| Hardness by plastometer, 1/100 mm. | 55-102 | 30-95 | | 41.0-51.0 | 66.5-121.4 | 159.0-185.0 | | |
| Resistance to abrasion (structural strength): | | | | | | | | |
| Loss in weight, per cent after 1st 10 min. run | 21.7-31.0 | 11.5-40.0 | | 6.0-20.6 | 22.0-35.4 | 25.0-30.0 | | |
| Loss in weight, per cent after 2nd 10 min. run | 36.3-49.3 | 21.2-60.0 | | 11.4-40.8 | 45.0-57.3 | 45.0-50.0 | | |
| Hardness after soaking heats: | | | | | | | | |
| After heating 6 hrs. at 750 deg. F. | | 57-93 | | 19.0-50.0 | 40.2-145.0 | 144.0-151.0 | | |
| After heating 6 hrs. at 1000 deg. F. | | 49-95.5 | | 20.5-48.0 | 36.0-139.0 | 131.0-138.0 | | |
| After heating 6 hrs. at 1200 deg. F. | | 41-109 | | 21.5-53.0 | 35.0-130.0 | 130.0-136.0 | | |
| After heating 6 hrs. at 1500 deg. F. | | 40-112.5 | | 21.5-56.0 | 31.8-118.0 | 120.0-130.0 | | |
| After heating 6 hrs. at 1800 deg. F. | | 31-154 | | 19.0-75.0 | 21.0-101.0 | Too Soft | | |
| Change in weight due to soaking heats: | | | | | | | | |
| Per cent loss in wt. after heating 6 hrs. at 750 deg. F. | | 3.3-4.6 | | 3.0-7.0 | 0.7-2.8 | Zero | | |
| Per cent loss in wt. after heating 6 hrs. at 1000 deg. F. | | 3.4-5.0 | | 5.0-11.0 | 1.0-4.8 | 1.0-1.3 | | |
| Per cent loss in wt. after heating 6 hrs. at 1200 deg. F. | | 3.6-19.0 | | 9.4-15.0 | 1.2-5.4 | 2.3-2.6 | | |
| Per cent loss in wt. after heating 6 hrs. at 1500 deg. F. | | 5.4-20.0 | | 10.5-18.0 | 4.6-6.1 | 4.3-4.7 | | |
| Per cent loss in wt. after heating 6 hrs. at 1800 deg. F. | | 7.1-21.0 | | 12.5-23.5 | 2.4-6.6 | 6.6-6.9 | | |
| Change in linear dimensions due to soaking heats: | | | | | | | | |
| Per cent shrinkage in length after heating 6 hrs. at 750 deg. F. | | 0.0-2.0 | | 0.00-0.31 | Zero | Zero | | |
| 1000 deg. F. | | 0.0-2.0 | | 0.00-0.68 | 0.00-0.63 | Zero | | |
| 1200 deg. F. | | 0.6-2.0 | | 0.63-0.94 | 0.31-1.25 | Zero | | |
| 1500 deg. F. | | 0.9-5.0 | | 0.93-4.36 | 0.63-2.52 | Zero | | |
| 1800 deg. F. | | 2.3-7.5 | | 2.90-5.70 | 1.26-4.65 | 1.1-1.4 | | |
| Moisture absorption: | | | | | | | | |
| Moisture absorbed, per cent by weight | | 3.3-8.3 | 6.7-12.9 | | | | 7.2-17.5 | |
| Moisture absorbed, per cent by volume | | 0.8-3.0 | 0.8-2.4 | | | | 1.8-4.2 | |
| Water absorption: | | | | | | | | |
| Water absorbed, per cent by weight | | 144.0-254.0 | 31.0-676.0 | | | | 284.0-332.0 | |
| Water absorbed, per cent by volume | | 70.0-78.0 | 4.0-74.0 | | | | 71.0-84.2 | |
| Water retained after draining 20 hrs. per cent by: | | | | | | | | |
| Volume | | 57.0-68.0 | 0.0-53.0 | | | | 55.0-65.0 | |
| Weight | | 117.0-212.0 | 0.0-499.0 | | | | 224.0-256.0 | |
| Coverage capacity, sq. ft., 1" thick per 100 lb. material | | | | 41.0-58.0 | 45.0-69.0 | 75.0-84.0 | | |
| Volumetric shrinkage (wet to dry), per cent | | | | 18.2-25.7 | 11.4-20.0 | 9.8-12.5 | | |
| Adhesive properties, lb. per sq. in. | | | | Zero | 2.1-12.1 | 9.0-11.2 | | |
| Tensile strength, lb. per in. width | | | | | | | | 162-208 |
| Change in tensile strength: | | | | | | | | |
| Per cent loss in tensile strength after heating 6 hrs. at 450 deg. F. | | | | | | | | 0-32 |
| 650 deg. F. | | | | | | | | 0-41 |
| 750 deg. F. | | | | | | | | 0-43 |
| Change in weight: | | | | | | | | |
| Per cent loss in wt. after heating 6 hrs. at 450 deg. F. | | | | | | | | 1.2-2.6 |
| 650 deg. F. | | | | | | | | 2.4-5.5 |
| 750 deg. F. | | | | | | | | 2.5-7.1 |

* As applied † Weight in lb. per 100 lin. ft.

TABLE 2.—NAVY DEPARTMENT SPECIFICATIONS

| *Title* | *Specification* |
|---|---|
| General Specifications for Machinery; (Heat Insulation and Lagging for Piping and Machinery) | Sub-section S39-1 |
| Cloth, Asbestos | 32C11 |
| Magnesia: Block, Cement and Pipe Covering | 32M2b |
| Insulation, High Temperature: Block, Cement and Pipe Covering (Diatomaceous Earth) | 32P3a and 32P3b |
| Rock Wool; Pipe Covering, Blanket, Cement and Fiber | 32P5b |
| Aluminum; Foil | 47A5a |
| Cements; General | In preparation |
| Pads and Blankets; Asbestos | In preparation |
| Tape; Insulation, Thermal. | Tentative Specifications only |

When applied and dried, the material forms a close bond with the surface to which it is applied. It does not crack, flake or crumble off. It becomes tough and strong, and in general not as brittle as the diatomaceous earth type. It is not as easily damaged. The coverage capacity of this type is generally higher than that of the diatomaceous earth type. Its weight and its heat-conductivity properties are higher than those of the diatomaceous earth type. The temperature range for which this material is suitable is approximately the same as that of the diatomaceous earth type.

*The exfoliated mica* type is comparatively new as regards its use in the naval service. Information relative to this material is limited as few

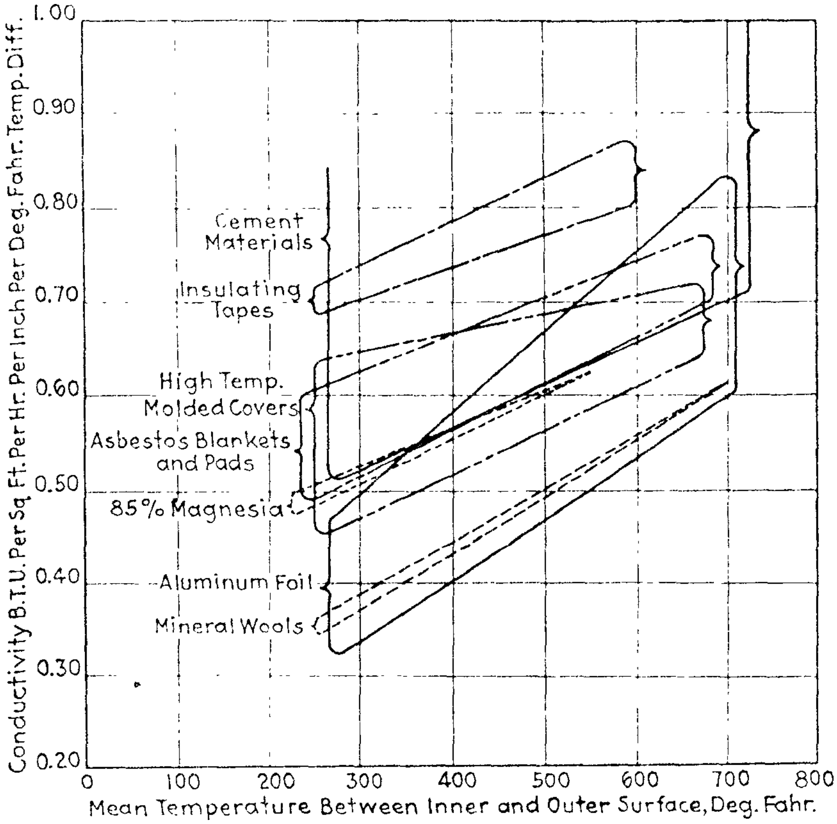



FIG. 6—CONDUCTIVITY RANGES OF VARIOUS TYPES OF HEAT-INSULATING MATERIALS

brands are available. The material is composed of particles of exfoliated mica, clay and asbestos fibers. The exfoliating of the mica particles is performed under heat at temperature of approximately 2000 degrees F. The particles in this form, because of the abundance of air voids, have very efficient heat-insulating properties. However, they possess very low structural strength and, in the mixing of the cement, the exfoliated mica particles become compressed, crushed and broken. Therefore, its heat-insulating properties are lower than those of the diatomaceous earth and rock wool types. As regards ease of application and adhesion, it compares favorably with rock wool. The salient properties, in comparison with other types, are its high coverage capacity and lightness in weight. After applied, molded and dried, the structural strength and the temperature range for which it is suitable are approximately the same as those of the other types of cements. However, it is relatively soft and is easily damaged.

*Asbestos pads* are composed of woven asbestos cloth in envelope form, filled with Amosite or Chrysotile asbestos fibers and tufted at close intervals with wire-inserted asbestos yarn. The woven asbestos cloth covering is cut and tailored so that the material in its finished form will conform with the curvature or shape of the surface to which it is to be applied. The edges and ends of the covering are sewed with asbestos cord or yarn. Metal lacing hooks sewed or secured to the outer surface of each section of the material provide means for securing and holding it in place after it has been applied.

*Asbestos blankets* are composed of Amosite asbestos fibers made up into the form of rovings. The rovings are located side by side and fastened together by wire-inserted asbestos yarns so as to form mat or blanket sections. The wire-inserted yarns in each section are located approximately ¾-inch apart and run transversely and alternately over and under the asbestos rovings. It is manufactured in the form of a felt, approximately 1-inch thick, 40 inches wide, and in any desired length. In its application, the material is built up in layers, the number of which depends upon the insulating effect desired. The layers are pliable and can be readily shaped to conform with the curvature of the surface to which they are applied

*Asbestos pads and blankets* are employed where the application of other types of insulating materials would be difficult or impracticable. The materials are frequently and extensively employed for insulating pipe flange joints, plain and corrugated pipe bends and turbine casings. The materials are suitable and used at temperatures up to 850 degrees F. Their thermal conductivities are higher than those of the molded type materials. Their weights are comparable to those of applied rock wool materials.

*Asbestos tapes* are of variant construction. Almost every manufacturer of this type material has his patented type of construction which he claims to be superior to all other types. The material is generally composed of Amosite or Chrysotile asbestos fibers in the form of rovings, slivers and listings, totally or partly covered with a braided or woven jacket. This type material is generally manufactured 1/4-inch and 3/8-inch in thickness, 2 inches wide, and in rolls 25 and 50 feet long.

Tapes are employed in the naval service to insulate 1/2-inch and smaller size pipe with curves or bends. The material has relatively poor insulating properties and it is used primarily to protect personnel and minimize fire hazards. Most materials of this type are unsuitable for temperatures in excess of 500 degrees F. Several special types, manufactured exclusively for naval service use, were found suitable for temperatures up to 750 degrees F.

### Comparative Data

As a handy reference, Fig. 6 and Table 1 give the conductivity range and the range of physical characteristics of the various types of heat-insulating materials discussed in this paper. Table 2 lists the Navy Department leaflet specifications covering these materials.

### Conclusions

The various types of insulating materials discussed in this paper have been approved for use in the naval service. There are undoubtedly other types which to date have not yet been tested for conformance to naval requirements. Some types, which are not discussed in this paper, have been tested and found to be unsuitable for naval use. A number of types have been rejected on account of their relatively high weight. The present weight and space restrictions in naval construction create a demand for light and compact materials. Manufacturers are aware of this and are continually striving to produce lighter and lighter heat-insulating materials possessing at the same time the other required characteristics and properties.

The author's thanks are due to Lieutenant Commander A. C. J. Sabalot, U.S. Navy, Superintendent Chemical Laboratory, and to Mr. W. P. Sinclair, Associate Mechanical Engineer, U.S. Naval Engineering Experiment Station, for aid in preparation of this paper.

## DISCUSSION

The President: I am sorry that Captain Cox could not be here, not that we regret the presentation by Mr. Whitaker, but as an old shipmate of mine when he was in the Design Department of the Bureau of Engineering, I know he would have liked to present his paper in person and to have handled the discussion.

He has introduced the subject of insulating materials in a manner which I am sure will lead to valuable discussion by others. The paper is now before you, gentlemen, for discussion.

Mr. E. C. Lloyd,* *Visitor:* The author is to be congratulated on his excellent presentation covering heat insulating materials, particularly as applied to temperatures in the range from 350 degrees F. to 1500 degrees F.

Special attention should be directed to the fact that tests are carried out on both cylindrical samples and flat samples so that the results gained by each method may serve to some degree as a check on the other. The combined use of the two types of samples is of particular interest to those who have been concerned with the testing of insulating materials over the years. Another interesting development in test methods is the abrasion test which follows the procedure of the rattler test used for many years by the paving brick manufacturer to determine the resistance to abrasion of the samples under test.

There is one test mentioned in the paper

* Armstrong Cork Products Company, Lancaster, Pa

on which I would like to ask a question. I refer to the moisture absorption test where samples are subjected to an atmosphere of 90 per cent relative humidity at 120 degrees F. dry bulb for six hours. It is difficult to see what bearing this moisture regain would have on the service of an insulating material used at 500 degrees F. It would be interesting to know just how the maximum allowable regain of 3 per cent by volume was arrived at. Quite frankly, it would seem that the water absorption as secured by immersion would furnish more valuable data as to the behavior of an insulating material in service than would the moisture absorption, though neither test would seem essential except in the case of insulating materials for use at temperatures below normal; i.e., on those ordinarily used for low temperature insulation.

On pages 475 and 476 the author points out some interesting features of aluminum foil insulation as it applies at temperatures up to 850 degrees F. I should like to ask if any tests have been made covering the effectiveness of this type of material after service of one year or more on shipboard. Also, it would be interesting to know whether the effect of moisture or sea water on this foil material has been determined by test.

There is one class of heat insulation largely used by the Navy and on shipboard generally that is not referred to in the paper, and I should like to know whether the author has tested insulating brick material such as is used for the insulation of boiler furnaces at temperatures up to 2600 degrees F. It would also be of interest to know whether or not tests of mineral wools have been extended to include the lighter and more efficient glass wools which are now available commercially.

Mr. R. W. Mollison,* *Visitor:* In Captain Cox's paper on heat insulation the fact is brought out that installation of light-weight materials for general use seems to be retarded because of their method of application together with application costs.

A new process of heat insulation has recently been placed before naval architects and marine engineers. This process affords a secure, easily applied method of light-weight and efficient coatings by spraying asbestos fiber. Research and invention of the necessary mechanical phases have shown that crocidolite asbestos fiber, known in the trade as Cape blue fiber, produces the best results. Asbestos fiber is blown from a nozzle directed towards the surface to be covered, the fiber appearing as a light cloud suspended in mid-air. Atomized binder propelled from a spray gun, contacts the fiber and lays it onto the surface. Mechanical pressing is necessary in order to even the surface built up to the required thickness. In this method all generally known characteristics of asbestos are retained; namely, ability to withstand high temperatures, low thermal conductivity, and the power to resist the attacks of chemical action.

This spray method of insulation differs from the application of cements, blankets, or molded insulations, yet combines the best properties of each. Like a cement it can be applied to irregular surfaces. It forms a continuous, homogeneous covering; tenaciously adheres to the surface, and is applied in place.

The spray application of asbestos is of particular interest in marine work. The average weights of commonly used insulation materials are as follows:

| | |
|---|---|
| Cement materials | 18 to 36 pounds per cubic foot |
| Insulating tapes | 14 to 22 pounds per cubic foot |
| High-temperature molded blocks | 19 to 27 pounds per cubic foot |
| Asbestos blankets and pads | 13 to 18 pounds per cubic foot |
| Cork boards | 8 to 18 pounds per cubic foot |
| Ground cork | 9 to 12 pounds per cubic foot |

Sprayed asbestos fiber weighs only 6 to 8 pounds per cubic foot. This lightness in weight is governed by the fiber used, the binder employed, the type of surfacing required, and the degree of firmness desired. In the spray application the density of the coating is reduced in proportion to the built-up thickness. Naturally this decrease correspondingly increases the efficiency as a heat insulator. The low thermal conductivity of the material compares favorably with the other insulating materials mentioned. The conductivity is particularly good for the lower refrigeration temperatures.

This sprayed material has been successfully applied in marine work for the insulation of partitions, ceilings, tops and side walls of cabins and salons, boiler room ceilings to prevent heat transmission to rooms above, underside of decks, bulkheads and stack up-takes. Among shipowners, this material has been applied by the French Line on the steamship *Normandie*. In America its use has been introduced by the Standard Oil Company of New Jersey and the Gulf Refining Company in their

* Keasbey & Mattison Company, Ambler, Pa.

oil tankers. In automobile and bus construction this method has shown additional advantages by spraying thin members subject to vibration. The firm adhesion of the coating to the metal backing has a deadening effect. There may be places aboard ship where a similar application would be helpful.

In all forms the sprayed insulation is fire resistant. While not entirely impermeable, it is highly resistant to the action of water. In general, the fiber-binder combinations resistant to fire are least resistant to water. Where conditions require, it is adaptable to surfacing for decorative effects or appearances, protection against abrasion, ease of cleaning, weather proofing, and additional fire protection. The insulation possibilities of this material in marine construction and repair work present a large field for future investigation.

Practical applications have been made with entirely satisfactory results, for temperatures ranging from minus 10 degrees F. to plus 700 degrees F.; and under test conditions this insulation has withstood temperatures rising from room temperature to 1700 degrees F. within one hour.

MR. C. L. NORTON,* *Visitor:* The paper in general seems to be very well presented and the scope and methods of tests shown seem to be very satisfactory. The pipe covering conductivity testing apparatus is practically a standard setup and is in accordance with accepted practice. The flat plate conductivity apparatus is a good setup which should give accurate values. The tests devised for measuring resistance, to vibration, abrasion and adhesion appear to be excellent tests and should give very representative figures.

The choice of materials covers the low-temperature insulating field quite thoroughly with the possible exception of insulating brick, which might possibly have been included in this report.

The only criticism of this paper which comes to mind is the question of aluminum foil insulation. This particular material has been the subject of much controversy and I feel that a little more might have been said in its favor in the paragraph under this heading.

In general, I believe that this is a very good description of available low-temperature insulating materials and should be of great benefit to a person contemplating the use of such materials.

* The Babcock & Wilcox Company, New York.

MR. MAX BRIETUNG,* *Visitor:* The author is to be highly complimented on his clear and concise description of the methods of testing various types of heat insulation; also his detailed analysis of the merits and demerits of the various materials to which he refers.

We are particularly interested in the comments about aluminum foil insulation, and wish to emphasize the fact that the author most assuredly refers to high-pressure steam pipe insulation in all of his statements and not to the use of aluminum foil insulation for high-temperature surfaces such as boilers, turbines, uptakes, etc.; nor for low-pressure surfaces such as decks, ship sides, cold storage rooms, bulkhead insulation, etc.

In general the methods of applying Alfol, as developed abroad, have been followed by the United States Navy Department in the application of aluminum foil to high-pressure steam pipe lines. This method of application is frequently less costly than for other insulations when equal insulating effect is required. The author states, "The big advantage claimed for aluminum foil insulation over other types is its lightness in weight. This advantage is much reduced, if not entirely lost, by the added weight of the sheet metal protectors." It is the usual procedure of the Navy Department to metal jacket exposed high-pressure steam pipe lines, regardless of what type insulation is applied. Materials such as 85 per cent magnesia and high-temperature insulation for pipe lines are frequently jacketed with metal. These metal jackets are of a similar weight to that required for jacketing aluminum foil insulation. The weight of the Alfol insulation is approximately one hundredth of that of 85 per cent magnesia or other molded types of high-temperature insulation thereby making a much lighter weight complete application. This weight saving is particularly important on pipes 4 inches and over in diameter. In fact, 14-inch pipe insulated with 3½ inches of Alfol shows a weight saving of approximately 15 pounds per linear foot when compared with 14-inch pipe insulated with 1½ inches of high-temperature insulation and 2 inches of 85 per cent magnesia.

The author makes the following statement: "There have been some cases where the outer metal cover of the insulation on steam lines passing through confined areas was of such high temperature that it had to be covered with other types of insulating material for

* Alfol Insulation Company, Inc., New York.

protection of the personnel." The impression is gained that this refers only to Alfol insulated steam pipe lines, but there are many cases where steam pipe lines insulated with other materials and metal jacketed have had to be covered with another jacket of insulation for the protection of the personnel. We feel that this point should be made clear, because we are confident that it was not the author's intention to infer that aluminum insulated pipe lines metal jacketed were the only lines aboard ship which have had to be covered with an additional layer of insulation in order to lower the surface temperature to a point where the personnel would not be burned.

The data recorded in Table I (Range of Physical Characteristics), as compiled by the author, is of utmost interest. Although no figures are given in this table for aluminum foil insulation, it is an established fact that the aluminum foil insulation is not subject to the following factors: Increase in hardness after soaking heats; change in weight due to soaking heats; change in linear dimensions due to soaking heats; moisture absorption; water absorption; water retention.

On the other hand, the figures for water absorption as established for diatomaceous earth molded insulation, rock wool blanket insulation, and asbestos blanket and pad insulation, are most important. These figures are:

| | Diatomaceous Earth | Rock Wool Blanket | Asbestos Blanket and Pad |
|---|---|---|---|
| Moisture Absorption: | | | |
| Moisture absorbed, percentage by weight | 3.3 to 8.3 | 6.7 to 12.9 | 7.2 to 17.5 |
| Water Absorption: | | | |
| Water absorbed, percentage by weight | 144.0 to 254.0 | 31.0 to 676.0 | 284.0 to 332.0 |

When one considers that the conductivity of water is approximately ten times greater than an average good insulating material and, furthermore, that the types of insulation referred to absorb moisture and absorb water at a relatively high rate of percentage, it is obvious that laboratory test conductivity figures do not and cannot apply in actual service regardless of the amount of heat which is within the pipe line upon which such materials are applied. This is because of changing temperatures within the pipe line and within the surrounding area.

The possibility of condensation within an insulation is far greater on surfaces such as ship sides, decks, bulkheads, cold storage room compartments, etc., than it is on high-temperature steam pipe lines. Therefore it is obviously highly desirable to provide insulating material which cannot absorb moisture and whose insulating value cannot be appreciably affected by condensation. Aluminum foil insulation, being all metal, meets this requirement.

The author states, "Installations of the material in horizontal layers gave unsatisfactory service. The layers of the foil sagged or closed into the lowest level." We have never heard of a condition of this kind. When aluminum foil is properly crumpled, it is so stiff in proportion to its weight that any number of layers used in insulation practice would be self-supporting without any settlement even under severe vibration. There are many applications which have been in use for approximately ten years, in which there has been practically no change in the insulating effect of this type of construction nor is there any sign of settlement of the various layers of foil.

In closing this discussion we believe it is a matter of public record that a great many ships of the United States Navy are using Alfol (Aluminum foil) insulation, and we have received no serious complaints about its performance during the five-year period in which it has been in operation. Furthermore, there are now many more ships under construction in which aluminum foil insulation is being extensively used for many purposes, as the result of its past performance aboard ship.

Lieutenant Commander R. W. Bruner, U.S.N., *Visitor*, and Mr. F. M. McGreary*, *Visitor:* We have read this paper and are in agreement with what has been stated therein, with one exception. We believe the following statement, appearing on page 476, should be qualified; "The big advantage claimed for aluminum foil over other types is its lightness in weight. This advantage is much reduced, if not entirely lost, by the added weight of the sheet metal protector." This statement is true when aluminum foil insulation is applied to pipe and other pressure containers which are not customarily lagged with sheet metal protectors.

Professor Gordon B. Wilkes, † *Visitor:* This paper by Captain Cox illustrates the thoroughness with which the Navy investigates materials that are to be used on its ships.

* Engineer (materials) United States Navy Department
† Massachusetts Institute of Technology, Cambridge, Mass.

The thermal conductivity apparatus requires some comment. From the drawings, there is no indication that any attempt has been made to insulate thermally the heater plates from the guard-ring heater plates. This would necessitate a much more accurate balance of temperature between the heater and guard than in the case where one has a definite thermal break, because of the much higher thermal conductivity of metals as compared in insulating materials. The design of plate conductivity apparatus usually calls for a groove cut in the metal plates, in an attempt to reduce the cross sectional area of the "through metal." In the apparatus at Massachusetts Institute of Technology, all through metal has been eliminated between the heater and the guard.

The moisture absorbed by the rock wool blanket insulation is amazingly high and is probably due to a typographical error. Many experimenters have found that rock wool, slag wool and glass wool will only absorb a few tenths of 1 per cent of moisture by weight when exposed to high humidities.

Under aluminum foil insulation, it is stated that the cost of applying "spaced" foil is "too great for the material to be considered a practical insulation." This may be so for Navy work but there have been many examples in the past few years where aluminum foil has been applied in this manner at a comparable cost and efficiency to that of the older types of insulation. The insulation of the air space between the studs of a frame wall by spaced aluminum foil is an excellent example of good insulation at a cost comparable with other types of equally efficient insulation.

The paper also states that "installations of the material (crumpled aluminum foil) in horizontal layers gave unsatisfactory service. The layers of the foil sagged or closed in to the lowest level." It would be interesting to know the actual conditions of some of these unsatisfactory installations. There are a great many commercial installations where crumpled foil, approximately 2½ layers to the inch, has been used in a horizontal position over considerable periods of time with satisfactory results. Many refrigerator cars and trucks, both in this country and abroad, have their roofs insulated with crumpled foil and the results have been satisfactory despite the obvious vibration. Laboratory vibration tests on crumpled aluminum foil in a horizontal position show no indication of settling when it is spaced about 2½ layers per inch, 2 inches thick and with a foil thickness of about 0.0003 inch.

THE PRESIDENT: I was glad Mr. Lloyd made inquiry as to whether aluminum foil insulation has stood up in service, and whether it has been resistant against corrosion. That was very prominently in the minds of those in the Navy Department who were considering the question of using aluminum foil more than five years ago, at a time which was given by one of the later discussors. I think this type insulation has been in use for one or two years longer than that.

It seems to me that the time has been sufficient for examinations to show how this material has stood up in service and the reason I go into it in what may sound like repetition is that there may be someone here from the Bureau of Construction and Repair, who is familiar with the results of investigations such as are always made at periodic intervals on materials of this nature. If a representative of the Bureau is present and is disposed to speak, he may be able to add information as to the materials which have been tried out and which, as I understand, have been replacing the aluminum foil.

One of the points which seemed to be made against the use of aluminum foil insulating material; namely, that it required sheet iron covering, would apply only in certain instances. We were using it very largely on vertical surfaces which were already covered by sheathing of some kind. The only weight that we had to add to hold the foil in place was in the form of some clever contrivances which were arranged to hold it up. As I remember, no large additional coverage was necessary for a very large amount of it, in connection with the uses contemplated for it at that time.

MR. R. C. PARLETT,* *Visitor:* The author is to be complimented on presenting such a clear and concise description of the Navy Department's methods of test, of the nature of the various insulating materials in naval use, of the advantages and disadvantages of each, and of their properties, not only physical and thermal but actual application qualities as determined by service experience.

The writer is in entire agreement with the author of this paper that there is no single insulation material which will meet all the

* Johns-Manville Corporation, New York.

requirements. Each type must be used where its individual characteristics best serve the particular conditions of service. When new materials are produced, there is quite often the tendency on the part of a producer to believe that the material will supplant everything else in existence. However, the proper field for any insulating material, as this paper shows, is determined only after thorough development and testing in the research laboratory, followed by adequate field service tests.

Among the various required properties which an insulation must have, the author lists durability as second in importance because of the severity of shock, vibration, abrasion, moisture, and other unusual conditions on shipboard. Also low density is listed as especially important. It is appreciated that low density in insulating materials is generally obtained by sacrificing durability and for this reason, information on the relative value of these two properties would materially assist producers in developing insulation for naval service.

The Navy test requirements for insulation are very complete. The test for resistance to abrasion indicates the ability of a material to withstand handling, shipping and general resistance to abuse. In reference to the test for determining the physical change of a material under heat, it has been the experience of the McMillan laboratory, with which the writer is associated, that the full effects of subjecting some insulating materials to soaking temperatures in an electric oven, are not obtained unless the material is heated over a considerable period of time. This is particularly true of those materials which show crystalline changes under heat.

An extreme example of this is molded monohydrated bauxite block which required nineteen days at 1000 degrees F. before complete shrinkage occurred, the shrinkage having increased during that period by 400 per cent over that shown after the first twenty-four hours. On a precalcined diatomaceous earth block, however, the full shrinkage is obtained in approximately seven days with an increase of only 75 per cent over that shown after the first twenty-four hours.

The service experience with the various insulating materials as enumerated by the author are particularly valuable. They show that the lighter type of materials such as mineral or rock wool and aluminum foil, which in some cases (Fig. 6) show lower conductivity in the laboratory tests than the molded types such as 85 per cent magnesia and diatomaceous earth, are also subject to greater variation in application than the molded forms. For example, it is stated that the rock wool type is more difficult to apply, a snug fit being imperative to prevent damage from vibration. Also that installations of aluminum foil in horizontal layers gave unsatisfactory service, the layers of foil sagging or closed in to the lowest level.

These changes in physical properties of the material undoubtedly change the insulating value. It would be very desirable if tests could be devised to determine the extent of this change in insulating value after the material had been subjected to service conditions. It would also be of considerable interest to have data on the effect of moist air, particularly salt air, on the metals contained in insulations. Exposed metals on board ship are painted or kept clean and protected as far as possible from oxidation but metals within the insulation, such as wire reinforcement in the rock wool type covering and the foil proper in aluminum foil covering, might be subject to rapid deterioration. It is well known that metallic aluminum exposed to air and moisture does not remain bright, indicating a change in the surface, so that data on the permanency and ultimate insulating efficiency of these coverings containing metals would be valuable.

In addition, I would like to ask the author whether the thermocouples in the pipe covering apparatus are all on one plane, as the drawing might indicate. It has been our experience that unless these are placed in planes 90 degrees apart in a spiral direction around the pipe, you do not get a true average temperature of the pipe, since there is a difference between the temperatures on the top, sides, and bottom of the pipe.

Another point on which I would like some information is in connection with the conductivity curves on page 478. These show a wide variation between the maximum and minimum values for some materials such as aluminum foil, cements, etc., but 85 per cent magnesia and mineral wools are shown to have a very small variation. This agrees with the experience of the McMillan Laboratory with the exception of tests on mineral wool. In many tests on all types of mineral wool we have found a wider variation in conductivity than with most other types of material, excluding cement. The mineral wool curves are steeper than found by the author, particularly on low density material. The variation in conductivity has been such that in many cases the values were higher than for 85 per cent Magnesia.

In conclusion, it should be stated that this paper has given a clear picture of the naval requirements for insulation and it is hoped that future papers will follow from time to time as more materials are tested and used in naval service.

CAPTAIN COX: I am grateful to Mr. Whitaker for the excellent manner in which he presented the paper and I am greatly pleased with the spirit in which it has been received and discussed. Before replying to the discussion, I would like again to point out that the principal object of the paper was to discuss heat-insulating materials from the standpoint of the requirements of the naval service, service experience and the results of tests conducted at the U. S. Naval Engineering Experiment Station. For many obvious reasons, I could not discuss specific brands of materials but had to confine myself to a discussion of the properties of various types; neither could confidential information be divulged, nor could unsuitable types or brands be discussed. If in answering the various questions raised I stray from my original purpose, it will be only because the question cannot be answered in any other way.

Mr. Lloyd questions the value of the moisture absorption test and further adds that it would appear that more valuable data would be obtained from water absorption by immersion. Some types of materials are not appreciably affected by moist-air conditions. However, there are other types in which the stability is affected by moist-air. The 3 per cent limit on moisture absorption by volume was arrived at from the results obtained from the tests of the various types and brands of satisfactory materials. The main propulsion plants of naval vessels are secured over 50 per cent of the time and during the shut-down periods the insulation material is subjected to low-temperature moist-air conditions. The range of water absorption by the various materials varies considerably. Such a wide range made it impracticable to set definite limits. Although no water absorption limit was established, the materials are required to withstand this test without showing signs of deterioration.

The data on rock wools does not include glass wool. Only one partial test has been made on glass wool and that was some five years ago. The material submitted at that time was not considered satisfactory because the method employed for its application was not practicable and the supporting members were combustible.

Insulating brick material was not included in this paper, as the tests of such material are not conducted at the Engineering Experiment Station.

Mr. Mollison discusses a type of insulating material which has not been fully tested at the Engineering Experiment Station. Some time ago one brand of this type of insulation (sprayed asbestos fibers and binder) was tested for its acoustical properties. This material took quite some time to apply and the binder supported combustion. For these reasons it was not even considered as a heat-insulating material.

Referring to Professor Wilkes' comments about the conductivity test apparatus, the heater plates consist of two alundum disks and are not of metal, as is to be inferred by the comment. This apparatus and the pipe test apparatus are in accordance with the recommendations of the Committee on Heat Transmission, Division of Engineering and Industrial Research, National Research Council, published February 1, 1929. The data on moisture absorption of rock wool blanket insulation, as given by Table 1, are correct. These values appear high to Professor Wilkes, but it must be remembered that standard-size specimens 4 inches by 4 inches by 2-1/2 inches are used in the test and that the relation between exposed surface area and weight is high. For large blanket sections, in which the relation between exposed surface area and weight is less, the per cent of moisture absorbed will also be less. The Station has tested water-repellent rock wool blankets which absorbed little or no moisture.

The author agrees with Mr. Parlett that the full effect of the soaking heat tests cannot, with some materials, be obtained within twenty-four hours. However, the soaking heat test is not fully representative of service conditions. A test of only six hours' duration is employed to determine if the material is susceptible to change.

The thermocouples of the pipe test apparatus are all in the same plane. The Station has not conducted any tests or experiments to determine the best positions for the thermocouples. According to Mr. R. H. Heilman, staggering the thermocouples in different planes is a useless refinement (*Mechanical Engineering,* Volume 46, No. 10, pages 605-606). In any case, as previously stated, the apparatus is constructed in accordance with the recommendation of the National Research Council.

Referring to the conductivity curves for mineral wools, the curves shown in Fig. 6 are only for three approved types which are in accordance with Navy Department Specifications.

In regards to aluminum foil insulation, let us first discuss the sheet metal protectors. Galvanized sheet steel or aluminum alloy sheet are required in the naval service to be used on the main steam lines and on other lines only when exposed to chafing, abrasion or to weather. When aluminum foil is used as the heat-insulating material, the sheathing is 0.025 inch nominal thickness; with other types of heat insulation, the sheathing is required to be 0.014 inch nominal thickness.

The author concurs with Mr. Brietung's comment that aluminum foil insulated pipe lines, metal jacketed, are not the only lines on board ship which have had to be covered with an additional insulation in order to lower the surface temperature to a point where the personnel will not be burned.

All aluminum foil insulation requires sheet metal protectors, while other types of heat-insulating material, especially for many pipe lines, do not require metal protectors. There are a number of steam lines on board ship which, if insulated with aluminum foil, require additional insulation over the metal protector to prevent burning of personnel, while these same lines, if insulated with other materials, would not require this additional insulation over the canvas cover.

I feel that my choice of words in the following sentence, "The layers of the foil sagged or closed in to the lowest level," has been misleading. It did not intend to imply that the layers flattened out completely, but that in horizontal layers the optimum void space for obtaining best efficiency was considerably reduced. The Navy continues to use aluminum foil for vertical insulation but found it very difficult to apply properly in a horizontal plane. The insulation was made up in sections and then installed. During the installation the thickness of the material changed as much as from one inch for three layers to less than one-half inch for three layers.

In reply to Mr. Lloyd's question, no tests of aluminum foil have been made after it has been in service for a year or more on board ship.

THE PRESIDENT: We will convey the thanks of the Society to Captain Cox for his very interesting paper, which we are so glad to have from a man of his very outstanding experience in that field.