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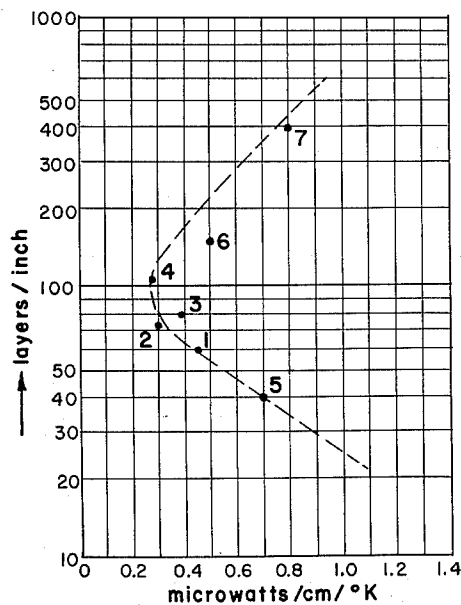
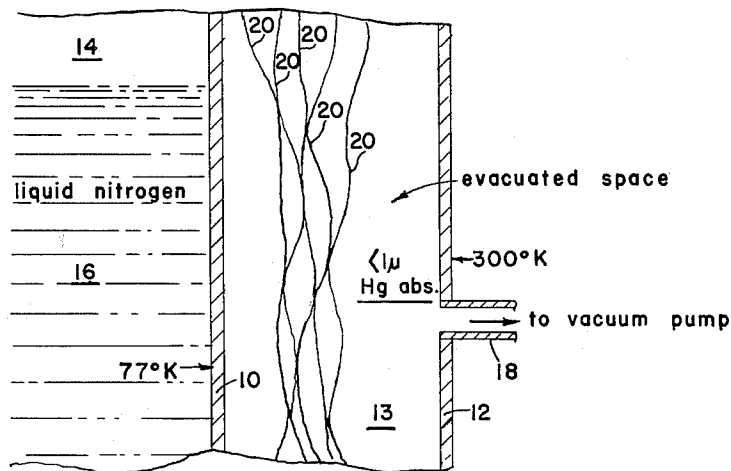


FIG. 2

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VACUUM DEVICE

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This invention relates to containers for holding materials at a temperature widely different from ambient temperatures, and more particularly to containers for holding very cold materials such as liquid oxygen, liquid nitrogen or liquid hydrogen. This application is in part a continuation of my copending application Serial No. 724,296, filed March 27, 1958, now abandoned.

A principal object of the present invention is to provide a novel container particularly adapted for holding liquefied gases wherein the cost and weight of insulation for the container is considerably less than that embodied in presently available commercial containers for such liquefied gases.

Another object of the invention is to provide an insulated container or pipe of the above type wherein the weight and space requirements of the insulation are greatly reduced over those utilized in present commercial practices so as to provide smaller, lighter containers or pipes for handling given quantities of a low temperature liquid.

Other objects of this invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the apparatus possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawings wherein FIG. 1 is a diagrammatic, schematic view of one embodiment of the invention; and FIG. 2 is a graph showing the effect of insulation density upon the apparent thermal conductivity "K."

Presently available containers for liquefied gases include a double-wall container having an evacuated space between the walls, which space is filled with a bulk insulation such as silica gel and the like. Examples of such commercially available containers are shown in U.S. Patents Nos. 2,460,355 and 2,396,459. While these containers have advanced the art for storage of liquefied gases, they are relatively bulky, heavy and expensive. It has been discovered that considerable savings in both space and weight of insulation of such evacuated double-wall containers can be accomplished by the present invention.

In general, the objects of the present invention are achieved by providing such an evacuated structure which can be maintained at a low absolute pressure of less than one micron Hg abs. (preferably less than 0.1 micron Hg abs.) so as to substantially completely eliminate gaseous conduction of heat across the evacuated space. In this evacuated space, there is provided a plurality of layers of metal-coated, nonmetallic substrate of poor thermal conductivity. It has been discovered that such metal-coated, nonmetallic substrates can be positioned in the evacuated space without any requirement for separate spacing means. However, in order to fully utilize this important characteristic, the metal coating must be relatively thin, having some transparency to visible light, and it is preferred that the metal coating be only on one side of the substrate. The substrate is also very thin, pref-

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erably on the order of $\frac{1}{4}$ mil, and is crinkled to provide only point contact between adjacent layers.

The very thin metallic coating and the very thin plastic substrate together have very low lateral conductivity and extremely low mass per unit area. Accordingly, a great many of these very thin layers can be placed in a small space to provide a large number of radiant heat shields having extremely low bulk density and low heat capacity. Since no separate spacers are required, the bulk density and heat capacity of the insulation is only that of the extremely thin plastic with its almost negligibly thin layer of metal coating. While the individual layers may have relatively high emissivities (e.g. .04-.06) as compared to the minimum emissivity (about .02) obtainable with solid aluminum, the larger number of shields which can be employed more than compensates for the somewhat higher emissivity per layer.

The substrate must be capable of remaining under vacuum for long periods of time without suffering damage, and it must not contain volatiles which can be slowly released to the evacuated space. Accordingly, preferred substrates are organic plastic films which are free of volatile plasticizers. The plastic should contain no material having an equilibrium vapor pressure at 20° C. in excess of 10 microns Hg abs. Particularly satisfactory materials are the polyester resins. A sheet of polyethylene terephthalate .25 mil thick has a lateral conductivity of less than 1×10^{-6} watts/square/° K. The metal coating on the plastic substrate preferably has a thickness less than a few micro inches (e.g. 0.5 microinch) so as to provide only slight lateral conduction in the plane of the metal coating. However, this metal coating is sufficiently thick so as to have an emissivity of less than .06. An aluminum film of 0.5×10^{-6} inches has a sufficiently low heat conductivity (about 3.8×10^{-6} watts/square/° K. at 300° K.) and the substrate on which the metal is deposited is sufficiently thin to give a lateral heat conductivity to the composite, metal-coated substrate of about 4.75×10^{-6} watts/square/° K. at 300° K.

The variation in lateral conductivity as a function of temperature is illustrated in Table 1.

Table 1

Material	Lateral Conductivity as watts/square/° K.		
	300° K.	77° K.	20° K.
A. $\frac{1}{4}$ mil (.000625 cm.) aluminum	1.91×10^{-3}	2.54×10^{-3}	25.4×10^{-3}
B. $\frac{1}{4}$ mil (.000625 cm.) polyethylene terephthalate	$.9 \times 10^{-6}$	$.858 \times 10^{-6}$	$.533 \times 10^{-6}$
C. $\frac{1}{2}$ microinch (.0125 micron) aluminum	3.83×10^{-6}	5.1×10^{-6}	$51. \times 10^{-6}$
D. Composite B+C	4.75×10^{-6}	5.98×10^{-6}	51.53×10^{-6}

The critical importance of having a thin metallic layer, particularly near the cold surface, can be appreciated when one observes the great increase in conductivity of the metallic layer with decreasing temperature.

At least 20 layers of this metal-coated substrate are provided in the space between the two walls of the container so as to provide an apparent thermal conductivity across the evacuated walls of less than 1 microwatt/cm./° K. Sufficient space is provided between the two walls in which the metallized substrate is positioned so that there will be some space between each of the layers and only point contact will be provided from one layer to the other. In order to provide uniformity of construction, alternate layers of metallized substrate may be crimped.

In one preferred embodiment of the invention, the substrate is formed of polyethylene terephthalate film .00025 inch (.000625 cm.) thick having an aluminum film of

about .1 microinch (.0025 micron) thick applied to one surface thereof. In one preferred embodiment, this aluminum film is applied by vacuum vapor deposition techniques of the type described, for example, in U.S. Patent No. 2,665,223. The aluminum surface of such a product has an emissivity of about .04. Fifty layers of this aluminized, polyethylene terephthalate, when packed in a space which is $\frac{1}{16}$ inch (1.7 cm.) across and is evacuated to a pressure of .05 micron Hg abs., provide an apparent thermal conductivity

K_{77}^{300} of 0.2985 microwatts/cm°K.

Referring to FIG. 1 there is illustrated a portion of a liquid nitrogen container embodying the present invention. This container comprises an inner vessel 10 adapted to confine liquid nitrogen 16 in a space 14, the liquid nitrogen being at a temperature of 77° K. and at atmospheric pressure due to a suitable vent (not shown). Only one wall of inner container 10 is shown for simplicity of illustration. An outer chamber 12 surrounds the inner chamber 10 and defines therewith a space 13 which is evacuated through a suitable outlet 18 to a free air pressure less than 1 micron Hg abs. Substantially all of the air and other vapors are pumped out of space 13 and, in a preferred embodiment of the invention, the free air pressure is reduced to less than .1 micron Hg abs. A plurality of layers 20 of metallized polyethylene terephthalate are provided in evacuated space 13. As illustrated, these layers make only point contact with each other at random locations and serve as radiant heat barriers.

The metallized substrate used as radiant heat barrier is preferably a material which will not outgas so that a relatively high vacuum may be maintained in its presence for extended periods of time. For this purpose, a polyester resin is very suitable, and polyethylene terephthalate has been found to be eminently satisfactory, particularly when the radiant heat barrier is not subjected to temperatures substantially in excess of room temperature. When high temperatures are to be encountered, then it is preferred that there are employed the more heat stable materials such as the fluorinated polymers (e.g. polymers of tetrafluorethyl). From the standpoint of cheapness, aluminum is a preferred coating metal, although gold, silver and copper can equally be employed. It is desired that the metal coating have an emissivity of less than .06 and that the lateral conductivity of a metallized plastic of .25 mil (.000625 cm.) be less than 10×10^{-6} watts/square/° K. at 300° K. This is about 200 times lower than the lateral conductivity of aluminum foil of equal thickness (see Table I).

For convenience of construction, uniformity of physical characteristics of the various layers is desirable, but this is not required and may not be preferred in some cases. For example, it is possible to use a thinner aluminum coating on the first few layers of metallized plastic adjacent the cold wall, these layers having a somewhat higher emissivity than preferred for most of the layers but having a lower lateral conductivity, particularly at the lower temperature, to minimize conductive heat transfer through the coldest layers of the insulation.

In a preferred embodiment of the invention, as mentioned previously, the nonmetallic sheet material is a plastic, and the plastic is preferably of extreme thinness such as .25 mil (.000625 cm.) as illustrated in Table I. Such a plastic, when vacuum coated with a microinch (.025 micron), or less, of aluminum, has an extremely low lateral conductivity so that, even though there may be many points of contact between adjacent layers of metallized plastic, the lateral conductivity is sufficiently low to permit the various layers to retain their separate identities from a heat transfer standpoint. Thus, each layer can assume its proper equilibrium temperature to serve as a radiation heat shield in accordance with the Boltzman Law.

In inserting the metallized layers into the insulation space, these layers are preferably crimped or crumpled so that only point contact between the layers is achieved. It is also very important that not too many layers be jammed into a given space, since the number of points of contact between the layers then becomes sufficiently great that the number of conductive paths so created overcomes the increased radiation barrier effect and actually decreases the effectiveness of the overall insulation. This aspect of the invention is illustrated in FIG. 2, which is a graph showing apparent thermal conductivity plotted as a function of layers per inch of metallized plastic. For convenience, the various numbered points in FIG. 2 are identified in Table II.

Table II

Point on Fig. 2	Total Number of Layers	Total Thickness of Layers, inches	Layers Per Inch (2.5 cm.)	Bulk Density, Pounds Per Foot ³
1-----	100	$\frac{1}{16}$	61.5	1.7
2-----	50	$\frac{1}{16}$	73.0	2
3-----	25	$\frac{1}{16}$	80.0	2.1
4-----	10	$\frac{1}{16}$	107	2.9
5-----	10	$\frac{1}{16}$	40	1
6-----	100	$\frac{1}{16}$	160	4.5
7-----	100	$\frac{1}{16}$	400	14

All of these data were taken with .25 mil "Mylar" polyethylene terephthalate film having a thin (.1 microinch) vacuum deposited aluminum coating which had a resistivity of about 8 or more ohms per square. These measurements of electrical resistivity were taken after completion of the heat transfer tests.

In connection with the utilization of metallized plastics, it is preferred, as mentioned previously, that the plastic be metallized on only one side, since it has been found that the apparent conductivity of an insulating system of the present invention including a number of layers seems to be about double for plastic which is coated on both sides as compared to plastic coated on only one side, other conditions being the same. The reason for this is not clearly understood, since, even when the total lateral conductivity in the plane of the metallized plastic may not be substantially increased by the use of two-side coating instead of a single coating, there is a definite increase of thermal conductivity of the composite insulation structure. It is probable that contact between the adjacent metallized surfaces provides substantial areas of adjacent surfaces having identical temperatures, thus decreasing the effectiveness of these reflective surfaces as separate radiation barriers.

While plastics are preferred for the nonmetallic substrate, good results have been obtained utilizing thin metallized papers, such as metallized glassine. In this case, it is impractical to pump the system down by normal vacuum pumps, but it has been found that the pressure in the space between the two walls rapidly decreases to the submicron pressure range when the inner container wall is chilled by contact with the liquefied gas. When materials such as metallized paper are used as the insulation medium, it is preferred that the cold wall be provided with an extended surface area, such as an adsorbent or fibrous medium, to provide a large area for retaining substantial quantities of frozen water and other volatiles which can be released from the paper over relatively long periods of time.

While the invention has been described in connection with a preferred embodiment thereof, it can be widely modified without departing from the scope thereof. For example, the invention is equally applicable to the insulation of low temperature pipes as well as low temperature containers.

The invention has been described above in connection with systems wherein two walls define an evacuated space.

While this is a preferred and usual embodiment of the invention, it is equally applicable for insulation of containers, pipes and the like normally positioned in an evacuated surrounding. For example, it can be utilized by wrapping the insulating layers around a pipe extending through a vacuum system. Equally, the insulation of the present invention can be utilized for insulation of containers forming portions of rockets and space vehicles where the container is to be carried out of the earth's atmosphere.

An outstanding advantage of the insulation of the present invention is the fact that it can be applied immediately adjacent the cold surface in a very thin space (e.g. less than one inch) so that the outer layers of the insulation are at about room temperature. This provides maximum freedom for design of the outer wall of the container since its area no longer has any effect upon the radiant heat transfer. Another advantage of this insulation is its low bulk density and low heat capacity. This is particularly important when used in conjunction with airborne equipment or liquid transfer lines. Additionally, the insulation of the present invention can be easily applied to all types of irregular surfaces.

Since certain changes may be made in the above apparatus without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An insulated vessel comprising an inner chamber to be maintained at a predetermined low temperature, said inner chamber being defined by a first wall, a second wall outside of said first wall and spaced therefrom, said walls being sealed together to form a space between said walls which is evacuated to a total pressure of less than 1 micron Hg abs. when said first wall is at a temperature less than about 100° K., said space containing at least 30 layers of metal-coated-nonmetallic, flexible plastic material surrounding the inner wall, said plastic material being essentially free of any substance having an equilibrium vapor pressure at 20° C. of greater than 10 microns Hg abs., there being between 12 and 120 layers of flexible material per cm. of thickness of insulation space, the metal coating on the flexible material having a thickness less than .25 micron and being sufficiently thick to have an emissivity less than .06, the flexible material having a low heat conductivity to give a low lateral heat conductivity to the metal-coated flexible material of less than 10×10^{-6} watts per square per ° K. at 300° K., the layers of flexible material being permanently deformed, as by crumpling, so that they are free of extensive areas of planar contact while having numerous point contacts

therebetween, said layers being essentially free of spacer elements therebetween, the major portions of said layers being held in spaced relation by said point contacts between layers, the apparent thermal conductivity of the insulation being less than about 1 microwatt/cm. ° K.

2. The apparatus of claim 1 wherein the flexible material is polyethylene terephthalate and the metal coating is aluminum.

3. An insulated vessel for confining a liquefied gas, said vessel having an inner gas-tight wall serving to provide a storage chamber for said liquefied gas, and an insulating member supported outside of said wall, said member substantially completely surrounding said storage chamber in heat-shielding relation thereto to prevent any substantial transfer of radiant heat to said storage chamber, said member having a pressure thereabout of less than 1 micron Hg abs., said member comprising at least 30 layers of metal-coated-nonmetallic flexible plastic material, said layers being assembled to provide between 12 and 120 layers of plastic material per cm. of insulated member thickness, said plastic material being essentially free of any substance having an equilibrium vapor pressure at 20° C. of greater than 10 microns Hg abs., the metal coating on the flexible material having a thickness less than .25 micron and being sufficiently thick to have an emissivity less than .06, the flexible material having a low heat conductivity to give a low lateral heat conductivity to the metal-coated flexible material of less than 10×10^{-6} watts per square per ° K. at 300° K., the layers of flexible material being permanently deformed, as by crumpling, so that they are free of extensive areas of planar contact while having numerous point contacts therebetween, said layers being essentially free of spacer elements therebetween, the major portions of said layers being held in spaced relation by said point contacts between layers, the apparent conductivity of the insulating member, when at said low pressure, being less than about 1 microwatt/cm. ° K.

References Cited in the file of this patent

UNITED STATES PATENTS

1,757,479	Schmidt et al. -----	May 6, 1930
1,970,120	Badger -----	Aug. 14, 1934
2,098,193	Munters -----	Nov. 2, 1937
2,102,698	Gould -----	Dec. 21, 1937
2,181,074	Scott -----	Nov. 21, 1939
2,817,124	Dybvig -----	Dec. 24, 1957
2,863,179	Gangler -----	Dec. 9, 1958

FOREIGN PATENTS

143,219	Great Britain -----	Dec. 9, 1920
217,667	Australia -----	Oct. 13, 1958