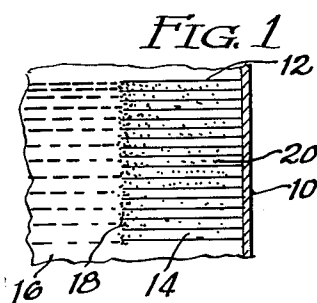
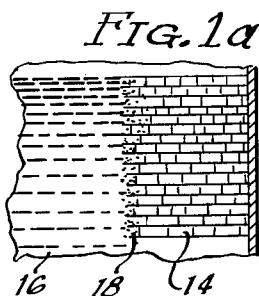
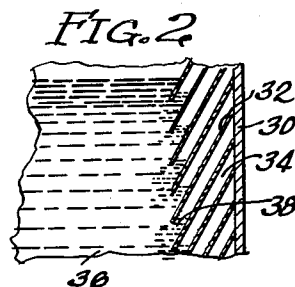
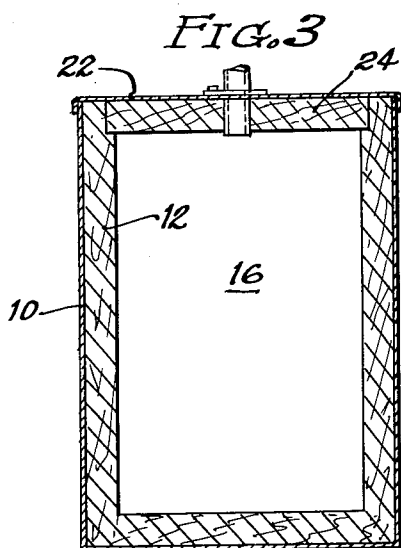
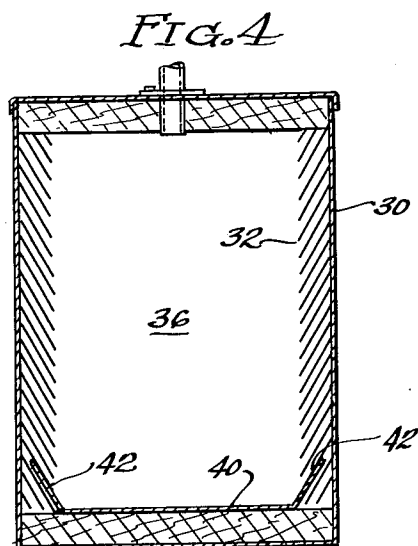
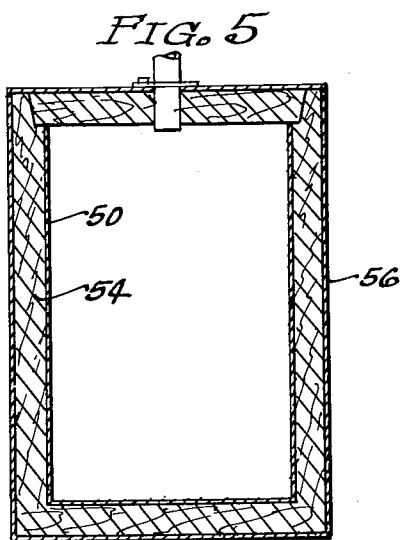
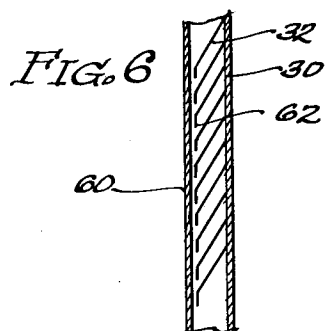


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INSULATED TANK FOR STORAGE AND TRANSPORTATION
OF LOW BOILING LIQUEFIED GAS
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3,019,937

INSULATED TANK FOR STORAGE AND TRANSPORTATION OF LOW BOILING LIQUEFIED GAS

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This invention relates to the storage and transportation of a low boiling liquefied gas and it relates more particularly to an insulated container in which a low boiling liquefied natural gas may be housed for storage and transportation.

As used herein, the term "low boiling liquefied gas" is meant to include gaseous materials in a liquefied state and which can be maintained in a liquefied state at ambient temperature only by confinement of the liquid in a container at extremely high pressures, or which can be maintained in a liquefied state at atmospheric pressure only by holding the liquid to an extremely low temperature. Included are such gaseous materials as nitrogen which boils at about -320° F. at atmospheric pressure, liquid air which has a boiling point of -316° F. at atmospheric pressure, and oxygen which boils at -295° F. at atmospheric pressure. While the inventive concepts described herein have application to containers for the storage and transportation of liquefied gases of the type described, the principal object of this invention is to provide a means for the storage and transportation of a liquefied natural gas which is composed mostly of methane and which is characterized by a boiling point temperature within the range of $250-260^{\circ}$ F. at about atmospheric pressure, depending upon the amount of higher boiling hydrocarbons and aromatics in the liquefied system.

Storage and transportation of the gaseous material in a liquefied state is desirable because the gas can then be reduced to about $\frac{1}{600}$ of its original volume when converted from a gaseous state to a liquefied state at atmospheric pressure. The difficulty with a low boiling liquefied gas resides in the means by which the liquefied material can be housed in large volumes for safe and economical storage and transportation.

Low boiling gases have been housed in pressure containers wherein the material can be maintained under high pressure for storage and transportation at or preferably somewhat below atmospheric temperature. While the absorption of heat from the atmosphere is minimized because of the lesser temperature differential between the temperature of the material and the ambient temperature, thereby to minimize dependence upon insulation, it will be apparent that the extremely high pressures demand the use of high strength containers. Such containers are not only expensive from the standpoint of the cost of materials and fabrication, but, of necessity, the capacity of such containers is limited by the ability to fabricate containers of sufficient strength with the materials available to the industry.

Thus such pressure containers are employed chiefly where the amount of material to be stored or transported is in small volume. Where natural gas is to be liquefied at a source of plentiful supply for ultimate use in an area where a deficiency exists, it is anticipated that the amount of gas to be processed greatly exceeds that which can be efficiently and economically handled in pressure containers. As the capacity of the container is increased, it will become apparent that the amount of pressure capable of being maintained will rapidly decrease to the point where containers operating under atmospheric pressure or at most slightly above atmos-

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pheric pressure are the only type of container which can be employed practically for holding the amount of liquefied natural gas transported to supply the fuel requirements of an entire section of a country for use in the generation of power or heat.

Thus the problem which presents itself is in the storage and transportation of a liquefied natural gas in large volume from a source wherein the natural gas is in plentiful supply to a distant area wherein there is either a shortage of an equivalent fuel or where such fuels are available only at a large premium. It is conceded that the natural gas can be liquefied at the source of plentiful supply for reduction of the gas to about $\frac{1}{600}$ of its original volume for transportation of the liquid to the point of use where it can be reconverted from the liquid stage to a gaseous form for use as a fuel thereby to make it economical and practical to transport natural gas from a source of plentiful supply to a point where a deficiency exists. The problems which characterize the storage and transportation of natural gas in large volumes will also be found to exist in the storage and transportation of other low boiling gases, such as oxygen, nitrogen, helium, and the like.

In the described modification wherein a container is to be designed for use in the storage and transportation of liquefied natural gas at atmospheric pressure, it becomes necessary to house the liquefied gas within the container at about -258° F. or slightly less, depending upon the amount of higher boiling hydrocarbons or aromatics present in the liquefied gas. At these extremely low pressures, the differential from the ambient temperature outside the container is such that the heat will naturally migrate from the outside into the liquid to cause volatilization thereof, the amount depending greatly upon the rate of heat flow.

To minimize heat transfer, containers for housing a low boiling liquefied gas at about atmospheric pressure have been designed embodying the principles of a thermos wherein use is made of an inner metal shell within an outer metal shell with the space in between either filled with an insulating material of low heat conductivity or else sealed and evacuated to maintain sub-atmospheric conditions. The inner metal shell is usually interconnected with the outer metal shell for structural support and the inner shell is usually constructed with walls of sufficient thickness to provide structural strength to support the liquid load plus the static forces existing when positive pressure conditions are maintained within the liquid storage tank.

For many applications, thermos type storage units of the character described have been found to be quite satisfactory but, where the material to be housed within the container comprises a low boiling liquefied gas such as natural gas, a number of deficiencies will be found to exist. For example, there are very few metals available which are capable of desired structural strength especially at temperatures of -100° F., let alone at temperatures as low as -258° F. to -300° F. Structural steel plate, such as used in tank construction and in tanker construction, becomes embrittled and weak at the temperature of liquefied natural gas at atmospheric pressure such that cracks have been found to develop in the steel even without the application of load. This is of extreme importance to this new industry especially where the liquefied natural gas finds its greater demands in countries or in sections of the country which cannot economically be joined to the source of supply by pipe line or the like and thus relies upon tankers or trucks for transportation.

Further, many corrosive materials, such as acid gases, are present as impurities in the liquefied natural gas, the amount depending greatly on the source of supply and the cleaning systems employed in the liquefaction process for

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the removal of moisture, the various acid gases and other impurities which might be present in the natural gas. Such acid gases and impurities corrode the surfaces of some metals which may be employed in tank construction. Corrosive attack is undesirable and, if progressive, will eventually eat away the material and require replacement or reconstruction of the tank—either of which would amount to the entire reconstruction of a ship when, as in the preferred concept, the tank is constructed as an integral part of the hold of the ship. Reconstruction for replacement of the metal shell will require the tie-up of the ship for many months and the expenditure of large sums of monies and labor.

Still further, a large number of elements are required properly to support the inner load carrying shell in the desired spaced relationship within the outer metal shell. These supporting elements, usually constructed of metallic material, provide direct pathways for the transmission of heat from the outer shell to the inner shell and to the liquefied gas contained therein thereby partially to nullify the effect of the insulation packed between the shells.

For these and for a number of other reasons, double-walled or thermos type tanks of the character heretofore constructed do not represent the most efficient and economical means for the storage and transportation of low boiling liquefied gases in large volume at about atmospheric pressure.

It is an object of this invention to produce a large capacity tank for the storage and transportation of a low boiling liquefied gas and it is a related object to produce a tank for the storage and transportation of liquefied natural gas in large volume at about atmospheric pressure.

More specifically, it is an object of this invention to produce a tank of the type described which avoids the limitations found in thermos or double-walled insulated tanks of the type heretofore employed; which has good thermal insulating properties to minimize heat transfer from the ambient atmosphere to the cold liquefied gas present as a content material in the tank; which makes use of materials in contact with the liquefied gas that are not affected by the cold of the liquid or any of the corrosive materials which might be contained in admixture or in solution therewith; which avoids the use of materials of high heat conductivity communicating the liquefied content material with the ambient atmosphere thereby to minimize the transmission of heat from the outside to the cold boiling liquefied gas within the container, and which makes use of a material of low heat conductivity which retains its flexibility and strength under the temperature conditions existing in the container and which permits for a wide temperature differential without loss of the characteristics thereof as a thermal insulating material.

These and other objects and advantages of this invention will hereinafter appear and for purposes of illustration, but not of limitation, an embodiment of the invention is shown in the accompanying drawings in which—

FIG. 1 is a schematic diagram of a portion of a tank wall illustrating the practice of this invention;

FIG. 1a is a schematic diagram of a modification in the construction as illustrated in FIG. 1;

FIG. 2 is a schematic diagram in section of a portion of a tank wall embodying a construction different from that of FIG. 1 but which further illustrates the concepts of this invention;

FIG. 3 is a schematic sectional elevational view of a container embodying the construction of FIG. 1;

FIG. 4 is a schematic sectional elevational view of a container embodying the construction of FIG. 2;

FIG. 5 is a schematic sectional elevational view of a container embodying a modification in the construction of FIG. 3, and

FIG. 6 is a schematic sectional view of a container embodying a modification of the construction in FIG. 4.

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In the construction and operation of a tank embodying the features of this invention, an entirely new concept has been developed. The inventive concept depends for its operation upon the characteristics of the low boiling liquefied gas to vaporize upon the absorption of heat and the ability to control the rate of escape of the vapors to prevent the escape at a rate greater than their rate of generation whereby the low boiling liquefied gas is held back by the vapors to avoid contact with the fluid impervious walls of the tank to provide an insulating space of low heat conductivity to insulate the liquefied gas from the ambient atmosphere.

The inventive concept can perhaps best be described by reference to the diagrammatic sketch of FIG. 1 wherein the tank wall of a structurally strong, fluid and preferably vapor impervious material is represented by the numeral 10. The numeral 12 represents a means lining the inner wall of the tank having a plurality of separated pores 14 or pockets and the numeral 16 represents the low boiling liquefied gas housed within the container in direct contact with the lining means 12.

The heat which penetrates through the wall of the tank from the ambient atmosphere is transmitted to the liquefied gas at the interface to cause some vaporization thereof. Such vapors 20 as are formed at the interface will enter the pockets to become entrapped therein. In accordance with the concepts of this invention, the pockets are constructed to prevent the escape of the vapors entrapped therein at a rate greater than the rate of introduction of vapors into the pockets, as by vaporization at the interface or by transmission through the walls from adjacent pockets or pores thereby to build up a cushion of vapor in the pockets which prevents deep penetration or entrance of the liquefied gas into the lining. In general, such vapors as are introduced into each pocket in excess of that capable of escaping from the outer portions of the pockets beyond the liquid interface are forced to be released from the pockets from the open end at the interior thereof to force back the liquid in the pockets to uncover the release openings for the excess.

Theoretically, the inventive concept resides in a container formed of an impervious outer shell having a lining on the inside of the container and in direct contact with the liquid wherein the escape of vapor by transmission through the pores is less than the rate of introduction of vapor into the pores whereby the entrapped vapors build up a back pressure sufficient to limit undue penetration of the liquefied gas into the porous lining thereby to provide and maintain an insulated space between the liquid and the wall of the container.

When openings are present in the insulating layer, such as in the form of pores, cracks, or voids, they should be so oriented or of such size as to build up the back pressure and not spill or release the pressurized vapor exerting the back pressure. It will be apparent that a number of characteristics are demanded in a material capable of use as a lining employed in the practice of this invention. For example, the lining material should be a material having low heat conductivity with pores running generally in a horizontal direction, as illustrated in FIG. 1, and preferably with the horizontally disposed pores running generally in a direction parallel with the walls of the container, as illustrated in FIG. 1a. The pores can extend horizontally endwise and perpendicular to the container, but preferably at a slight upward tilt from the inner edge outwardly toward the wall of the container. The desirability for an upward tilt will depend greatly on the cross-sectional dimension of the pores; the larger the pores, the greater the preference for an upward incline to build up the pocket effect for blocking penetration of the liquid. The lining material should possess mass integrity and structural strength to avoid deformation or deterioration under the load conditions existing. It should be relatively unaffected from the standpoint of strength and flexibility under

the extremely low temperatures of the materials to which it will be exposed, and it should retain a substantial proportion of its flexibility under such condition for use under the wide temperature differential which will exist from the inside out to the wall. It should be capable of retaining the vapors within its pores or pockets under sufficient pressure to hold back the liquid so as to block the flow of liquid through the pores into engagement with the outer wall. Finally, it should be free of attack by the liquefied gas or the acid gases or impurities admixed or dissolved therein.

The described characteristics are available in combination in very few materials. Best results have been secured by the use of a material in the form of a highly porous wood having structural strength sufficient to maintain the loads existing and which is capable of being formed into a composite structure, such as insulating panels which can be mounted onto the walls in substantial sealing relation therewith to provide the desired porosity wherein the desired back pressure principle can be developed. Woody materials having the described porosity and low heat conductivity are relatively unaffected from the standpoint of strength and flexibility under the extremely low temperature conditions of the liquefied gas and, for the most part, they are relatively free from attack by the liquefied gas and other gases or impurities admixed or otherwise contained therein.

Thus use can be made of panels formed of wood, such as balsa, or quippo, having mass integrity and strength and which are capable of being formed into a continuous composite layer from the inside out to the container wall and which are capable of supporting the load under the temperature conditions existing. Such woods are to be distinguished from other materials used as thermal insulation, as represented by cork, wool or glass fibers, asbestos fibers, exfoliated mica, and the like. When use is made of balsa wood or quippo or other similar low density, good insulating woody material having structural strength, the grain of the wood should be arranged horizontally in the built-up layer of insulation and it should preferably run horizontally in a direction parallel to the wall to which it is attached.

While not equivalent, use can be made of other inorganic, thermally insulating materials, such as foamed glass and foamed plastics which are not embrittled by the low temperature conditions existing and which are not affected by the components present in the liquefied gas.

The described pocket structure capable of development of the back pressure of vapors generated from the liquid at the interface of the pores or pockets to maintain a vaporous phase between the liquid and the wall of the container can also be secured by the structure represented diagrammatically in FIG. 2 of the drawings.

In this modification, the wall 30 of fluid and preferably vapor impervious material provides the support for a plurality of vertically spaced apart, downwardly and inwardly inclined baffle plates 32 which extend continuously about the walls as a lining with the space between the baffles forming the described pockets 34. The liquefied natural gas 36 fills the area between the baffles in the tank and as much of the pockets as permissible. The vapors introduced into the pockets are incapable of escape at the rate of introduction so that the liquefied gas is forced back to a level, as represented by the line 36, which is horizontal with the inner edge of the upper baffle forming the pocket to enable the excess vapor to escape from the pocket through the interior of the tank. To effect the desired sealing relation of the pockets formed by the adjacent tiers of baffle plates, it is essential for the upper baffle plates to overlap the lower baffle plates for a substantial distance beyond the plane horizontal with the inner edge of the baffle. In the preferred modification, it is desirable to have the baffle plates dimensioned to have a length and to extend downwardly at an angle to provide for the described overlap with

two or more of the underlying baffle plates so as to insure the development of a vaporous phase notwithstanding the possible failure of one or more plates in the system.

It is not essential for the upper edges of the baffle plates to be secured in sealing relationship with the walls of the tank and it is not essential for the baffle plates to be formed of a fluid and vapor impervious material. It will be sufficient if the permeability to the transmission of vapor at the points of attachment to the wall and through the plates is such as to prevent the escape of vapors from the pockets at a rate greater than the introduction of vapor therein. It will be evident that the vapor introduced into any one pocket will comprise not only the amount of vapor generated in the liquid at the interface 36 but will also include the amount of vapor which enters the pocket from the underlying or overlying pockets by transmission through the plates or about the edges of the plates at the point of attachment to the wall. If the plates are formed of a fluid and vapor impervious material, then reliance is had almost exclusively on the amount of vapor generated at the liquid interface 36 which, of necessity, will be greater than the amount capable of escaping from the pockets other than about the inner edge of the plates, unless openings are provided in the inner ends of the baffle plates forming the top walls of the pockets to enable the escape of vapor from the pockets at a point spaced inwardly from the end of the overlying pockets. When such openings are provided in the inner portions of the plates, it will be apparent that the vapors escaping from the pockets beneath will be introduced into the interior of the pockets above to become entrapped therein and thereby further to increase the amount of vapor introduced therein.

In the preferred practice of this invention, the baffle plates 32 can be formed of wooden shingles or shingles formed of other structural elements which are not harmfully affected by the cold or liquefied gas and which have relatively low heat conductivity. Members of higher heat conductivity may be used, such for example as metal strips, but, under such circumstances, it is desirable to make use of as thin strips as possible and to employ maximum space between the strips to minimize heat transfer through the metal members. When the space between the tiers of baffles is substantially filled with an insulating material, as previously described, the barrier elements can be in the form of very thin films or sheet stock. When a metal is employed, it is preferred to make use of aluminum, or alloys of aluminum, or stainless steels which have been found capable of use without excessive strength loss or corrosion while in direct contact with the cold boiling liquefied gas.

When the build-up of pockets is achieved by the techniques which employ baffle plates, the bottom wall of the tank can be constructed with a metal pan 40 resting upon a thick layer of insulating material with the side edges 42 of the pan extending angularly upwardly into the space between baffle plates spaced from the bottom to be sandwiched therebetween to provide the described pocket structure in cooperation with the pan and to build up the insulating vapor space in between, as illustrated in FIG. 4.

FIG. 3 diagrammatically illustrates a container embodying the concepts of construction represented by FIG. 1 wherein the liquefied gas 16 is housed within the open space between the thick layer 12 of porous insulating material provided as a lining on the inner face of the wall 10. The enclosure can be covered by a top plate 22 having a thick layer 24 of insulating material on the underside thereof to effect a thermal seal at the open end of the container. The insulation material in the layer 24 need not embody the complete concepts described because liquid will not have as great a tendency to flow therethrough to the cover plate, but it is more desirable to embody some of the concepts of the described

insulation layers in the cover to avoid difficulties when the ship lists or otherwise rolls or tosses to bring the liquid into substantial contact with the tank roof. An access opening is provided in the cover for the introduction of liquefied gas and for the removal of liquefied gas and vapors generated in the container.

If the pores of the insulating layer 12 are disconnected or extend horizontally in a direction parallel with the walls of the tank, as demonstrated by the arrangement in FIG. 1a, it will be apparent that the membranes separating the pores may still be vapor and fluid permeable to enable inflow of the liquid partially through the insulation until resisted by the vapor pressures extending beyond the liquid interface to the wall of the tank.

The modification illustrated in FIG. 4 embodies the concepts described in FIG. 2 wherein use is made of a plurality of vertically spaced apart tiers of shelves or baffle plates 32 extending downwardly angularly from the inner face of the wall 30 to separate the liquefied gas 36 from the wall upon the development of the back pressure principle by the vapors which are released by evaporation from the liquid. Each tier may also be subdivided by vertical partitions to prevent flow of vapor from one side for concentration on another and thereby relieve pressures which would enable the liquid to flow a greater distance into the pockets.

The ability to confine the fluid within the tank in spaced relationship with the walls to provide an insulated space in between enables the use of tank structures of the type described by way of a second line of defense where use is made of an inner shell for housing the liquid. Thus in the event of failure of the inner shell, the insulating layer of porous material becomes effective to hold back the liquefied gas from contact with the wall of the tank thereby to save the ship, the tanker, or the tank itself.

The foregoing modification is diagrammatically illustrated in FIG. 5 wherein the numeral 50 represents the inner shell for housing the liquefied gas 52. When this construction is employed, it is preferable to make use of the modification illustrated in FIGS. 1 and 3 because then the insulating layer 54 can also be allowed to function as a load carrying member to support the inner shell 50 without the use of additional supports of heat conductive material. When an inner shell 60 is employed in the modification of FIGS. 2 and 4, it is preferred to provide a downturned flap 62 on the inner ends of the shelves to provide more surface for support of the shell, particularly when formed of a thin foil incapable of self-support.

Under such circumstances, the inner shell can be formed of fluid and vapor impervious material having insufficient strength to support the load and which under load will deform sufficiently to rest upon the inner face of the insulating layer 54 for its support. For such purposes, use can be made of relatively thin films of metal, such as aluminum, alloys of aluminum or stainless steel. In the alternative, and more desirable from a commercial standpoint, the inner shell 50 can be formed of a structural material capable by itself of maintaining the load and which rests upon the lining of insulating material by way of support. In the event of failure, the concepts described and which embody the features of this invention are available for operation as an insulated tank to confine the liquefied gas within the tank in spaced relationship with the outer walls 56.

It will be appreciated that slight penetration of liquefied gas into the insulating layer will take place until the temperature conditions existing cause an amount of vapor to

be generated at a rate in excess of that capable of escaping from the pockets or pores in the outer portions of the insulation. Thus, for the development of a suitable insulating space, it is desirable to make use of a relatively thick insulating layer, such for example as a layer at least 3 and preferably 8 to 24 inches in thickness. It is desirable to avoid vertical channels in the insulation through which the vapors are capable of rapid escape though an occasional channel is not fatal if spaced inwardly a sufficient distance from the wall. Thus, in the use of panels of a porous wood, it is best to join the panels to form a composite structure substantially free of open, vertical spaces or channels in between. The insulation lining may be built up of a preformed plank of balsa or the like wood built up to the desired thickness and secured in substantial sealing relationship to the wall of the tank or it may be fabricated of separate panels of smaller dimension which are bonded one to the other in building up an insulated layer of the desired thickness with the outermost panels being bonded to the inner face of the tank wall.

This application is a continuation-in-part of my copending application Ser. No. 354,216, filed May 11, 1953, and now abandoned, which is a continuation-in-part of the then copending application Ser. No. 288,214, filed May 16, 1952, and now abandoned, and it is a continuation-in-part of my copending application Ser. No. 408,220, and now Patent No. 2,889,953, filed February 4, 1954.

It will be understood that changes may be made in the details of construction, arrangement and operation without departing from the spirit of the invention, especially as defined in the following claims.

I claim:

1. A container for the storage and transportation of a low boiling liquefied gas in large volume at about atmospheric pressure comprising an outer fluid and substantially vapor impervious wall of a structurally strong material, a relatively thick layer of a porous insulating material formed of a highly porous wood of low density lining the inner face of the container wall and having its inner surfaces in direct contact with the liquid content material, the pores of the insulating lining having permeability controlled to prevent the escape of vapors at a rate greater than the introduction of vapors therein from the liquid and from adjacent pores whereby a back pressure is built up within the pores to block deep penetration of the liquid into the porous insulation lining thereby to maintain a spaced relationship between the liquid and the outer wall of the container to define a vapor filled insulation space therebetween which is free of liquid.

2. A container as claimed in claim 1 in which the porous wood lining is in the form of a composite panel secured in substantially sealing relationship to the wall of the container.

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