This invention relates to means for transporting low temperature liquids in bulk. It relates particularly to ship means for bulk transportation of low temperature liquids. It relates more particularly to a vessel or tank ship construction suitable for bulk transportation of low temperature liquids at substantially atmospheric pressure, and it relates still more particularly to a vessel or tank ship construction suitable for bulk transportation at substantially atmospheric pressure of liquid materials having normal boiling points down to about 

-50° F.

This application is a continuation-in-part of an application Serial No. 824,427, filed in the United States Patent Office on July 1, 1959, now abandoned.

Considerable interest has been shown in recent years in the storage and transportation of low-boiling hydrocarbons such as propane (43.7° F. normal boiling point) in the liquid state and at substantially atmospheric pressure. Under these conditions the cold hydrocarbons are placed in thermally insulated containers and allowed to vaporize or boil off at heat leaks in the container structure. The vapors thus produced may be either vented directly to the atmosphere, consumed as a gaseous fuel, or recondensed by suitable refrigeration equipment and returned as liquid directly to the insulated container. Obviously the efficiency and economy of such storage and transportation of low-boiling liquids are dependent upon in large degree upon the effectiveness of the thermal insulation applied to the liquid container.

Another problem besides that of vaporization loss of stored materials which arises in the course of storing and transportation of low-boiling liquids is that of embrittlement of metallic structural components of the liquid container. At temperatures of the order of that of liquid propane at atmospheric pressure (43.7° F.), ordinary ferrous materials such as low carbon steel may suffer at least some loss of energy absorbing capacity at high rates of strain, that is, loss of impact resistance. Storage tanks in general, and storage tanks aboard ship in particular, may be expected to be exposed to some shock loads during their working lives, even though such loads be applied accidentally. Accordingly, when low-boiling materials such as propane are liquefied for storage and/or transportation in bulk thought must be given to the matter of loss of impact resistance of a steel-walled container and the attendant increased susceptibility of this structure to brittle fracture.

It will be readily understood that the physical failure of a wall of a tank containing cold liquid hydrocarbons in bulk, liquid propane for example, could be extremely dangerous to both life and property. To minimize the possibility of such failure, proposals have been made for storing liquid propane and other cold materials in steel tanks or container shells provided with internal insulation of substantial thickness. By placing the insulation on the inside of the steel container shell rather than on the outside, the shell material is allowed to remain at substantially atmospheric temperature for its entire thickness even though the container be fully charged with cold liquid. In this way, low carbon, relatively inexpensive steels may be used in the tank structure instead of resort

Having to be had to costly alloy steels or other materials retaining significant impact resistance properties at low temperatures. The insulating materials which have been proposed for such use include balsa wood and cork in the form of rather sizable blocks or slabs.

Whether the insulation comprise blocks or slabs of the traditional materials or be otherwise constructed, however, direct exposure of the insulating material to the cold liquid being stored or transported has usually not been desired. Accordingly, a liner or inner tank shell is placed within the insulating blocks. One possibility known to the prior art for creation of this inner tank shell is to have it made of aluminum or another metal such as stainless steel which retains a significant impact resistance property at low temperatures. For shipboard containers intended to hold liquids at very low temperatures, for example, containers to hold liquid methane at about 

-239° F., an inner tank shell of proper metallic material is the only practical possibility. However, when liquids at about the temperature of liquid propane, that is, at about 

-50° F., are to be carried the inner tank shell may be non-metallic and susceptible of easier handling and installation than a metal. Likewise, in this temperature range, the insulation blocks may be of material other and less expensive than and at least as easily installed as the balsa or cork of the prior art.

According to the present invention, a vessel for transporting low temperature liquids is provided in which the inner one of two cargo liquid tank shells both independent of the hull structure of the vessel comprises a polyester sheet material.

Further, according to this invention, a vessel of the kind described is provided in which the insulation between the two inner and outer tank shells is a preformed plastic material.

Still further, according to this invention, a vessel of the kind described is provided in which the inner and outer tank shells and the insulation therebetween are bonded in leak-proof fashion by a Thiokol-epoxy sealing material.

Even still further, according to this invention, means are provided for conveniently loading cold cargo liquid into and discharging such liquids from the insulated storage tanks of the above-described vessel; for either recondensing and preserving or else distantly venting the vapors boiled off from these storage tanks, and for rendering inert the atmosphere around the outer shell of any tank structure to prevent escape of combustible gaseous mixtures in this atmosphere upon the leakage thereof to vaporized cargo materials.

The nature and substance of this invention may be more clearly perceived and fully understood by referring to the following description and claims taken in connection with the accompanying drawings in which:

FIG. 1 represents a side elevation view, partially broken away, of a tank vessel designed to carry liquefied, normally gaseous materials, such as liquefied petroleum gas according to this invention, particularly illustrating in schematic form the piping systems for handling the cold liquid cargo material and the vapors generated therefrom:

FIG. 2 represents a deck plan view of the tank vessel of FIG. 1, likewise partially broken away;

FIG. 3 represents a transverse sectional elevation view of the tank vessel embodying this invention taken along the line of direction of the arrows shown in FIG. 1, particularly illustrating features of support and internal construction of an insulated container for cold liquid cargo material, and

FIG. 4 represents a schematic diagram of the refrigeration apparatus provided to recondense vapors generated from the cold liquid cargo material carried in insulated containers in the tank vessel of FIGS. 1 and 2.
Referring now to the drawings in detail, especially to FIGS. 1 and 2 thereof, a marine vessel externally configured more or less similarly to a conventional tank ship is designated 11. It has fore and aft hull and superstructures 13 and 15 of customary form except that the aft superstructure includes a refrigeration apparatus 17 which will be described in greater detail presently. Ship 11 is characterized by a main deck 19, bottom plating 31, and port and starboard shell plating 23 and 25.

Transverse bulkheads 27 and 29 define the fore and aft limits of the middle body of the ship wherein the various tank spaces for the storage of cargo liquids are located. Intermediate bulkheads 27 and 29 are a number of other transverse bulkheads such as 31 and 33 running the full width of the ship. Extending fore and aft within ship 11 at least between bulkheads 27 and 29 are port and starboard longitudinal bulkheads 35 and 37, and extending transversely between the longitudinal bulkheads and the shell plating there may be local, noncontinuous bulkheads such as 39 and 41. The structural items of deck, bulkheads, shell plating, and bottom plating so far designated will serve to define a series of port and starboard wing tank spaces such as 43 and 45. These wing tank spaces will be used for storage of materials which are ordinarily liquids at atmospheric conditions of temperature and pressure. Such liquids would include various crude petroleums and petroleum distillates.

The central part of the vessel is divided into a plurality of compartments such as 47 which are bounded fore and aft by continuous transverse bulkheads and laterally by longitudinal bulkheads 35 and 37. Within each of these compartments are located two tank structures for the storage of cold liquid cargo materials. These tank structures will be more completely described presently, but may here be said to each consist of a vapor space 59 bordered by an outer steel shell 49, an inner non-metallic shell 50 of a material such as polyester film in non-contacting relation to the outer shell, and thermal insulation material substantially filling the region between the two shells. A cold liquid storage volume 51 is defined within the inner shell 50.

All of the storage regions 51 are connected to a manifold system comprising a main liquid filling and discharge line 53, a recompressed liquid return line 85, a vapor suction line 57 going to the inlet connection of refrigeration apparatus 17, and a vapor vent line 59 terminating in an exhaust pipe 61 curving downwardly over the stern, and which is fitted at its lower end with an exhaust head 63 wherefrom vapor may be finally vented to the atmosphere. This arrangement assumes that the cold liquid cargo will gasify to vapors heavier than air, as in the case of propane.

Considering the individual connections associated with a particular tank space 51, an admission valve 65 in a branch off of line 53 must be opened to allow cold liquid to be filled into the tank from one of the main shore filling connections to be identified presently. An admission valve 67 in a branch off of line 55 must be opened to allow cold liquid to be filled into the tank from refrigeration apparatus 17 or from one of the auxiliary shore filling connections to be identified presently. An outlet valve 69 in a branch off of line 57 must be opened to allow vapor to flow from this tank to the inlet connection of refrigeration apparatus 17 in which this vapor may be recompressed. Connection from tank space 51 to vapor vent line 59 is made through a branch which contains a pressure relief valve 71. This valve is set to open at relatively low pressure on the order of a half to one pound per square inch gauge. Thus, cargo material vapors generated within tank space 51 which are not drawn off through suction line 57 cannot accumulate to any significant pressure before they escape through the atmospheric vent system, that is, through vent line 59 and exhaust pipe 61, and finally out of exhaust head 63.

On the main deck 19 of ship 11 are means whereby connection may be made to a shore facility (or another ship) to allow cold liquid to be filled into or discharged from tank space 51. This means includes the main shore connection valves 73 and 75 located port and starboard respectively. These valves terminate a common line 77 running transversely across deck 19, and from a T-connection in this line a liquid line 79 is brought aft to the vicinity of refrigeration apparatus 17. Connection is made from line 79 as shown through valve 81 to liquid line 53. This valve and valve or valves 65 will be open when cold liquid cargo material is being filled into tank spaces 51 from facility valve through valve 73 or 75.

Within each tank space there is a deep well pump 83 which is driven by conventional means such as a steam turbine 85 located at about the main deck level. The discharge line of this pump is connected to liquid line 53 through a valve 87. Near its aft end, liquid line 53 is connected through two valves 89 and 91 to the inlet sides of booster pumps 93 and 95. These pumps are provided respectively with discharge valves 97 and 99 through which connection is made as shown to liquid line 79. When cargo liquid is to be discharged from tank space 51, one or one set of booster pumps 93 and 95 will be closed; valve 87 will be open; at least one of pump valves 89 and 97 or 91 and 99 will be open, and one of the main deck valves 73 or 75 will be open also. Pressure relief valve 71 might be reset to a greater opening value in order to allow a higher vapor pressure to be built up above the surface of liquid in tank space 51 to insure that this liquid will be driven positively into the suction of pump 83. Such resetting of the relief valve may be particularly desirable when the level of liquid in tank space 51 is rather low.

Close by valve 83 are two valves 101 and 103 located port and starboard on main deck 19. These valves terminate a common line 105 running transversely across the deck. Recompressed liquid return line 55 passes through a cross fitting in line 105. It may be seen, therefore, that valves 101 and 103 can be used as auxiliary connections for filling tank spaces 51 from the shore.

Located in the forward region 13 of ship 11 is a dry inert gas source 107, for example a source of dry nitrogen gas. This source may be either an actual gas generating plant or a bank of cylinders suitably manifolded, and which are refilled or drawn from time to time. Running aft from gas source 107 is in inert gas main 109. A branch from this is connected to each of the compartments 47 through a pressure reducing and regulating valve 11. The particular purpose of the inert gas system is to condition the atmosphere in compartment 47. Considering this purpose, if there should be cold liquid cargo through both tank shells 49 and 50 the leaked material will be vaporized by the time it reaches space 47 outside of shell 49. If this space has an atmosphere of ordinary air, a combustible mixture of air and the cargo material may be created, for example a combustible mixture of air and propane. On the other hand, if compartment 47 has an atmosphere of nitrogen, gaseous propane leaking through tank shell 49 will mix with a material which will not support combustion.

Suitable ventilation equipment of a kind well known in the art may be provided for compartment 47 to flush the inert atmosphere, and provide a breathable atmosphere whenever access to this compartment is desired for parties to inspect the outer shells 49 of cold liquid storage tanks. A suitable sniffing connection may also be provided for compartment 47 to allow sampling of the atmosphere therein. Such a connection would conventionally be located in deck 19.

A further possible use of the inert gas system, although not one specifically illustrated in the drawings, would be that of applying pressure to the surface of the cold cargo liquid in tank space 51 to drive this liquid positively into the suction of deep well pump 83, and of simultaneously
maintaining a non-combustible atmosphere within the vapor space of the tank. To achieve this a connection would be made, for example, from inert gas line 109 through a shut-off valve and a reducing and regulating valve to the tank vent branch line upstream of relief valve 71. After the latter had been reset to a higher than normal opening value, nitrogen or other inert gas would be admitted to tank space 51 to aid in piping operation. An atmosphere of substantially inert nature could then be maintained in the tank until a fresh cargo of cold liquid was brought aboard. Heaviest boiling off of liquid may be expected during the initial phases of the loading operation, as well as during that time, therefore, with tank space 51 initially filled with inert gas the vapors surging from vent head 63 on exhaust pipe 61 would be a non-combustible mixture rather than essentially pure hydrocarbon.

Insulation of the cargo liquid storage tanks has been mentioned generally in connection with FIGS. 1 and 2, and will be discussed in greater detail presently. It is obvious, however, that all of the piping systems so mentioned with the exception of the inert gas lines will also be filled with cold materials from time to time. All of the liquid lines such as 53, 55, and 79 should be thermally insulated as shown in FIG. 3 to reduce evaporative loss of cargo materials. Vapor line 57 should be insulated as shown in FIG. 3 to prevent unnecessary warming of vapors which are to be recondensed. Vapor vent line 59 may, on the other hand, better be left uninsulated to allow warming and reduction in density of vapors which are being dispersed to the atmosphere.

Referring next to FIG. 3, the flat plate keel of tank ship 11 is designated 113. Extending upwardly from this is the centerline vertical keel 115. The vertical keel is surmounted by a platform structure 117 which is otherwise suitably braced, and which provides immediate support for the cold liquid tank structure of which shell 49 defines the outer boundary. The tank structure may be located and secured on platform 117 by any appropriate and customary means, proper allowance being made for dimensional changes due to thermal effects. Piping elements 53, 55, 57, 59, 79, and 109 already described in connection with FIGS. 1 and 2 are illustrated above deck 19. Particularly shown is the valve and piping connection from inert gas line 109 to compartment 47. Also illustrated are a connection from compartment 47 to vapor vent line 59 containing a valve 119, and a valved vent line 121 leading to compartment 47 from the atmosphere.

Valve 119 and the valve in line 121 may be of the spring-loaded variety to protect compartment 47 against being overpressured by inert gas or air on the one hand, or against being unduly evacuated on the other.

Now considering particularly the structure of the cold cargo liquid storage tank and its internal attachments, the outer shell 49 will be of steel. Being internally insulated, this steel will preferably be of a low carbon, relatively inexpensive grade. It may be of course be of a stainless or other high alloy grade, but the particular beneficial properties of these considerably more expensive steels will not have significant opportunity of development in the course of such use. On its interior bottom surface, tank shell 49 is fitted with a series of structural elements such as T-beams 123 which support a steel plate 125, and this in turn supports the bottom layer of the thermally insulating material 127 with which tank shell 49 is lined. The heat path from the bottom plate 21 of ship 11 to any cold liquid cargo in tank space 51 may be examined. Heat will flow in through what may be a fairly easy path of structural plates and ship's as far as the bottom of tank and from there to the liquid in the tank will be only a narrow path available through the webs of T-beams 123. It may be thermodynamically desirable and economically worthwhile to make T-beams 123 and plate 125 out of some material such as stainless steel which in comparison with ordinary carbon steels such as that usable for tank shell 49 has a rather low coefficient of thermal conductivity. Thus it may be seen that even before any inflowing heat reaches the lower layer of insulating material 127, it must travel a rather difficult path. Therefore, the rate of heat leakage into cold liquid in tank space 51 is kept quite low according to the structural arrangements shown in FIG. 3.

Primary location of outer tank shell 49 with respect to the hull structure of ship 11 is effected by its seating and securing on platform 117. To prevent undue sway of this shell, however, with rolling and pitching movement of the ship, it is held transversely centered by such means as buffer brackets 129 and 131 secured to longitudinal bulkheads 35 and 37 near the top of the tank shell. These brackets have no effect of restricting movement of the tank due to temperature changes. It is to be clearly understood, of course, that tank shell 49, bulkheads 35 and 37, bottom plating 21, shell plating 23 and 25, and deck plating 19 may and will all be stiffened locally as needed in conformity with standard structural and naval architectural practice.

Deep well pump 83 previously identified in connection with FIGS. 1 and 2 is shown in FIG. 3 to be located in the bottom of cold liquid cargo tank space 51. This pump may be of any conventional design suitable for handling hydrocarbon liquids at low temperatures. The prime mover 85 whereby pump 83 is driven is located on and above main deck 19. This prime mover will preferably be a steam turbine of any suitable design and including any appropriate speed reducing gearing. The use of a steam turbine is preferable to that of an electric motor in order to keep any possible sparking apparatus away from a deck region in close association with piping carrying flammable liquids and vapors. Sleeve 133 extending from turbine 83 downwardly to pump 83 is within it the turbine power transmitting means such as shafting of conventional nature. It may also contain the discharge line of pump 83 where through cold liquid cargo to be unloaded is sent to liquid line 55. This sleeve is attached by a bellow 135 to the outer tank shell 49 for maintenance of vapor sealing of this outer tank shell and to each other. The blocks which insulation layer 127 comprises may be the traditional balsa or cork or other materials of the prior art such as insulating concrete. They may also, however, and indeed preferably will be blocks of prefoamed, closed cell plastic.

Because of their cellular structure and large number of dead air spaces, plastic foams are ideally suited as thermal insulations. In addition to providing low thermal conductivity, these materials are also recommended because of their high strength-to-weight ratio, their low odors, their good resistance to water vapor, and their ease of fabrication. In general, the thermal properties of plastic foams are determined by resin content, density, and type and size of cellular structure. Among the plastic materials which may be prefoamed to rigid or semi-rigid blocks are polyurethane urethanes. The chemical stability of these materials may be used as insulation at temperatures as low as -50° F. without danger of their becoming unduly embrittled and susceptible to crumbling under stress or impact. Another characteristic of these plastic materials prefoamed in block form, even those designated as rigid plastics, is that they can accommodate themselves to at least slight changes in shape and size
of outer tank shell 49 due to normal working of vessel 11. Insulation layer 127 will be about two inches thick for cold liquid cargoes at temperatures of about -50°F. To effect the above-mentioned liquid-tight and gas-tight bond between the blocks of insulation layer 127 and the outer tank shell 49 and between the blocks themselves, a proposal was made to use a novel Thikol epoxy compound having generally good hydrocarbon resistance, adhesive properties, thermal insulating qualities, and flexibility at low temperatures, and that is, at about -50°F. The Thikol-epoxy bonding or sealing material of this invention may be compounded using the following commercial ingredients in the exemplary percentages indicated:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Weight percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP-3 Thikol (Thikol Corp.)</td>
<td>200</td>
</tr>
<tr>
<td>Epon 828 (Shell Chemical Co.)</td>
<td>100</td>
</tr>
<tr>
<td>DMP-30 Aminie (Rohm &amp; Haas Co.)</td>
<td>10</td>
</tr>
</tbody>
</table>

Thikol LP-3 is one of a series of liquid polymers of varying viscosity capable of being converted to tough resilient rubbers at room temperature without appreciable shrinkage. Other polymers of the series include those designated LP-2, LP-5, LP-7, LP-12, and LP-33. The cured (converted) liquid polymers are resistant to oil, most commercial solvents, and water swelling. They have good electrical resistivity and aging characteristics. They retain a considerable degree of flexibility at temperatures as low as -65°F as well as the ability to flow plastically under stress. Other desirable characteristics of these polymers include high impermeability to gases and moisture, resistance to ozone and sunlight, and strong adhesiveness to many materials. Particular properties of LP-3 Thikol are as follows: viscosity at 77°F (approx. 1.0x10^6 poise); molecular weight (approx.), 1.000; pour point, -15°F; flash point (open cup), 418°F; fire point (open cup), 465°F; and moisture content (max.), 0.1%. Epon 828 is one of a series of synthetic resins possessing terminal epoxy groups. These resins range from mobile liquids to viscous liquids to solids, Epon 828 itself being a viscous liquid. The primary difference among the various types is the molecular weight which increases as the identifying number increases. Polymerization and copolymerization reactions of the epoxies can be effected through either or both of their reactive groups, that is, the epoxy groups and the hydroxyl groups. By the addition of small amounts of organic polyanimes, epon resins can be polymerized to form clear, light-colored, tough products with high physical strength and chemical resistance. DMP-30 amine is a diethyleniminoethyl phenol which is used as a catalyst in the compounding operation whereby the Thikol-epoxy bonding and sealing material of this invention is formulated. The particular exemplary percentages indicated may, of course, be varied as desired to give variations in physical properties of the compounded material, so long as final set is obtained in a reasonable time such as about twenty-four hours.

To the mixture of LP-3 Thikol, Epon 828, and DMP-30 amine is added up to an equal volume of lightweight, hydrocarbon resistant material of fine gradation to permit troweling. A finely divided material suitable for this purpose is one comprising a large number of very tiny particles commonly called "microballoons" which are best known as a means for providing a non-rigid continuous coating of some thickness on the surfaces of hydrocarbon liquids in storage vessels to reduce evaporation losses of these liquids. These particles are of low density and float on the liquid surface.

A species of such particles or microballoons are nitrogen-filled microspheres of thermo-setting plastic. They may be made from phenol-formaldehyde resin or other oil-insoluble resins, polyethylene, etc., according to the process disclosed in U.S. Patent No. 2,797,201 issued to F. Veatch and R. W. Burhans on June 25, 1957. These microspheres may have an average diameter of 1 to about 500 microns, preferably 25 to 250 microns. Their bulk density is within the range of 0.01 to 0.3, preferably 0.1 to 0.2, and liquid displacement density within the range of 0.05 to 0.6, preferably 0.2 to 0.5.

In building up the insulation structure shown in FIG. 3, the individual insulating blocks of layer 127 will be coated on their abutting surfaces with the Thikol-epoxy compound described above as with a mortar, and laid up like brickwork. The abutting surfaces of these blocks will include both those bearing against the inner surfaces of outer tank shell 49 and plate 125, and those giving bearing block-to-block. There may, of course, be some primary locating means for the blocks, such as studs 128 set on tank shell 49 and plate 125 to enter prepared holes in the blocks. If such studs or other locating means be used, however, they must be made of stainless steel, for example, and such short length to create no easy path for the flow of heat into tank space 51.

With the blocks of insulating layer 127 in place and bonded to outer tank shell 49 and to each other, the inner tank shell 50 may be erected. A highly desirable material for this inner shell is a polyester film known commercially as "Mylar," and manufactured by E. I. du Pont de Nemours Co. This film comprises essentially a highly durable, transparent, water-dispersible, methyl ethyl ketone phthalate resin. It is characterized by outstanding strength and chemical inertness. It is characterized further by a high degree of flexibility even at temperatures far below -50°F, an attribute of great importance for purposes of the present invention. Mylar is available in thicknesses up to about ten mils (0.01") and in strip widths up to about fifty-four inches. Strips of this material may be joined to each other by butt fusing or welding upon application of heat as from a hot iron, or by lapping and the use of a suitable adhesive material.

In erecting inner tank shell 50, it will, of course, be necessary to obtain a firm edge joint between abutting strips of Mylar to insure the creation of a tank shell that is both gas and liquid tight, and it will at least be highly desirable to obtain a bond between the Mylar strips and insulation layer 127 to prevent any collapse or significant degree of deformation of inner tank shell 50 once it has been fabricated. Such a bond may be obtained by applying a light coating of the above-described Thikol-epoxy adhesive compound to the inner surfaces of the insulation layer 127 before the polyester film strips are set in place on these surfaces. The film strips may be either butted or lapped along their mating edges, and joined by heat or an adhesive material such as a Thikol-epoxy to complete the fabrication of a gas-tight and liquid-tight inner tank shell 50.

In order to insure that there will be a two-shell barrier all around tank space 51, inner shell 50 must be tightly but flexibly joined to pump sleeve 133. This joint can be achieved, among other ways, by use of a polyester film bellows 137 adhered to or formed integrally with tank shell 50, and secured to the pump sleeve by a suitably clamping ring 139. It may be seen, therefore, that by the use of bellows elements 135 and 137 the cold liquid storage tank structure of this invention may flex quite freely due to temperature variations, working of vessel 11, or any other reason other than there being danger of rupture of the double-shell barrier surrounding the cold liquid cargo or of any undue stressing of structural parts.

Inner tank shell 50 will preferably and most conveniently be of polyester film, that is, of Mylar. It may, however, be formed of the same Thikol-epoxy compound used as a mortar and sealing agent between individual blocks of insulation layer 127, and between these blocks and the inner surfaces of outer tank shell 49 and plate 125. This compound, as before noted, is an aggregate of microballoons to give it consistency for troweling. It may thus be spread on the inner surfaces.
of insulation layer 127 to a finite thickness, a thickness of one quarter inch for example, and allowed to set to form a tank shell structure in and of itself. For completion of this shell structure, a separate bellows 137 and clamping ring 139 could be used as shown in FIG. 1, to make the final joint to pump sleeve 133.

Referring finally to FIG. 4, what is shown is a refrigeration system generally similar to that shown in FIGS. 1 and 2 which uses, for example, propane as a working substance. Only a part of the propane operates in a closed cycle. The net material inflow of the whole system is the gassed-off propane collected from cold liquid cargo tank spaces 51 through vapor line 57, and the net material outflow is substantially the same amount of propane recondensed to a liquid flowing back to tank spaces 51 through liquid line 55. The operation of this refrigeration system will be described in terms of a numerical example.

Assume that a pressure of 162.2 p.s.i. (1.5 pounds of positive pressure) is maintained in tank spaces 51. The liquid propane stored in these spaces and the vapors arising therefrom will then be at a temperature of 40° F. These vapors are taken through line 57 to knock-out drum 141 which is fitted internally with steam coil 143. This drum and steam coil have the purpose of vaporizing any droplets of liquid propane which may be carried over from tank spaces 51. From the knock-out drum the now fully vaporous stream of gassed-off propane flows to the first stage inlet of a compressor unit comprising first stage 145, second stage 147, and prime mover 149. In this first stage the propane is compressed to about 59.5 p.s.i. At the outlet of first stage 145, the vapor which has come back from cold liquid cargo tank spaces 51 is mixed with additional propane vapor about half its own weight or rate of flow. This additional propane vapor, representing that quantity of propane operating in a closed cycle, arises from flash chamber 151.

The mixing point of the vapor streams from the first compressor stage 145 and flash chamber 151, the combined weight of propane flows to and through the second compressor stage 147, being therein increased in pressure to about 226 p.s.i. Leaving the second compressor stage, the high pressure propane flows to and is condensed in the water-cooled heat exchanger 153, and from there is collected in receiver or surge tank 155 as a liquid at about 226 p.s.i. and 115° F.

A line connecting the bottom of receiver 155 with about the mid-height of flash chamber 151 and provided with a stable stop valve 157 and throttle valve 159 allows a controlled flow of liquid propane from the receiver to the top of the flash chamber. As it flows through this line and these valves, particularly through valve 159, the liquid propane is reduced in pressure down to about 59.5 p.s.i.a., and about one-third of it flashes away to vapor. This vapor fraction rises through the stop-check valve 161, and mixes with the outlet stream from the first compressor stage 145 to form the inlet stream to the second compressor stage 147.

In steady operation of the system, a certain level of liquid propane at intermediate pressure (59.5 p.s.i.a.) will be carried in flash tank 151, just as there will be a certain level of liquid propane at high pressure (226 p.s.i.a.) carried in receiver 155. A liquid discharge line, which becomes the liquid return line 55 on the downstream side of throttle valve 163, leads away from the bottom of flash chamber 151. Saturated liquid propane flowing through valve 163 on the way back to tank spaces 51 is reduced in pressure from about 59.5 p.s.i.a. to about 16.2 p.s.i.a.

Some of this liquid, approximately 20%, flashes to vapor, so that the material arriving back at tank spaces 51 through line 55 is not all liquid but is rather a mixture of liquid and vapor. The gaseous fraction of this stream is, of course, returned to the refrigeration system through vapor line 57 along with that vapor which represents propane actually gassed-off due to heat leakage into tank spaces 51. In its normal utilization, refrigeration apparatus 17 will be most heavily loaded when tank spaces 51 are being filled with cold liquid cargo. The prior mention of possible use of the inert gas system for blanketing and purging these spaces during filling operations does in no way exclude employment of the recondensation system just described for accommodating vapors boiled off from the cold cargo liquid at this time.

Although this invention has been described with a certain degree of particularity, it is to be understood that the present disclosure has been made only by way of example, especially with regard to numerical quantities given herein, and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and scope of this invention as hereinafter claimed. In particular, it is to be understood that when inner tank shell 50 is made of polyester film it may be given any desired wall thickness by cementing together in superimposed relation a plurality of film sheets. Such cementing may be effected with the Thiokol-epoxy compound described above. Likewise, any convenient degree of prefabrication of the polyester film inner tank shell 50 may be carried out depending upon the construction sequences chosen for erection of the cold cargo liquid storage tank. Such prefabrication would be in contrast to laying up individual inner tank shell panels of polyester (Mylar) film after the cold cargo liquid tank structure had otherwise been substantially completed.

What is claimed is:

1. A thermally insulated tank structure for containing low temperature liquids, said tank structure being adapted for installation in marine vessels and comprising a first shell member of a low carbon steel which is susceptible to reduction in its impact resistance property at the normal low temperature of said liquid, a second shell member of a plastic, non-metallic material which retains a significant degree of rigidity at the normal low temperature of said liquid, and an adhesive substance between said blocks and said shell members whereby an essentially liquid-tight and gas-tight seal is made between said blocks and said first and second shell members.

2. A thermally insulated tank structure for containing low temperature liquids, said tank structure being adapted for installation in marine vessels and comprising a first shell member of aluminum which is susceptible to reduction in its impact resistance property at the normal low temperature of said liquid, a second shell member of a plastic, non-metallic material which retains a significant degree of rigidity at the normal low temperature of said liquid, and an adhesive substance between said blocks and said shell members whereby an essentially liquid-tight and gas-tight seal is made between said blocks and said first and second shell members.

3. A thermally insulated tank structure for containing low temperature liquids, said tank structure being adapted for installation in marine vessels and comprising a first shell member of a metal which is susceptible to reduction in its impact resistance property at the normal low temperature of said liquid, a second shell member of a plastic, non-metallic material which retains a signific-
3,031,856 cant degree of flexibility at the normal low temperature of said liquid, said second shell member being located within said first shell member and in spaced relation thereto, thermal insulation material substantially filling the space between said first and second shell members, a plurality of semi-rigid block elements in abutting relation one to another, and an adhesive material between said blocks and said shell members whereby an essentially liquid-tight and gas-tight seal is made between said blocks and said first and second shell members, said adhesive material comprising an admixture of about equal volumes of an aggregate substance and a Thiolok-epoxy compound including about one hundred parts by weight of a synthetic resin possessing a terminal epoxy group and about two hundred parts by weight of a liquid polymer.

4. A thermally insulated tank structure according to claim 3 in which said aggregate substance comprises essentially microspheres of thermosetting plastic.

5. A thermally insulated tank structure for containing low temperature liquids, said tank structure being adapted for installation in marine vessels and comprising a first shell member of a metal which is susceptible to reduction in its impact resistance property at the normal low temperature of said liquid, a second shell member of a plastic, nonmetallic material which retains a significant degree of flexibility at the normal low temperature of said liquid, said second shell member being located within said first shell member and in spaced relation thereto, thermal insulation material substantially filling the space between said first and second shell members, said thermal insulation material comprising a plurality of at least semi-rigid block elements in abutting relation one to another, and an adhesive material between said blocks and said shell members whereby an essentially liquid-tight and gas-tight seal is made between individual abutting blocks and between said blocks and said first and second shell members, said adhesive material comprising an admixture of about equal volumes of an aggregate substance and a Thiolok-epoxy compound including about one hundred parts by weight of a synthetic resin possessing a terminal epoxy group and about two hundred parts by weight of a liquid polymer.

6. A marine vessel for bulk transportation at substantially atmospheric pressure of liquefied materials which are normally gaseous at atmospheric pressures and temperatures, said vessel comprising a basic structural hull and at least one tank structure mounted in said hull and occupying a substantial portion of the interior volume thereof, said tank structure including a first shell member of low carbon steel, a second shell member of a plastic, non-metallic material which retains a significant degree of flexibility at temperatures down to at least about -50° F. disposed in spaced relation to said first shell member within said first shell member, thermal insulation material intermediate said first and second shell members, said insulation material comprising essentially a pre-formed plastic, and a Thiolok-epoxy adhesive material between said insulation material and said shell members whereby an essentially liquid-tight and gas-tight seal is made between said insulation material and said first and second shell members.

7. A marine vessel according to claim 6 in which said second shell member comprises essentially a Thiolok-epoxy compound admixed with an aggregate substance.

8. A marine vessel according to claim 6 in which said second shell member comprises essentially a polyester film.

9. A marine vessel according to claim 6 which includes conduit means for supplying said liquefied material into said second shell member of said tank structure, pump means for discharging said liquefied material from the lower portion of the space within said second shell member, and conduit means connected with the upper portion of the space within said second shell member for atmospheric venting of vapors arising from said liquefied material within said second shell of said tank structure.

10. A marine vessel according to claim 9 which includes conduit and refrigeration means whereby said vapors arising from said liquefied material within said second shell of said tank structure may be gathered, liquefied, and returned in a substantially liquid state to said space within said second shell member preferentially to venting said vapors to the atmosphere.

11. A marine vessel according to claim 9 which includes a source of dry inert gas and conduit means for injecting gas from said source at a pressure at least slightly greater than atmospheric into said hull structure exteriorly of said first shell member of said tank structure to provide an atmosphere of a substantially inert nature in contact with said first shell member.

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