

[54] **CRYOGENIC TRANSPORTATION METHOD AND APPARATUS THEREFOR**

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Related U.S. Application Data

[63] Continuation of Ser. No. 829,207, June 2, 1969, abandoned.

[52] U.S. Cl. **62/47, 62/240, 114/74 A, 220/9 LG, 220/22.1**

[51] Int. Cl. **F17c 3/10**

[58] Field of Search **114/74 A, 74 R; 220/9 LG, 220/18, 22.1; 62/45, 47, 240**

[56] **References Cited**

UNITED STATES PATENTS

1,347,241	5/1921	Bates	114/9
2,938,359	5/1960	Cobb, Jr. et al.	62/47

Primary Examiner—Meyer Perlin
Assistant Examiner—Ronald C. Capossela

[57]

ABSTRACT

A marine transportation system in which natural gas, oil, and other suitable liquid and liquid and dry bulk cargoes are solidified by freezing so as to permit such cargoes to be shipped by sea safely and efficiently in light-weight, inexpensive carriers. The invention further relates to a sea-going carrier suitable for use in the method wherein the frozen cargo itself provides the necessary structural strength to accommodate the static and dynamic loads imposed on the carrier during the transportation of such bulk materials. A method and means are also provided for freezing large masses of matter efficiently so as to make the transportation method of this invention commercially advantageous. Advantage is also taken of the change of density of substances due to a change of their temperature to regulate the refrigerating means utilized to thereby control the resulting buoyancy of those substances during their transportation by sea.

16 Claims, 27 Drawing Figures

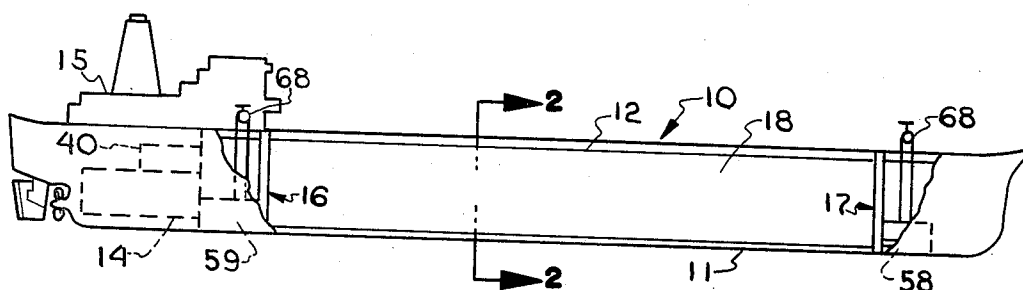


FIG. 1

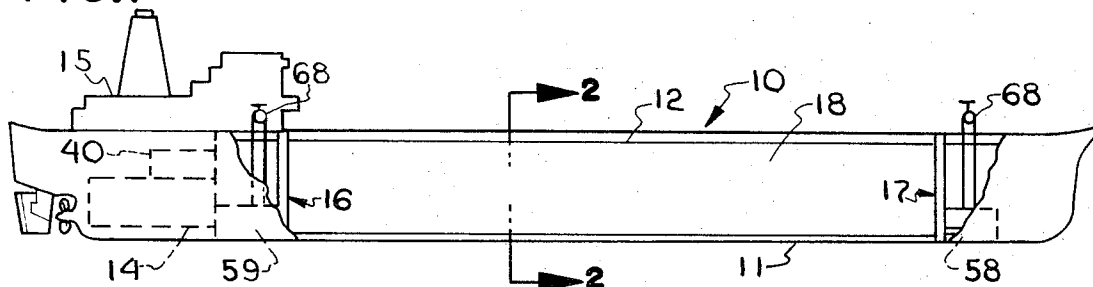


FIG. 2

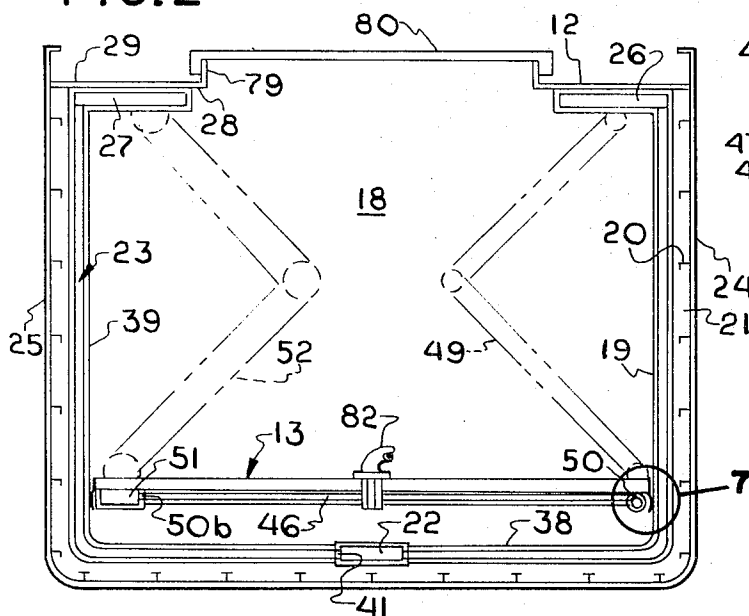


FIG. 7

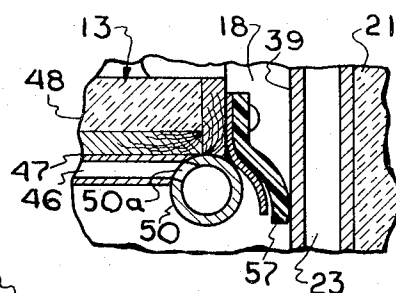
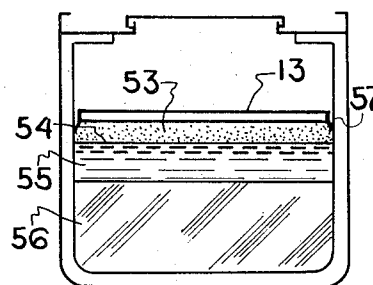
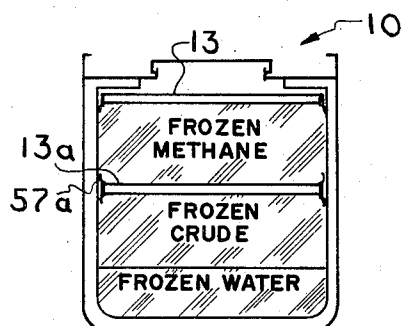
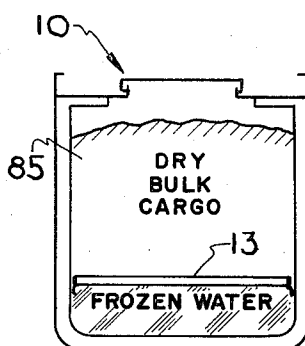
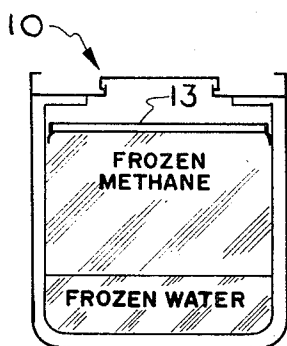


FIG. 8



A cross-sectional view of a container. A lid, labeled 10, is shown at the top. The container has a neck, labeled 13, which is partially filled with a substance. The main body of the container is filled with two distinct layers: the upper layer is labeled 'FROZEN METHANE' and the lower layer is labeled 'FROZEN WATER'.



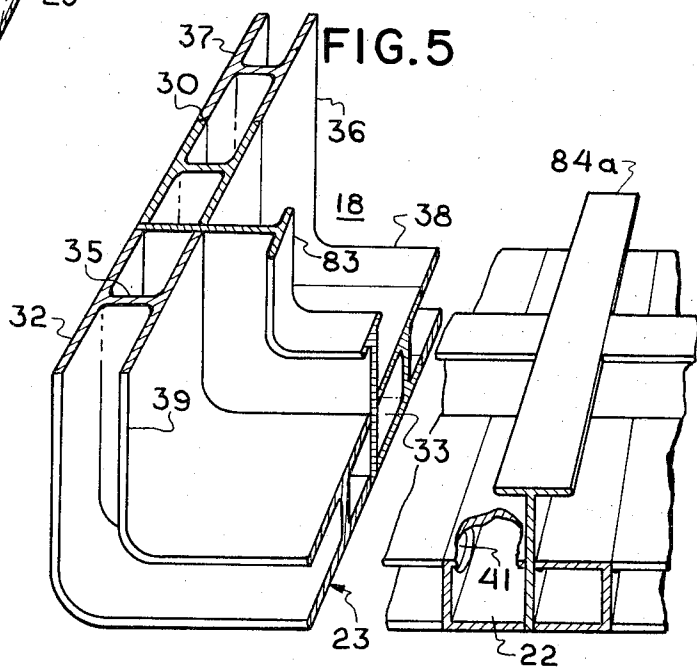
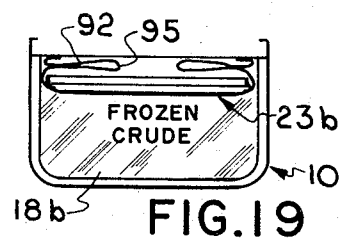
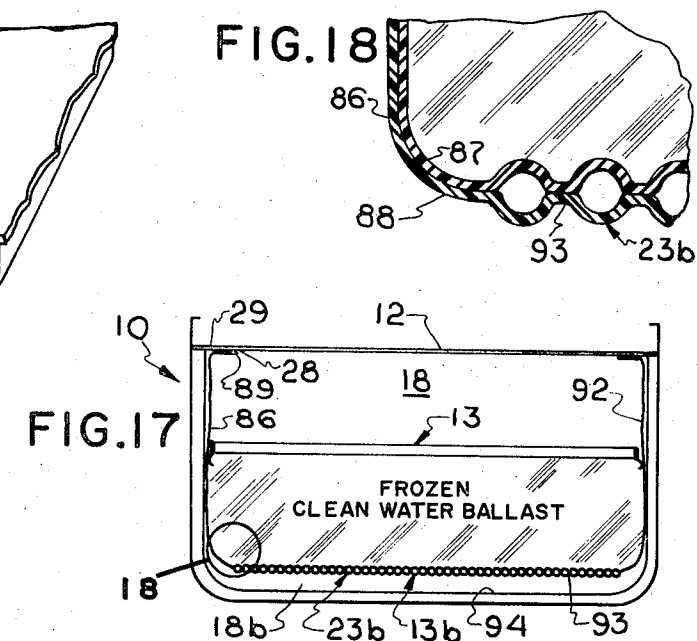
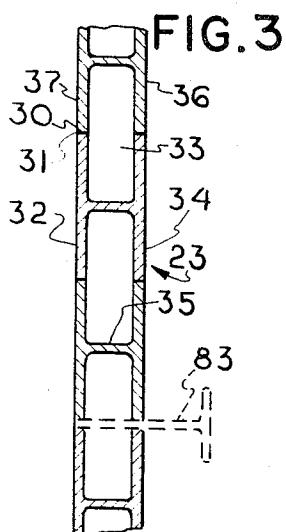
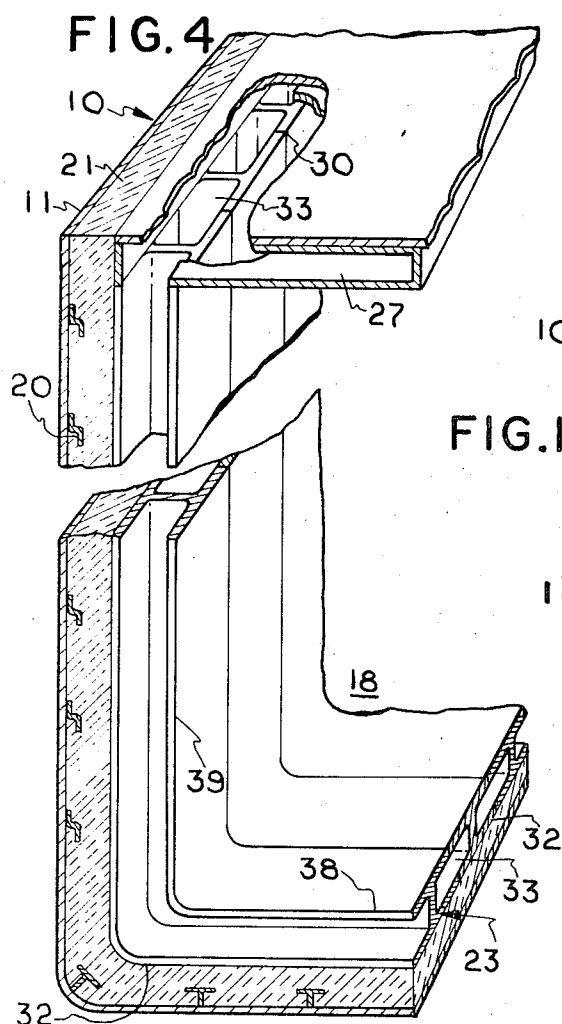


FIG. 10

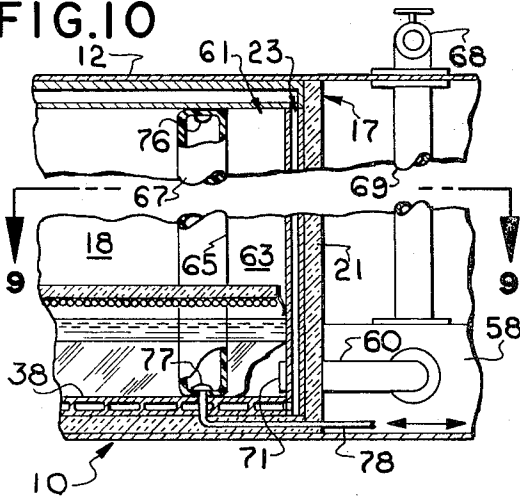


FIG. 9

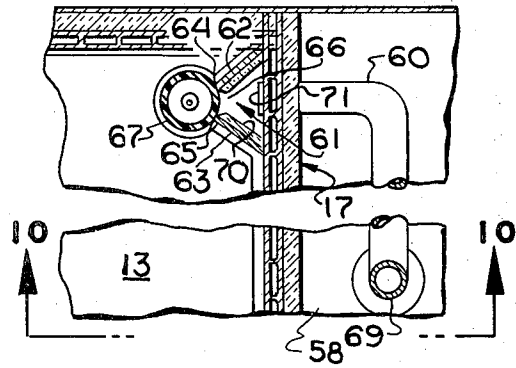


FIG. 11

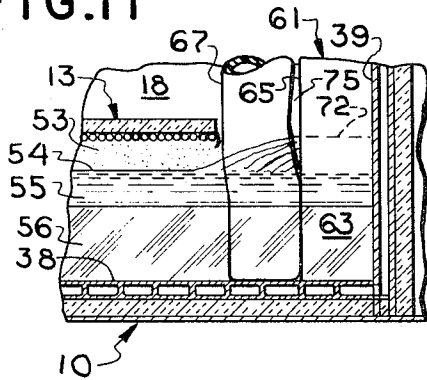


FIG. 12

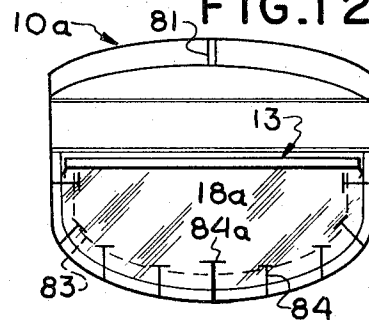


FIG. 13

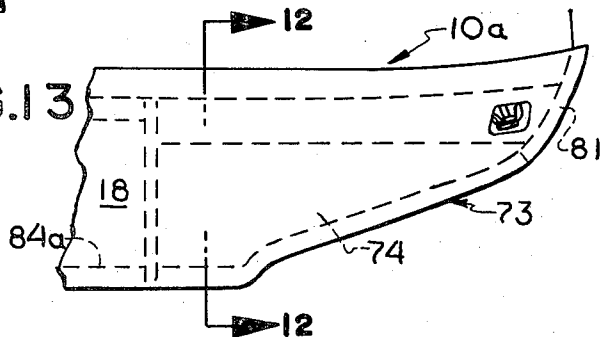


FIG. 6

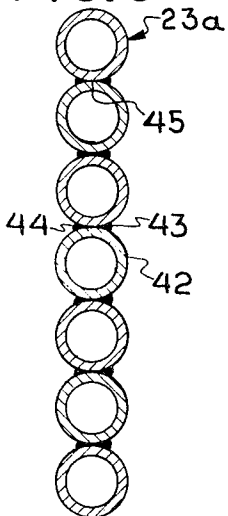


FIG. 25

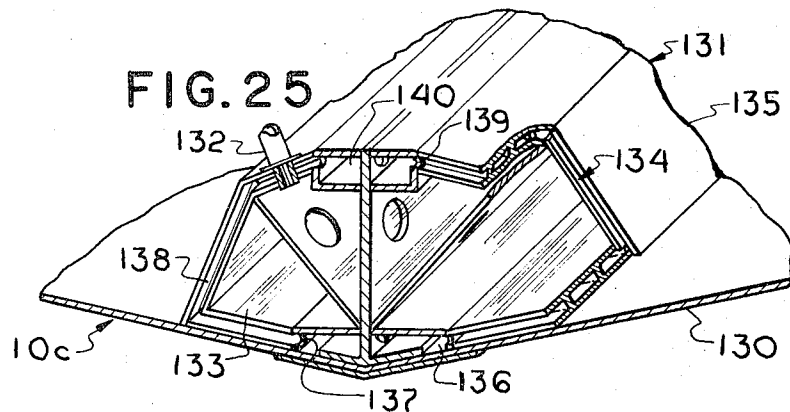


FIG. 26

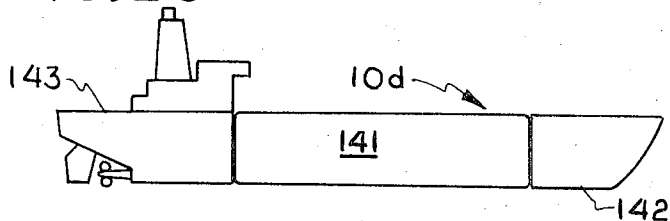


FIG. 27

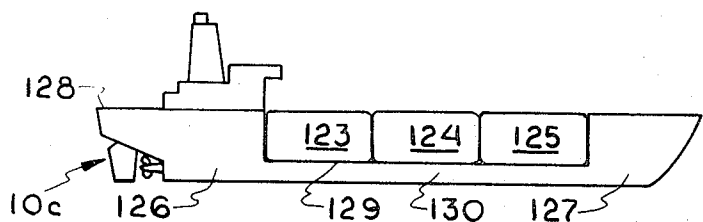
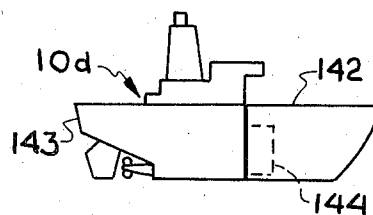


FIG. 24

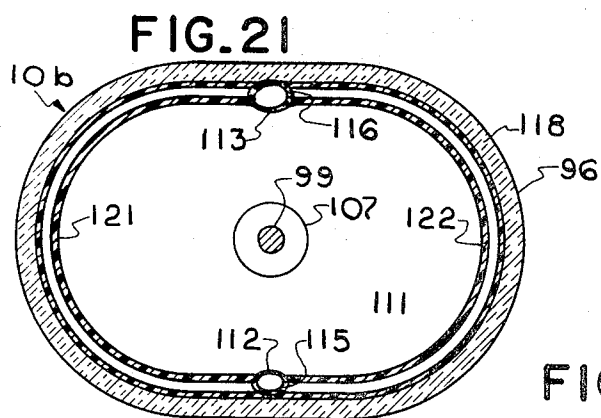


FIG. 22

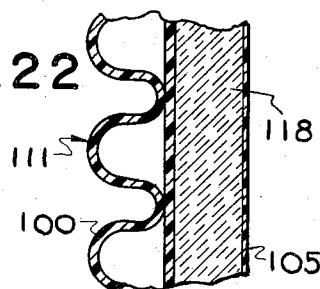


FIG. 23

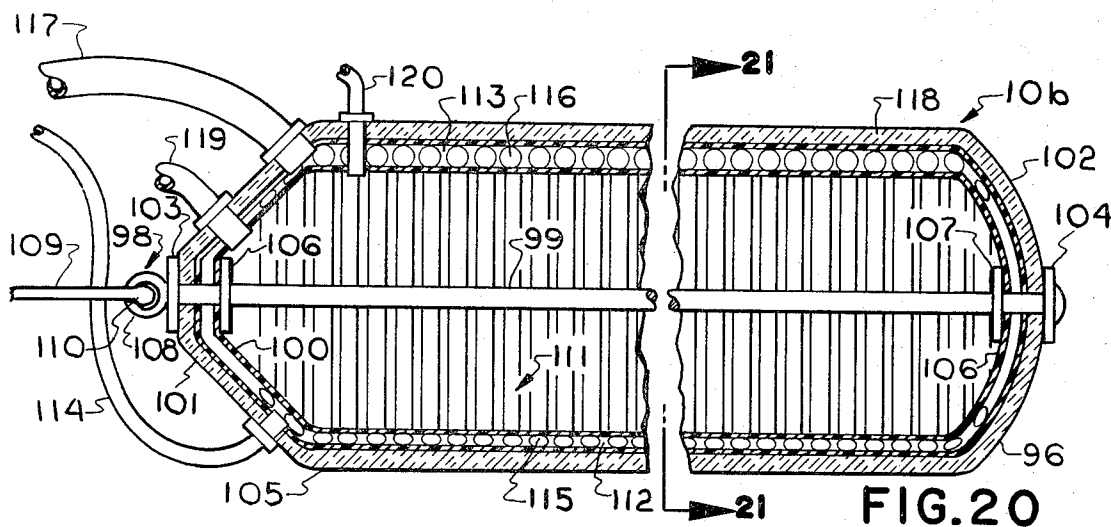
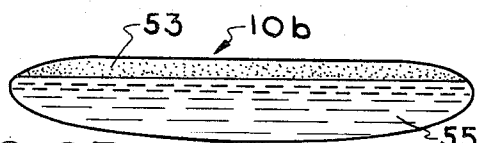


FIG. 20

CRYOGENIC TRANSPORTATION METHOD AND APPARATUS THEREFOR

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of co-pending patent application Ser. No. 829,207, filed in the U.S. Pat. Office on June 2, 1969, and now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to a method and apparatus for transporting fluid and mixed fluid and dry bulk cargoes in which the cargo itself is employed as a structural element of the transportation means and, more particular, to a method in which cryogenic means are used for the purpose.

There have been a number of examples in the prior art of the use of cryogenic techniques in marine transportation systems. In U.S. Pat. No. 1,379,241, L. W. Bates discloses the technique of freezing liquid or mobile fuel carried in the fuel tanks of a ship into a solid or semi-solid body that serves to protect vital areas of the ship from the explosive effects of torpedo and gun fire and internal explosions. P. N. Lucas-Girardville, U.S. Pat. No. 1,680,873, discloses a method for storing or transporting gases in the liquified or solid state. In a still further example, J. R. Cobb, Jr., et al., U.S. Pat. No. 2,938,359, discloses a method and apparatus for the storage and transportation of acetylene in which the substance is congealed into a solid state for the economical and safe handling thereof. In another prior art method, J. C. Garret, U.S. Pat. No. 3,147,593, discloses a method for reducing the volume of tankage in an aircraft required to supply hydrogen fuel for vehicular power wherein the hydrogen is converted to its solid phase for the purpose.

SUMMARY OF THE INVENTION

In its broadest sense this invention relates to the use of the structural characteristics of suitable substances in the solid state in a container to permit the use of wall members of reduced strength for the container. In the marine transportation embodiments of the invention, suitable liquid and mixed liquid and dry bulk cargoes are solidified by freezing so as to permit such cargoes to be shipped safely and efficiently in light-weight, inexpensive carriers in which the frozen cargo is used as a structural element to provide a significant strength contribution to the carrier. In this invention, the frozen cargo acts as an internal, integral strength member of the structural parts of the hull of the ship. The structural parts of the hull are considered to include those parts which contribute to its strength as a "girder" and provide what is known as longitudinal strength. Structural parts include the framing, both transverse and longitudinal; the shellplating; the decks; and the longitudinal and transverse bulkheads. These major strength members enable the ship to resist the various stresses to which it is subjected. Shell-plating serving as a major strength member in the conventional sense is not required in the ships of this invention, but the plating or skinsheets that are used are stiffened and kept from bulging or buckling by the walls of the cargo hold which is backed by the structural mass of cargo. The cargo acts to take the loads imposed on the hull mem-

bers including bulkheads, decks, and bottom, and to absorb forces exerted by load weight, and water and impact forces. Although the structure of the ship outside of the sections strengthened by the frozen cargo will be of more or less conventional design, this invention permits a significant reduction in the structural requirements of the ship as a whole, particularly in larger ships where a smaller fraction of displacement is represented by the sections of the ship not reinforced by cargo. Because of the reduced scantlings permitted by the utilization of the structural characteristics of the frozen cargo, there will be a significant decrease in the steel weight of the ship which in all probability can exceed an estimated 20 percent of the weight of steel of a standard hull having an identical deadweight capacity.

In this specification and in the claims, the matter which is frozen to produce a structural mass is referred to as "cargo"; however, the term is intended to cover any matter that can be used for the intended purpose, and can be cargo being shipped, ballast fluid, or suitable matter which is loaded aboard solely to be frozen to reinforce structure. The strength that can be derived from the cargo can be appreciated when the maximum tensile stress of various fluids in the solid state are considered. Values as high as 296 psi for water ice have been obtained in tests and frozen propane and methane tested to 110 and 140 psi respectively maximum tensile stress. Thus, a mass of frozen methane in the cargo hold will impart a tensile strength ranging into the million of pounds to the hull of the ship and the cargo will be a positive rather than a negative strength factor in the design of the vessel.

This utilization of the structural characteristics of a frozen mass of cargo to impart structural strength to the vehicle, to my knowledge, is a technique that has not been taught in the prior art. Thus, although Bates congeals the liquid or mobile fuel carried in a ship's tanks so that it acts as protective means to shield vital parts of the ship, much in the same way that coal in the coal bunkers was once used for the purpose, Bates does not use a hull having a minimal scantling number nor does he employ congealed fuel to strengthen structurally the hull structure of the ship as set forth in this invention. Further, once the fuel is used, the shielding derived therefrom is lost. Because of this factor, Bates is required to provide a hull that has a scantling number that will produce a required strength for all operating conditions whether the fuel tanks are empty or full and he does not teach the use of a structural mass of frozen cargo to reinforce the shell of a vessel such that a light inexpensive construction having a reduced scantling number can be used. Lucas-Girardville, Cobb et al., and Garrett disclose either the solidification of fuel to reduce its volume or the freezing of cargo to inert it for safety and they do not teach the use of the solid mass to stiffen the vehicle to thereby reduce the structural requirements of the vehicle or the tank in which the mass is carried.

To my knowledge, also, there is no teaching of the method and apparatus of this invention used to freeze efficiently large masses of matter nor of the use of such refrigerating means to vary the density of such matter so as to produce a required buoyancy for the effective transportation of the matter by sea.

DESCRIPTION OF THE DRAWINGS

For the purpose of illustrating the invention, there is shown in the drawings the forms which are presently preferred, it being understood, however, that this invention is not necessarily limited to the precise arrangements and instrumentalities here shown.

FIG. 1 is a longitudinal elevation partially in section of a cryogenic carrier of the present invention;

FIG. 2 is a transverse section of the carrier of FIG. 1 taken along line 2—2;

FIG. 3 is a fragmentary sectional view of wall structure embodied in a vessel of the invention;

FIG. 4 is a fragmentary sectional view in perspective of the hull at the cargo hold of a vessel of the invention;

FIG. 5 is a fragmentary sectional view in perspective of a further embodiment of the hull at the cargo hold of a vessel of the invention;

FIG. 6 is a fragmentary sectional view of a further embodiment of wall structure according to the invention;

FIG. 7 is a fragmentary sectional view of the detail of FIG. 2 circled at 7;

FIG. 8 is a transverse section at the cargo hold of a cryogenic carrier embodied in the invention;

FIG. 9 is a plan view in fragmentary section taken along line 9—9 of FIG. 10 showing details of an embodiment of cargo loading and unloading means;

FIG. 10 is an elevation view in fragmentary section taken along line 10—10 of FIG. 9 showing details of an embodiment of cargo loading and unloading means;

FIG. 11 is an elevation view in fragmentary section of the cargo loading and unloading means of FIGS. 9 and 10 showing cargo being admitted into the cargo hold;

FIG. 12 is a transverse section of an icebreaker embodiment of the carrier of the invention taken along line 12—12 of FIG. 13;

FIG. 13 is a longitudinal elevation of the bow section of an icebreaker embodiment of the invention;

FIGS. 14, 15, 16, and 17 are transverse sectional views at the cargo hold of various embodiments of cryogenic carriers of the invention;

FIG. 18 is a fragmentary sectional view of the detail of FIG. 17 circled at 18;

FIG. 19 is a transverse sectional view at the cargo hold of the embodiment of FIG. 17 showing an alternate loading of cargo;

FIG. 20 is a longitudinal sectional elevation view of a further embodiment of a cryogenic carrier of the invention;

FIG. 21 is a transverse section of the carrier of FIG. 20 taken along line 21—21;

FIG. 22 is a fragmentary sectional view of wall structure of the cryogenic carrier of FIG. 20;

FIG. 23 is a schematic transverse section of the cryogenic carrier of FIG. 20 illustrating a stage in the loading of cargo therein;

FIG. 24 is a longitudinal elevation of an embodiment of a cryogenic carrier of the invention;

FIG. 25 is a fragmentary sectional view in perspective of the carrier of FIG. 24 showing details of the hull structure reinforced in accordance with the invention;

FIG. 26 is a longitudinal elevation of an embodiment of a cryogenic carrier of the invention supporting cargo carrying means; and

FIG. 27 is a longitudinal elevation of the cryogenic carrier of FIG. 26 illustrating the bow section joined to the stern section after the removal of the cargo carrying means from therebetween.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, the cryogenic carrier or ship 10 has a shell 11, a single upper or weather deck 12, a movable tank top 13 (see FIG. 2), and provisions for engine room machinery 14 and quarters 15 at the stern of the ship. Between the engine room forward bulkhead 16 and the cargo hold forward bulkhead 17, the ship comprises a large unobstructed cargo hold 18. Because the frozen cargo provides a significant amount of the necessary structural strength, the ship does not require the number of longitudinal and transverse bulkheads usually found in tankers; however, transverse or longitudinal bulkheads can be provided to divide the cargo space into a number of cargo holds if such subdivision of the cargo space is desired. To provide transverse and longitudinal support for the ship when the cargo hold is not loaded and where it is not desired to freeze the ballast or other stiffening agent such that the ship thus does not derive structural strength from the frozen cargo or ballast, the usual transverse framing 19 and longitudinal stringers 20 can be employed. The inner walls of the shell 11 in the sections of the ship having refrigerated compartments and the bulkheads 16 and 17 are completely lined with thermal insulation 21 (see FIG. 4) which may be, as is well known, balsa wood or a suitable foamed plastic. Refrigeration of the selected sections of the ship is by means preferably of a closed-cycle refrigeration system having the usual pumping means (not shown) for circulating a refrigerant such as liquid nitrogen into refrigerant intake main 22 running longitudinally along the centerline of the ship from one end of the cargo hold to the other. Intake main 22 feeds the refrigerant into a grid of athwartwise disposed ducts 23 which extend from the intake main on the longitudinal centerline of the shell to the starboard 24 and port 25 sides and then run vertically up the side of the ship to return headers 26 and 27 which run longitudinally on either side of the cargo hold 18 on the underside 28 of the deck stringers 29. Duct grid 23 can be of any suitable construction and the ducts can be formed, for example, as shown in FIG. 3, by welding 30 the edges 31 of a plurality of wide-flange extrusions 32 such that the spaces between the flanges 34 and the webs 35 of the joined extrusions form passageways 33 for the refrigerant. It will be seen that the outer flange surface 36 of the joined extrusions forms the inside wall of the refrigerated cargo hold 18 and the outer flange surface 37 forms the outside wall such that the hold, in effect, is a large, fluid-tight tank having a double-wall construction to thereby meet safety standards and to present a primary and a secondary or backup barrier as required by present Coast Guard regulations for liquid cargoes. Each of the extrusions 32 may be formed with a base portion 38 and an upright portion 39 so that, when the extrusions are welded together upon assembly, the combined base portions 38 act as inner bottom plating for the hold and the combined upright portions 39 act as wall portions thereof (FIG. 4). Bulkheads 16

and 17 on either end of the hold will, of course, also be provided with an appropriate duct grid 23 for the circulation of refrigerant therethrough and will be suitably insulated 21.

To refrigerate the hold, a suitable refrigerant, preferably liquid nitrogen, is circulated from a refrigeration unit 40 of known design by means of appropriate piping (not shown) to intake main 22 and from thence through openings 41 (FIG. 5) in the sides of the main into the passageways 33 in the refrigerating grid 23 where the nitrogen evaporates to thereby extract heat from the cargo hold 18 to freeze the contents thereof. The vaporized nitrogen passes into return headers 26 and 27 and is drawn into a compressor which compresses it and then passes it to a condenser (neither of which is shown) where it is condensed for recirculation, all in a well-known manner.

In the aforementioned description a plurality of wide-flange extrusions are used to form a refrigerating duct grid: a still further construction suitable for the purpose is illustrated in FIG. 6. As shown therein, a refrigerating duct grid 23a can comprise a plurality of seamless pipes or tubes 42 positioned side-by-side with axes parallel in any one wall with a pair of welds 43 and 44 running the lengths thereof. Each weld can be made on either side of the line of contact 45 of adjacent tubes to produce a fluid-tight structure having essentially a double-wall construction.

In this invention, refrigerating means are also provided in the tank top 13. These means comprise a grid of refrigerating tubes 46 positioned in the bottom surface 47 of the tank top, which top can be made of a thermally insulating material or which can be furnished with a layer 48 of thermal insulation as perhaps best shown in the detail FIG. 7. The refrigerant, preferably liquid nitrogen, is circulated from the refrigeration unit 40 by means of appropriate piping (not shown) to a flexible conduit 49 into an intake main 50 and from thence is passed through openings 50a into the grid of tubes 46 covering the bottom surface 47 of the tank top. Liquid nitrogen passing into the grid evaporates to thereby extract heat from the cargo hold 18 and the vaporized nitrogen then passes through openings 50b into a return header 51 and from thence flows through flexible conduit 52 and appropriate piping (not shown) to the refrigeration unit 40 to be re-condensed for recirculation.

Because matter as it is frozen has a tendency to stick to the surface of the refrigerating means with which it is in contact during the freezing operation, the cargo liquid as it is frozen would have a tendency normally to adhere to the refrigerated inside wall surfaces of the cargo hold. If this occurs, the efficiency of the refrigerating means will be imparted because of the thermal insulating properties of frozen matter. It will be recognized that, as the bulk cargo is poured into the hold and frozen, the refrigerated surfaces 38 and 39 of the hold will become buried in "ice" and the efficiency of the freezing operation will thus be degraded progressively. In this invention, the problem is eliminated by the use of a heat transfer substance with the refrigerating tank top 13. The tank top is in thermal contact with the matter being frozen but, to prevent the formation of ice on the surface of its refrigerating tube grid 46 that will degrade its efficiency, it is kept out of physical contact with the cargo by means of the heat transfer substance. As shown in FIG. 8, a layer of heat transfer substance

53 floats on the surface 54 of the cargo liquid 55 being frozen 56; and, in turn, the tank top 13 floats on the layer of the heat transfer substance. Any suitable gas, liquid, solid, or combinations thereof can be utilized as a heat transfer substance, providing that the substance is less dense than the matter being frozen, is not readily soluble therein, and has a lower freezing point. The refrigerating means is, of course, operated at a temperature below the freezing point of the matter being frozen, but above the freezing point of the heat transfer substance. Thus, for example, for freezing methane, the refrigerant circulated through the refrigerating means in the hold and the tank top can be liquid nitrogen and the heat transfer substance can be nitrogen, neon, or helium in their gaseous states. As a further example, if crude oil is the cargo being frozen for shipment, the refrigerant can be liquid nitrogen and the heat transfer substance can be gaseous nitrogen. Tank top 13 can be constructed with sufficient buoyancy to allow it to float on the top of the heat transfer substance or, if the tank top is not sufficiently buoyant to float on the heat transfer substance, mechanical means (not shown) which are furnished with suitable sensors (not shown) can be provided to maintain the proper spacing between the tank top and the cargo to prevent contact therebetween while the hold is being filled. Appropriate sealing means such as a fluid-tight, lip-type seal 57 is provided around the periphery of the tank top to prevent the escape of the heat transfer substance during the travel of the tank top when the level of the cargo changes during loading or unloading. Seal 57 can be fabricated from a suitable gas-tight TFE or FEP fluorocarbon resin having good low-temperature properties.

For unloading the cargo, the ship can be provided with forward 58 and an aft 59 pump room. Mains 60 connect the pump rooms with standpipes 61 of which four may be provided, one each in the corners of the hold. Inasmuch as the construction and operation of each of the individual standpipe systems for loading and unloading cargo and the associated pumps and piping are essentially identical, in the interests of brevity, the following description will be confined to one exemplary system. Standpipe 61 is formed by two plates 62 and 63 (FIG. 9) aligned vertically and each having one edge welded to a bulkhead, such as 17, such that the plates have an angled relationship with one another. The plates form two sides of a triangular enclosure having an open apex 66 which provides a slotted passage connecting the interiors of the standpipe and the hold. An inflatable cylindrical member 67 acts as a valve in opening 66 of the standpipe. The operation of the cylindrical valve 67 is perhaps best shown in FIG. 11 which shows cargo being loaded into hold 18. During loading, the cargo is pumped from conventional on-shore facilities (not shown) through the usual piping (not shown) connected to deck main 68 and passes down riser pipe 69 to the pump room 58. From the pump room, the cargo is pumped through main 60 through fitting 71 in bulkhead 17 and into standpipe 61. As the level 72 of the incoming cargo 55 rises in the standpipe, the pressure head forces valve 67 away from the edges 64 and 65 of the angled plates, producing an opening 75 through which the cargo flows into the hold. When the level of the cargo in the hold rises, the pressure exerted by the cargo will force the portion of the valve that is below the cargo level into a sealing relationship with edges 64 and 65 of the angled plates. It

will be noted that the portion of the flexible cylindrical valve not under sufficient pressure by the cargo to seat it against the opening in the standpipe will be deflected by the head of pressure of the incoming cargo in the standpipe such that cargo will continue to flow through opening 75 until hold 18 is filled to the desired level. The valve and the walls of the standpipe are thermally insulated 70 so that the freezing operation does not interfere with the inflow of cargo.

Flexible cylindrical valve 67 is fixed in its operative relationship with the standpipe by means such as by bolt 76 (FIG. 10) secured as to the underside of deck 12 and by a hollow fitting 77 secured to the inner bottom plating 38 of the hold. A fluid line 78 which opens into the interior of the valve 67 through fitting 77 is connected to a suitable source of pressurized fluid (not shown) such that the cylindrical valve can be inflated or deflated as required. It will be appreciated that an appropriate return line or venting means (not shown) can be provided to facilitate the inflation and deflation of the valve. To unload the cargo hold 18, the fluid with which valve 67 is inflated is withdrawn by means of fluid line 78 to deflate the valve such that a gap is opened between the deflated valve and edges 64 and 65 of the standpipe. The liquified cargo (which has been converted from the solid state as by the addition of heat) will flow through the gap into the standpipe 61 from whence it is pumped ashore.

It is a current trend in the design of the larger dry bulk carriers to provide a width of hatch which is approximately 50 percent of the beam of the ship. A wide hatch reduces the amount of transverse overhand of the main deck and, thus, dry bulk cargoes can be loaded and unloaded with a minimum amount of hindrance by the overhanging sections of the deck that are in the way of the cargo holds. It is because of the large "free surface" that will obtain in conventional shipping methods if oil or water ballast is loaded into the cargo holds of the usual dry bulk carrier with wide hatches that Classification Societies will not grant approval for the carriage of a liquid cargo in the dry cargo holds. Inasmuch as methane, oil, and other normally liquid cargoes are transported as a solid in the method of this invention, the cargo does not produce free surface effects. As shown in FIG. 2, therefore, the vehicle in this invention can be designed with a wide hatch opening 79 so as to handle normal dry bulk cargoes efficiently and yet it will be possible to obtain approval by Classification Societies for the carriage of methane or oil in the same ship. Hatch opening 79 is provided with a thermally insulated hatch cover 80.

It will be recognized that, except for the fact that the cargo is brought to the solid state for shipment, the handling and operation of the ships used in this transportation method follow substantially conventional techniques. Thus, the loading and unloading facilities, the pipelines and their connections to the deck mains 68, and the like, will be of any suitable known arrangement and it is not believed that it will serve any useful purpose to describe them further. In operation, the carrier is brought to the loading facility and rigged for loading but, before loading begins, the cargo hold is chilled down by circulating liquid nitrogen through the refrigerating tube network in the hull and tank top. Dry nitrogen gas is pumped through cargo space 18 to purge all traces of air and moisture therefrom. After the purging and cool-down operation is completed, the

heat transfer substance 53, preferably gaseous neon, is pumped from a source of supply (not shown) through suitable piping 82 to the underside of tank top 13. Pumping of neon is continued to raise the tank top clear of the floor of the hold and also out of contact with the cargo that will be pumped into the hold. Once the proper clearance which, preferably is only a few inches, is established, pumping of the methane into the hold can commence. Preferably the methane is loaded in its liquid state and the pumping rate is coordinated with the freezing to achieve maximum efficiency. Inasmuch as, however, the liquified methane being pumped into the ship is at a temperature below about -162°C and the nitrogen in the refrigerating means is in the region of about -190°C , the liquid methane quickly reaches its freezing point of about -183°C . (With respect to crude, the freezing point will vary in accordance with the composition thereof; however, it is estimated that with most crudes the freezing will occur simultaneously with the filling of the hold even at high pumping rates.) As the cargo fluid flows into the hold and progressively fills it, the tank top, which is supported out of contact with the cargo by the layer of neon, will be elevated accordingly. When the hold is filled to the desired level, the neon can be pumped back to its supply reservoir and the tank top can be frozen into the upper surface of the cargo methane. This completes the loading operation and the ship can thereafter be operated in a conventional manner in its sailing to its destination. The refrigerating means will be operated as required to maintain the cargo in its solid state until such time as the cargo is to be melted for unloading.

At the destination, the cargo methane is liquified for unloading by circulating hot water or steam through the refrigerating tube network in tank top 13. It is preferred to use the tank top exclusively for liquifying the cargo and to avoid appreciable heat input into the refrigerating means in the hull. After the ship is rigged for unloading, the cylindrical valve 67 of each standpipe 61 is deflated such that the liquified methane flows into the standpipes such that it can pass into mains 60 and be pumped through pump rooms 58 and 59 up risers 69 and out deck mains 68 and then, in a well-known manner, to on-shore facilities.

The structural characteristics of the congealed cargo offer the marine architect unusual freedom in the design of the vehicles used in the method of this invention. Because the cargo may be frozen literally into any configuration desired, the "hull" shape can be of any desired configuration and it can be designed for any type of operation without the usual restrictions, such as strength and structural requirements, and the like faced by designers of conventional ships. As an example, the strength imparted by the cargo is particularly valuable in tankers constructed with icebreaking capabilities. Icebreaking tankers 10a designed in accordance with this invention will have main dimensions, hull lines, main machinery, and propellers dictated by conventional practices. To impart added stiffness and strength to the hull so that the stresses of icebreaking are absorbed, transverse framing 83 and longitudinals 84 which protrude into the cargo hold 18a (see FIG. 12) can be provided such that they will be embedded in the cargo and frozen therein so that icebreaking loads on the ship will be carried substantially by the cargo. Longitudinal 84a on the centerline of the ships of this em-

bodiment can serve as a keel member. At its forward end, longitudinal 84a can be welded to the lower end of the stem 81 and at its after end it can be joined to the stern-post (not shown) all as is well known in the art. To strengthen the bow 73 (FIG. 13), bow tanks 74 will be furnished with refrigerating means identical in design with the refrigerating means in the main cargo hold and will be operated therewith so the contents of the bow tanks (also indicated as cargo hold 18a) can be frozen to thus strengthen the bow. Except for design and operational considerations influenced by ice-breaking service, the icebreaking tanker 10a will otherwise be similar in its construction and operation to the cryogenic tankers set forth previously and reference should be made thereto for a pertinent description.

The tankers designed to carry the cryogenic cargoes of the method of this invention can also advantageously handle cargoes of slurried iron ore or other mineral concentrates. Thus, it is feasible to take advantage of the economies of the transportation of cargoes in the slurried condition, particularly in the loading and unloading thereof by means of pipeline. In this method, as is usual in slurry techniques, the minerals are mixed with a carrier fluid, which can be fresh water, to form a slurry which is pumped through pipelines into the cargo hold. The techniques and equipment employed to produce the slurry and to pump it aboard the ship and to subsequently unload it are in common use and it is not believed that it would serve any useful purpose to describe them in detail herein; likewise, the construction and operation of the cryogenic tanker for use with slurried cargoes will be similar with obvious exceptions to the tankers of this invention described previously. Use can be made of the standpipe and cylindrical valve system of the previous embodiments to admit slurry into the hold; however, instead of a de-watering operation as is usual in conventional systems, the slurry is frozen such that the minerals remain in suspension in the congealed slurry liquid. Mineral slurries are usually about 25 percent water and, once aboard ship, about 90 to 95 percent of the water is drawn off and pumped over the side, leaving the minerals as a tightly compacted cargo. This dense cargo results in a low vertical center of gravity that produces undesirable roll characteristics in the vessel. However, one of the advantages brought about by the freezing of the slurry so the minerals remain fixed in their dispersion in the carrier liquid is that the density of the cargo in the hold is, in effect, reduced so that the vertical center of gravity is raised. If it is desired to raise the vertical center of gravity still further, water or any other suitable fluid having an appropriate density can be pumped into the hold to the proper level and frozen and then the slurry can be loaded on top of the frozen mass. Except for obvious differences due to the fact the cargo is frozen, the vessel is operated in a substantially conventional manner. To unload the frozen slurry cargo, steam or hot water is circulated through the refrigerating means in the tank top and as the slurry melts it is pumped ashore by means of pipelines.

Because the cargoes transported by the method of this invention are in the solid state, it is feasible to carry mixed cargoes. Thus, if it is desired to raise the vertical center of gravity of the ship to compensate for a very dense cargo such as a mineral slurry, the hold can be filled to a predetermined depth as described immediately above with a less dense substance such as water

which is frozen prior to the loading and freezing of the slurried cargo. If it is desired to lower the center of gravity of a less dense cargo such as methane, a quantity of a denser substance such as, for example, water (see FIG. 14) can be loaded first in the hold. It will be appreciated, of course, that the act of solidifying methane (and most other substances) in itself increases the density: methane in its liquid state has a specific gravity of about 0.415 (at -164°C) and in the solid state, it has a specific gravity of about 0.507 (at -196°C). If methane is cooled even further to -253°C , it has a specific gravity of about 0.517. When transporting low-density cargoes such as grain, water ballast can be first pumped into the hold and frozen. Tank top 13 can then be frozen into the upper surface of the congealed ballast, as shown in FIG. 15, to thereby serve as a separator upon which the grain 85 can be loaded. Should there be a need for more than one physical separator to isolate one cargo from another, the carrier can be equipped to meet the requirements as shown, for example in FIG. 16, where an additional tank top 13a can be provided. Tank top 13a can be identical to the tank top 13 of the previous embodiments, although it may be desired to provide a second, fluid-tight, upwardly oriented, lip-type seal 57a around the upper periphery of the tank top.

According to the latest legislation which most maritime nations have agreed to adopt to prevent the pollution of coastal and estuarial waters, contaminated ballast cannot be discharged in those waters. For this reason, charterers are requesting shipowners to provide them with tankers which have a clean ballast capacity of not less than 25 percent of the deadweight. An embodiment of a carrier of this invention in which one cargo can be effectively isolated from another such that a clean hold capacity of substantially 100 percent of deadweight is provided and in which it is not necessary to steam, purge, or otherwise cleanse the cargo hold when loading clean ballast, for example, in a hold that has contained crude is illustrated in FIG. 17. In this embodiment, the tank top 13a is fabricated from a suitable sheet material 86, such as an appropriately reinforced gas-tight TFE or FEP fluorocarbon resin having good low-temperature properties. A two-ply construction which has a tube network 23b formed for the circulation of a refrigerant between the upper 87 and lower 88 plies of the sheet material is used for tank top 13b (FIG. 18). The inlet and return lines (not shown) to the network 23b can also be formed between the two plies. The peripheral edge 89 of the sheet material 86 is secured in an appropriate manner to the underside 28 of the deck stringer 29 such that when the tank top 13b is fully deployed it forms a fluid-tight lining for the cargo hold 18 with the depending portions 92 of the sheet material forming the sides and ends, and the tube network portion 23b the bottom of a pouch-like arrangement into which cargo, or clean ballast, can be loaded as shown in FIG. 17. (In FIG. 17, to prevent obscuring details of the drawing, a gap is shown between the bottom 93 of tank top 13b and the floor 94 of the cargo hold. In actual practice, the weight of the contents will force the pouch-like tank top into contact with associated surfaces of the hold.) A tank top 13 identical to those described in the previous embodiments can be utilized to freeze the cargo substance poured into tank top 13b. As also described previously, when tank top 13 is in operation to freeze the cargo

thereunder, a layer of heat transfer substance can be used. Under certain conditions, the use of a heat transfer substance may not be required, thus, the description given as to the use of such substance with the tank top 13 is not to be understood as limiting the various embodiments of the tank top to use only with a heat transfer substance. However, if a heat transfer substance is employed and the cargo being loaded is a clean water ballast, the heat transfer substance can be butane. To unload the clean water ballast, steam or hot water is circulated through the refrigerating tube network of tank top 13 and the water as it is melted can be unloaded. Loading of a diverse cargo, such as crude, can commence when the unloading of the water ballast is completed. The loading of the crude can be preceded by the admittance of a heat transfer substance into the hold 18b in the space between the underside 93 of the tube network portion 23b of the tank top 13b and the bottom of the hold 94 such that the refrigerating portion 23b will be supported out of contact with the crude being loaded and frozen. When the required amount of heat transfer fluid is admitted, the crude can be loaded and frozen. As shown in FIG. 19, as the level of crude in the hold 18b rises, the tank top 13b will be raised accordingly and the side and end portions 92 can be folded inwardly 95 by suitable means such as by the crew so that the loading operation is not impeded. To avoid needless repetition, a further description of this embodiment will not be set forth, but it will be understood that the details of operation and of construction where not shown will be in accordance with the teachings of this invention or of well known practice.

The freezing of a liquid like gasoline, or a substance that is normally a gas, like methane, or suitable mixtures such as a slurry formed of fresh water and a mineral concentrate, produces a frozen mass having cohesiveness or structural integrity. If the frozen mass has the required buoyancy it will form an ice-berg-like floating mass; thus, by freezing a suitable substance having the required buoyancy in the frozen condition into a solid mass, the frozen substance has a high order of structural stiffness and can serve as its own transportation means and a "ship" in the conventional meaning of the word is not required. However, to prevent erosion by sea water and thermal degradation of the solid mass, it is preferred to enclose the mass in a suitable envelope that will preserve the integrity of the mass during the transportation thereof. The envelope can be the cryogenic tankers of the previously described embodiments or advantage can be taken of the structural characteristics of the frozen cargo and a light-weight, non-structural envelope of a flexible, elongated type can be used.

As shown in the embodiment of FIG. 20, the flexible envelope or vessel 10b can comprise a closed tube having walls 96 fabricated out of a flexible material such as a suitable gas-tight TFE or FEP fluorocarbon resin having good low-temperature properties. The material used can be appropriately strengthened by known reinforcing means and surface coatings and preferably is flexible enough to be folded or rolled-up for stowage and transportation when not in use. Vessel 10b has a streamlined nose 101 provided with appropriate towing means 98. Towing means 98 has a spacer bar 99 which is connected to the wall 96 of the vessel 10b at the bow 101 and stern 102 thereof by suitable means such as by circular plates 103 and 104 respectively bonded to the

outer surface 105 and circular plates 106 and 107 respectively bonded to the inner surface 100 thereof. A ring 108 is provided on the forward end of the spacer bar for towing the vessel as by means of a towing cable 109 shackled 110 to the ring. Contents of the vessel are refrigerated by means of an appropriate pipe network 111 which is in the best thermal relationship obtainable with the cargo and which is fed with a suitable refrigerant by an intake main 112 running longitudinally along the length of the vessel. A longitudinal duct 113 is provided as a refrigerant return line. Refrigerant supplied from the towing ship (not shown) is introduced into intake main 112 through suitable flexible piping 114 and passes from the main into the pipe network 111 by openings 115. After extracting heat from the contents of the vessel, the refrigerant passes out of openings 116 into return duct 113 and from thence passes through suitable flexible piping 117 to the refrigerant supply (not shown) on the towing ship. The outer surface of the vessel is suitably insulated thermally as by an appropriate flexible, closed-pore polyurethane foam 118 (FIG. 22). One or more pipes 119 communicate with the interior of the vessel for loading or unloading cargo and one or more pipes 120 communicating with the interior can be provided for the admitting or withdrawal of a heat transfer substance if such is used. If a heat transfer substance is utilized in the freezing operation, walls 96 of the vessel 10b can be designed such that the flexible envelope folds longitudinally on a plane bisecting the walls at 121, 122 such that when empty it assumes substantially the flattened configuration shown in FIG. 23. To load vessel 10b, suitable refrigerant is circulated through the refrigerating pipe network to cool-down the vessel, then a heat transfer substance 53 is admitted. Cargo 55 can then be loaded and frozen: inasmuch as flexible vessels essentially similar to vessel 10b are in common use, it is believed that the loading and the subsequent unloading of the vessel and the handling and operation thereof including the refrigerating and the subsequent melting steps will be understood in light of the exposition of the invention given previously and a further description thereof will not be given.

Vessel 10b is adapted to be propelled or towed by suitable means such as by a ship or towboat. As is also known, vessel 10b can be equipped with propulsion means such that external towing means are not required. In addition, flexible containers 123, 124, and 125 similar in construction to vessel 10b can be carried on a more-or-less conventional ship 10c adapted for the purpose. As illustrated in FIG. 24, ship 10c has a shell 126, a bow section 127, a stern section 128 having propulsion means and the like, and a well deck 129 upon which the containers 123-125 are secured for shipment. The body 130 of the ship can be provided with refrigerating means such that ballast water or other fluid can be frozen in the body section in accordance with the teachings of this invention to thereby provide a frozen "spine" of great strength for the ship. A longitudinal of great strength can comprise a longitudinal fluid-tight compartment 131 appropriately constructed to impart strength to the body 130 of ship 10c when the compartment 131 is filled as through pipe 132 with a suitable fluid and then frozen 133. Freezing can be by means of suitable refrigerating means 134 in the walls 135 of the compartment. Refrigerating means 134 can be essentially similar to the means of the previous embodiments such that a refrigerant can be passed into in-

take main 136 and thence through openings 137 into tube network 138 and after passing through openings 139 can be returned by means of return header 140 to appropriate means (not shown) such that it can be processed for recirculation. As is known, if containers 123-125 have the proper buoyancy, the containers can be unloaded from ship 10c by flooding ballast compartments to lower the ship such that the containers can be floated free from the well deck 129, all in a well-known manner. The draft of ship 10c can be such, of course, that the containers themselves can contribute a significant share of the buoyancy of the ship.

A further embodiment of a ship for transporting flexible containers is shown in FIG. 26. In this embodiment, the flexible container 141 can provide a major share of the buoyancy of the ship 10d. Ship 10d has a bow section 142 and stern section 143 having propulsion means and the like. Container 141 is secured by suitable means between the bow and stern sections. It will be appreciated that more than one container can be employed if such is desired. At the destination, container 141 can be freed from the bow and stern sections and then the bow and stern sections can be coupled together as shown in FIG. 27 for the return voyage, or the container can be folded after being unloaded as taught in previous embodiments and the empty container can be stowed in a compartment 144 in the bow section (FIG. 27) for the return voyage. Although the containers 123-125 and 141 are of a type having flexible walls, containers which meet the requirements and having rigid walls can be utilized in the embodiments employing ships 10c and 10d.

With mixed cargoes having substances of one specific gravity mixed with substances of a different specific gravity, the buoyancy of the vessel can be varied by varying the proportions of one of the substances relative to the other such that a mixture having required specific gravity is produced. To transport mineral slurries in a vessel such as 10b, the slurry should have a high enough water content so that the slurry when frozen has a specific gravity that will give the required buoyancy. Control of the buoyancy of a slurried cargo can also be affected by using a liquid having a relatively low specific gravity such as petroleum or other suitable fluid instead of water to thereby produce a slurry having a required specific gravity.

It is also a teaching of this invention to control the temperature of a frozen mass of cargo to control its buoyancy. Advantage can be taken of the decrease in density of water when it freezes and to utilize the decrease in density to attain a predetermined buoyancy. However, as was discussed previously, it is also true, with few exceptions, that most solids expand when heated and contract when cooled such that their density increases with a decrease in temperature. Even water in the solid state experiences an increase in density when its temperature is lowered. Gases in their solid state show a significant increase in density at lower temperatures. Argon, for example, which is a solid having a specific gravity of about 1.65 at -233°C, will attain a specific gravity of about 1.76 at -253°C. When various parameters such as the coefficient of volume expansion of the cargo, the fraction of displacement set aside for the ship itself, and the like are taken into consideration, it is possible to use well-known methods and calculate the temperature at which the cargo should be maintained to give a required buoy-

ancy. By lowering the temperature sufficiently it is therefore possible to impart substantially negative buoyancy to a substance like ammonia that has positive buoyancy at about its melting point, such that it is possible to tow an ammonia cargo in a submerged condition. An added benefit of increasing the density by maintaining a cargo at low temperatures is that a greater quantity of the cargo can be carried per unit volume. For example, if petroleum is assumed to have a coefficient of volume expansion of $9.6 \times 10^{-4}/^\circ\text{C}$ that is a constant at all lower temperatures, a load of 6.8 million liters of petroleum would occupy a volume of 240,000 cubic feet at 20°C. If the temperature of the petroleum is reduced to -150°C a volume of about 210,000 cubic feet would be occupied.

In this specification, the main emphasis has been on the use of frozen cargo to provide structural strength or to reinforce structure in a marine transportation system. It will be appreciated that, in addition to the lightweight tankers and carriers set forth, the invention has significant advantages when other carriers such as submarines and other vehicles are employed. It will be recognized also that the invention has utility for land vehicles and aerospace craft and the description of the carriers given should be taken as exemplary of vehicles that can be used.

The term "freezing" is used herein principally to denote the congelation of matter to the solid state by a reduction in temperature, and it should be noted that the terms "freezing" or "congealing" are also intended to cover conditions in which matter may be in an intermediate condition in which it is not in the hard, solid state but may, for example, have a waxy consistency. This invention is broadly concerned with matter that freezes at approximately the freezing point of water and below, although this is not intended to exclude substances such as benzene which has a melting point of 5.5°C or even some substances like de-sulfurized oils which may have a melting point at about 20°C or approximately room temperature. Also, although in common usage, the term "cryogenic" is usually applied to temperatures below the liquification point of methane (-182.5°C), in this specification the term is intended to encompass a temperature range of about 20°C and below.

In the construction of the ships used in this invention, it is intended that standard shipbuilding materials employed in the building of LNG and cryogenic tankers substantially be utilized throughout. It is specifically contemplated that the improvement effected in deadweight-to-displacement ratio and/or steel-to-cargo ratio be realized by using the frozen mass of cargo as a structural member and not be simply switching from conventional materials such as mild steel and using reduced scantlings by employing highly alloyed and high-strength steels or by employing light-weight metals such as aluminum. However, because of their desirable properties at ultra-low temperatures, it may be preferred to use structural aluminum alloys extensively in the construction of the cryogenic carrier of the invention.

Scantling number as employed herein is used in its commonly accepted sense and is defined as a number variously computed from a ship's dimensions, used in reference to a tabulated scheme specifying the scantlings or size of structural material such as framing or plating required to entitle a ship, according to type, to

a certain classification, or grading with respect to seaworthiness. This classifying of vessels is a function of the various Classification Societies. In this specification and in the claims, the setting forth the characteristics of this invention as permitting the use in vessels embodied therein of structure having a substantially reduced scantling number is understood to mean that a vessel strengthened by the structural mass of frozen cargo in accordance with this invention and with no compromise with respect to seaworthiness can be put into service with scantlings below those required by the Classification Societies for conventional vessels in the same service.

Although shown and described in what are believed to be the most practical and preferred embodiments, it is apparent that departures therefrom will suggest themselves to those skilled in the art and may be made without departing from the spirit and scope of the invention. I, therefore, do not wish to restrict myself to the particular details illustrated and described, but desire to avail myself of all modifications that may fall within the scope of the appended claims.

Having thus described my invention, what I claim is:

1. A method for the transportation of cargoes at least a portion of which is a fluid congealable by lowering its temperature comprising the steps of:

providing a vehicle to transport said cargoes, said vehicle having cargo space which is in structural association as an integral part with the body structure of said vehicle.

providing refrigerating means for said vehicle in thermal relationship with cargo in said cargo spaces such that at least a portion of said cargo can be congealed into a coherent mass having structural integrity;

admitting cargo into said cargo space; and

operating said refrigerating means to congeal at least a portion of said cargo by the extraction of heat therefrom whereby said congealed cargo serves as a structural member to reinforce said structure of said vehicle.

2. The method of claim 1 wherein the cargo also contributes to the buoyancy of the vehicle and wherein said cargo comprises substances whose density can be varied by a variation in their temperature whereby the operation of the refrigerating means to extract heat from said cargo is controlled selectively such that the buoyancy of said vehicle is regulated thereby.

3. The method of claim 1 wherein a heat transfer substance is interposed between the cargo and the refrigerating means, said substance having a lower freezing point and specific gravity than said cargo and being relatively insoluble therein, and wherein said refrigerating means is operated at a temperature below the freezing point of said cargo and above the freezing point of said substance whereby the extraction of heat from said cargo is through the medium of said substance.

4. A vehicle for the cryogenic transportation of cargoes at least a portion of which is a fluid congealable by lowering its temperature comprising:

a shell having cargo space;

cargo in said cargo space;

refrigerating means in a thermal relationship with said cargo space such that the operation of said refrigerating means extracts heat from said cargo to

thereby congeal at least a portion thereof into a coherent mass having structural integrity; and reinforcing means for imparting structural strength to said shell, said reinforcing means consisting of said structural mass of congealed cargo.

5. The vessel of claim 4 wherein scantlings of the shell of the vehicle are selected such as to accommodate the static and dynamic loads on said vehicle only when the cargo space therein is in the substantially empty condition and wherein the structural mass of congealed cargo strengthens the shell to thereby accommodate the static and dynamic loads on said vehicle when in other than the substantially empty condition.

6. The vehicle of claim 4 wherein said vehicle is a ship in which the strength members of the structural parts of the hull thereof comprise transverse and longitudinal framing, shellplating, decks, longitudinal and transverse bulkheads, and the congealed cargo, and wherein said congealed cargo is the principal strength member.

7. The vehicle of claim 4 wherein at least one valve means is provided to control the flow of cargo into and out of the hold, said valve means comprising a standpipe having a cargo opening thereinto communicating with cargo pumping means and an elongated cargo slot through the wall thereof opening into the cargo space, an inflatable valve member positioned in operative association with said standpipe slot, inflation means for selectively inflating and deflating said valve member, said valve member when inflated serving to close said slot when the cargo level in said space is higher than the level in said standpipe, and said valve member when deflated serving to open said slot to permit the passage of cargo.

8. The vehicle of claim 4 wherein at least a section of the refrigerating means is movably supported over the cargo to form a refrigerating tank top and wherein during the congealing operation unfrozen cargo is admitted on top of the previously admitted cargo as it congeals to thereby produce a build-up in the mass of congealed cargo.

9. The vehicle of claim 8 wherein the refrigerating tank top extends over cargo in the cargo space to form a physical separator dividing said space into a plurality of physically defined spaces.

10. The vehicle of claim 8 wherein a heat transfer substance is interposed between the refrigerating tank top and the cargo such that said tank top is maintained in a thermal relationship with said cargo but out of physical contact therewith, said substance having a lower freezing point and specific gravity than said cargo and being relatively insoluble therein, and wherein the refrigerating means is operated at a temperature below the freezing point of said cargo and above the freezing point of said substance whereby the extraction of heat from said cargo by said refrigerating tank top is through the medium of said substance.

11. The vehicle of claim 8 wherein the shell has a first cargo space and wherein the refrigerating tank top extending over cargo comprises the bottom portion of a flexible, open-ended, pouch-like envelope the edges of the open end of which are secured to the upper walls of said first cargo space such that the interior of said envelope when extended forms a second cargo space which is physically isolated from said first cargo space.

12. A method for the marine transportation of cargoes at least a portion of which is a fluid congealable by lowering its temperature comprising the steps of:
 providing a ship having cargo space;
 providing refrigerating means for said ship in thermal relationship with cargo in said cargo space such that at least a portion of said cargo can be congealed;
 admitting cargo into said cargo space, said fluid portion of said cargo comprising material whose density also can be varied by a variation in its temperature; and
 operating said refrigerating means to congeal said fluid portion of said cargo by the extraction of heat therefrom, the operation of said refrigerating means being controlled selectively to regulate the density of said cargo fluid portion such that the buoyancy also of said ship is regulated thereby.

13. A method for congealing material forming at least a portion of the contents of a vessel comprising the steps of:
 providing refrigerating means for said vessel in thermal relationship with the contents thereof such that at least a portion of said contents can be congealed, at least a section of said refrigerating means being movably supported over the contents of said vessel;

admitting uncongealed material into said vessel;
 operating said refrigerating means to congeal at least

a portion of said material by the extraction of heat therefrom;
 continuing to admit uncongealed material into said vessel on top of the previously admitted material as it congeals; and
 raising said refrigerating section as said admitted material congeals to accommodate the admission of uncongealed material whereby a buildup of congealed material from the floor of said vessel upward is produced.

14. The method of claim 13 wherein a heat transfer substance is interposed between the material being congealed and the movable section of the refrigerating means, said substance having a lower freezing point and specific gravity than said material and being relatively insoluble therein, and wherein said refrigerating means is operated at a temperature below the freezing point of said material and above the freezing point of said substance whereby the extraction of heat to congeal said material is through the medium of said substance.

15. The method of claim 13 wherein the movable refrigerating section is floatingly supported on the uncongealed material being admitted into the vessel.

16. The method of claim 13 wherein the congealed material is melted for unloading from the vessel by circulating a relatively high temperature fluid at least through the movable section of the refrigerating means.

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