

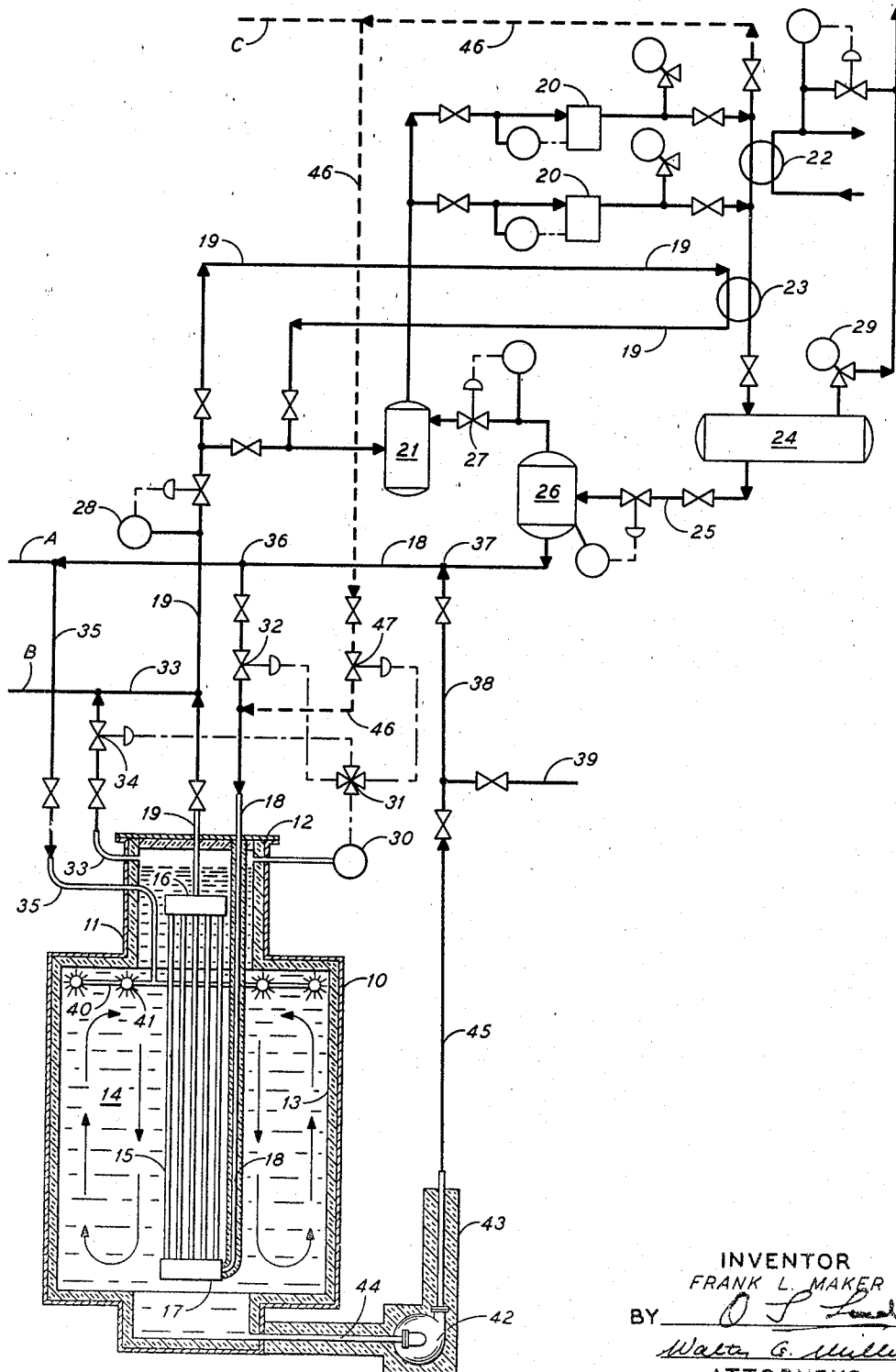
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LPG TANKSHIP REFRIGERATION SYSTEM

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LPG TANKSHIP REFRIGERATION SYSTEM

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This invention relates to the transportation of volatile liquids in insulated tanks on board ships at substantially atmospheric pressure, and specifically refers to a refrigeration system and method of operation for a plurality of tanks in such a ship whereby a minimum loss of volatile hydrocarbons is effected with a maximum degree of thermodynamic stability of the liquid in the separate tanks.

Heretofore, liquefied petroleum gases, such as methane, ethane, ethylene, propane, propylene, and butane, have been transported in ships provided with relatively small tanks and usually under a pressure substantially higher than atmospheric. Such tanks are expensive, and are generally limited to circular cross-sections for structural reasons. They are heavy and do not make economical use of the space in the ships.

If, however, the temperature of the liquefied gas is reduced to a sufficiently low value, it may be carried at approximately atmospheric pressure or within a very few pounds of it, thus making practicable cheaper and larger tanks shaped to fit the available space in the ship's hull.

This invention comprehends the provision of a system employing insulated tanks of relatively large dimensions, on the order of 40 to 80 feet wide by 60 feet long and a depth of 40 to 50 feet; and is particularly directed to a system of refrigeration and methods of operating it which will not only maintain these tanks in a stable condition thermodynamically, but will also insure a minimum of loss of volatile products while the ship is passing through tropical or semitropical latitudes. Generally, a single ship will utilize from 10-20 of such tanks, and they will normally be interconnected so that all tanks containing the same product will be served by a common vapor recovery system. These conditions may be maintained by a suitable vapor recovery compression and refrigeration system utilizing the liquid petroleum gas of the cargo as a refrigerant in an open system or in a closed system, or another suitable refrigerant in a closed system.

There are numerous important engineering and safety problems involved in such tankships. These include, among others, the prevention of excessive evaporation rates with change of barometric pressure, the maintenance of predetermined levels of liquids in the tanks, the maintenance of the original composition of the liquids in the tanks, particularly where multi-component mixtures such as propane and butane or the like are being handled, the prevention of intake of atmospheric air and resultant formation of explosive mixtures with changes of atmospheric temperature or barometric pressure, the maintenance of the entire liquid contents in a thermodynamically stable condition, and the reduction of temperature variations in the tank shell, thereby to prevent structural deformations. These will be discussed separately and in further detail below.

One of the objections heretofore raised to the utilization of tanks in this service and of the dimensions stated is the difference in thermodynamic properties of the liquid at the top and at the bottom of the tank due to the hydraulic head of LPG therein. The LPG is at or near

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its boiling point under the conditions of transportation, so that thermal differences or instability between the upper and lower portions of the tank may lead to excessively large and rapid release of vaporized product under conditions which will be discussed below.

A further problem in the transportation of LPG is that of changes in barometric pressure which may occur between the time the liquid is first loaded on the ship and finally discharged therefrom. Changes in barometric pressure of only one or two inches of mercury, which are not uncommon within a period of a few days, will affect drastically the vaporization rate of the LPG substantially independently of the rate of heat leakage through the insulation into the contents of the tank, and in the absence of the methods and means described herein, might require a much larger capacity of the vapor compressing and condensing system than is considered economical. One feature of this invention which will be discussed below is the step of maintaining the vapor space of the LPG tanks at a predetermined absolute pressure which will in general be sufficiently above the normal variations in atmospheric pressure so that there will be no tendency to expel vaporized product to the atmosphere or to draw in atmospheric air to contaminate the LPG vapors in the tank and refrigeration system.

It is an object of this invention to provide an improved method of transporting liquefied gases and particularly petroleum gas (LPG) illustrated, in this example, by the group consisting of ethane, propane, and butane. It could also include other and more complex hydrocarbons, e.g., ethylene, propylene, butene, isobutene, butylene, and butadiene. These may either be substantially pure hydrocarbon fractions or may be mixtures of two or more of them. As illustrative and not restrictive examples, in this application optimum conditions for transporting pure propane, as well as a mixture of propane and butane, will be discussed in some detail.

Another object is to provide a system for maintaining thermodynamic stability in large tanks of LPG under changing conditions of the motion of the ship and of external temperature and pressure variations.

Another object is to provide an improved method of maintaining low temperatures in an interconnected system of large tanks, particularly in a tankship transporting liquefied gas such as LPG in waters which may approach 90° to 95° F., and at atmospheric temperatures over 100° F.

Another object is to provide an improved method of introducing, as well as discharging LPG into a system of interconnected tanks of the kind described, whereby atmospheric contamination will not result and a minimum of vaporized product will be required to be handled by the loading and storage facilities, as well as by the tank refrigeration system.

These and other objects and advantages will be further apparent from the following specification and from the attached drawing, which illustrates a preferred embodiment of means for practicing the invention as applied to a tankship conveying liquefied petroleum gas. The drawing is a diagrammatic and part vertical sectional view of a refrigeration system and a single tank connected thereto.

In the drawing:

Reference numeral 10 designates the outer shell of a steel tank provided with an upward extension or trunk 11 and closed by a vapor-tight cover 12. Insulation 13 forms a lining for the entire structure and is designed to minimize the flow of heat to the LPG contents 14 within the tank, which would cause undesired evaporation of the very volatile material. In this example, the insulation is within the shell, but alternatively may be outside of it, without affecting the operation of the invention.

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Assuming that the tank contains substantially only liquefied propane, the boiling point will be about -6.53°F . at 2 pounds per square inch above atmospheric pressure. To maintain this temperature, heat which unavoidably enters the tank from the atmosphere or the ship's structure must be substantially continuously abstracted from the liquid 14 within the tank. In this example, a cooler comprising a plurality of vertical tubes 15, which may be finned on their outer surface to increase the rate of heat transfer, extends from an upper header 16 to a lower header 17 mounted in the approximate center of the tank, for reasons which will be pointed out in further detail below.

An insulated conduit 18 connected at its lower end to header 17 extends through the cover 12 from the outlet of a closed circulating refrigeration system which will be described presently. A propane vapor conduit 19 leads from the upper header 16 through cover 12 to the inlet of the same refrigeration system. This system, in this example, consists essentially of one or more vapor compressors 20 which take suction from a vessel 21 into which conduit 19 discharges propane vapor from the tubular cooler 15 in tank 10. The outlet from the compressors leads through a condenser 22 and, if desired, through a heat exchanger 23 to a condensate receiver 24, the latter being maintained, for example, at a pressure of about 180 p.s.i.g. at 100°F . From the receiver the condensed liquid propane passes through a pressure reducing valve 25 to a flash drum 26, the latter maintained at about atmospheric pressure, wherein the partial evaporation (about 20%) of the propane under that pressure will cause the temperature of the remaining liquid propane to be reduced to about -44°F . This liquid is returned through conduit 18 to the lower header 17 of the cooler 15 in tank 10 to absorb heat from the LPG 14 contained therein at about -36°F .

The vaporized product from flash drum 26 returns through the pressure control valve 27 to the suction vessel 21 and is recirculated to compressors 20. Desirably, a pressure control valve 28 is provided in conduit 18 leading to the suction vessel 21 to stabilize the operation of this system. Uncondensable gases which may accumulate in receiver 24 may be vented through a pressure control valve 29 to a vent stack, not shown, or to some location where they may be burned, for example, as fuel in the boilers of the propulsion machinery for the ship. The usual control valves for the conduits and equipment just described are conventional in vapor recovery systems, and hence, require no specific identification or description herein.

As stated above, the cooler comprising vertical tubes 15 in tank 10 is centrally mounted in that tank for reasons which will now be discussed. Assuming the pressure at the top of the tank 10 filled with pure propane is 15.8 p.s.i.a. corresponding to 32 inches of mercury barometer, with a total depth of liquid of 52 feet, the pressure at the bottom of the tank will be 10.4 p.s.i. higher than the top, or 26.2 p.s.i.a. The heat that unavoidably leaks into the tank 10 through insulation 13 tends to raise the temperature of the propane in contact with the insulation. If the heat leakage is very large there will be boiling on the surface of the tank, but with the desired economical rate of heat leakage, evaporation from the quiescent surface on top of the liquid will normally take care of it without actual bubble formation.

The effect of the hydrostatic head of liquid is to increase the pressure in the bottom of the tank, and at the higher pressure, which is about 10.4 p.s.i. greater at the bottom than at the top, a higher temperature is required to cause actual boiling or ebullition. From the vapor pressure charts it can be computed that 1 p.s.i. additional pressure in this region raises the boiling point of propane about 2.86°F . This means that the boiling point of the liquid under pressure at the bottom is about 30°F . higher than at the surface. Consequently, there is little likeli-

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hood of ebullition or boiling near the bottom of the tank for moderate rates of heat input. Thermal or convection currents that may be present are therefore entirely due to expansion of the liquid without any additional lift that might be caused by vapor bubbles along the side walls near the bottom and are, therefore, of rather small magnitude. Thus, it is possible for the liquid at the bottom to become heated several degrees higher than that corresponding to the boiling temperature at the surface. As a result of this, there may be an excess amount of heat stored in the liquid at the bottom of the tank as compared to that in the upper portions. If there were no vertical circulation, the average material in the tank, by the time the material at the bottom reached its boiling point, would contain about 13.2 B.t.u. per pound more than the liquid at the top, or in the total tank contents there would be an excess of about 40 million B.t.u.

Normal rolling and pitching motion of the ship will tend to roll this mass of liquid, bringing some of the hotter material that was near the bottom to the top of the tank. Thus, there could be evaporated suddenly and violently as much as 8-10% of the entire liquid contents, which would greatly increase the pressure in the tank and cause it to overload any feasible pressure relief facilities that might be provided.

To insure that a temperature gradient as just described cannot be set up in tank 10, the cooler comprising vertical tubes 15 is positioned vertically and in the central portion of tank 10. The abstraction of heat from the LPG 14 in the tank in this central portion will increase its density and cause it to induce a central downward circulation by its settling toward the bottom of the tank 10, which will in turn induce an upward circulation around the periphery of the tank, as indicated by the arrows.

This will be facilitated by the fact that it will be possible to get a substantially greater temperature difference between the cooling tubes 15 and liquid 14 than between the liquid and the tank walls.

Thus, the colder portion of the liquid in the tank will always be at the bottom, so that the unstable thermodynamic condition just described cannot be initiated or at least maintained. The net result will be that a much smaller refrigeration system can be used and also that there does not need to be provision for rapid vapor release from the tank 10 to the atmosphere, as will also be pointed out in further detail below. In other words, the tank can be completely closed and maintained in that condition during transportation of the LPG as well as during the filling and emptying operation.

If the usual vapor pressure and vacuum relief valves were to be provided on tank 10, these valves being responsive to the pressure differential between the vapor inside of the tank and the atmosphere, and if the ship should be loaded at a time when the barometric pressure is relatively high, and there should thereafter be a lowering of atmospheric pressure, this would lower the pressure within the tank. Because the tank had been loaded with LPG substantially at its boiling point under the higher barometric pressure, a reduction in the latter and consequently the pressure within the tank would cause the LPG to boil, because it would then be at a temperature above its boiling point for the new and lower pressure. The heat to cause this vaporization would come from the sensible heat of the fluid and would ultimately result in cooling the contents of the tank to be in equilibrium with the lower pressure. A tank of the size contemplated would hold about 3 million pounds of liquid propane which, at this temperature, has a specific heat of about 0.87 B.t.u. per pound per degree F.

A barometric pressure drop of 2 inches of mercury in the course of 24 hours would thus lower the tank pressure about 1 p.s.i. which, to insure subsequent vapor pressure equilibrium, would require a reduction in temperature of 2.86°F . of the entire tank contents. This would

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require the evaporation of almost 2% of the liquid content of the tank and would be at the rate of approximately 28,000 pounds per hour. Additionally, if this quantity were to be vented to the atmosphere a substantial loss of valuable product would result.

This loss can be prevented and the cost of the refrigerating equipment kept to only the nominal value required by the heat leakage through the insulation by maintaining the pressure within the system substantially constant at about 16.8 p.s.i. absolute. Pressure controllers including means independent of atmospheric pressure, e.g., a sealed constant pressure chamber, are available for this service. In the absence of such a pressure controller responsive to absolute pressure, a subsequent rise of barometric pressure in the usual tank venting system responsive to atmospheric pressure would result in having the tank contents at a lower temperature corresponding to the new pressure. This would mean that the partial pressure of the vapor in the extension 11 of tank 10 would be less than atmospheric, and unless a provision were made to prevent entrance of air, some air would be drawn into the tank and would contaminate the vapor therein.

To maintain the absolute pressure within tank 10 at a constant value, there is illustrated an absolute pressure controller 30, which may be of the type described and which includes a control selector valve 31 adapted to control the refrigerating fluid inlet valve 32 in conduit 18 which supplies the refrigerating propane to the vertical tubes 15.

Before equilibrium conditions as outlined above are established and to supply vaporized propane to the refrigerating system comprising compressors 20, cooler 22, receiver 24, and flash drum 26, a vapor outlet conduit 33 communicates with the upper portion of tank extension 12 and is provided with a pressure controller valve 34 also responsive to the selector 31 of absolute pressure controller 30, to admit vapor to conduit 19, which is the inlet conduit to the refrigerating system.

For initially filling tank 10 with LPG, an inlet conduit 35 is provided, connected at 36 to conduit 18 which leads from the flash drum 26 of the refrigeration system into the cooling tubes 15. At 37 conduit 18 is connected to a conduit 38, which in turn communicates with a filling and emptying conduit 39, leading from shore tanks or other sources of LPG (not shown). Within the upper portion of tank 10 at the outlet end of conduit 35 is a header 40 desirably provided with spray nozzles 41. During the course of filling tank 10 from the charging conduit 39 through conduits 38 and 35, the initially cold liquid LPG, in this example, propane, is sprayed against the inner wall of tank 10, which will induce a certain amount of evaporation to withdraw the heat contained in those walls. Vapor from this evaporation will be withdrawn through conduit 33 under the control of regulator 34 to the compressor inlet conduit 19, after which it will be condensed by the refrigerating system mentioned above and returned through conduit 18 either to the cooling tubes 15 or through conduit 35 to mingle with the incoming LPG being charged into tank 10. Meanwhile, the absolute pressure within the system will be maintained by controller 30 actuating regulators 32 and 34 as outlined above.

As shown diagrammatically in the drawing, a pump 42, indicated as being adequately insulated as at 43, communicates with the bottom of tank 10 by means of conduit 44 and is adapted to discharge liquid LPG through conduit 45. In actual practice, and to conform to certain rules such as U.S. Coast Guard regulations, pump 42 would normally be submerged in a sump in tank 10, e.g., that illustrated below header 17, and driven by an elongated shaft extending downwardly through appropriate packing into the tank. For simplicity of illustration this has been distorted to show the pump at one side of the tank as shown. When the tank is being emptied, the valves illustrated are set so that the liquid

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LPG is discharged through conduit 39 to whatever shore storage facilities are available.

As the liquid LPG 14 is discharged from tank 10, the closed space above it must be replaced by propane vapor.

The heat to evaporate this vapor must come from the body of liquid in the tank, unless other means are provided. When the tank is nearly full, there is a large supply of LPG to supply the heat, but, as the level lowers, the amount of liquid is naturally reduced. Consequently, the temperature of the liquid will tend to drop more and more rapidly as the tank is emptied. To add heat to the remaining LPG, it is desirable to circulate a warm material through tubes 15. In this example, warm compressed propane vapor from the discharge of compressors 20 may be passed through conduit 46 and regulator 47 to conduit 18 and tubes 15 under the control of selector valve 31, which is in turn actuated by the absolute pressure controller 30. This will continue to maintain the absolute pressure within tank 10 at a constant value during the liquid propane discharging operation.

Although only a single tank is illustrated, it is apparent that the refrigeration, charging and emptying system could be manifolded to additional LPG tanks in the same ship. For example, the tank filling conduit 35, which communicates with refrigerated liquid return line 18, could communicate at A with additional LPG tanks (not shown) also controlled by absolute pressure controllers 30. Vapor outlet line 33, which is similarly controlled by absolute pressure controller 30, could be manifolded at B with similar connections to additional tanks (not shown). Also, the heated gas line 46 from the discharge of compressors 20 could similarly communicate at C with conduits 18 of other tanks (not shown).

Although the foregoing example illustrates the system and method applying to an LPG which is entirely propane, it is apparent that mixtures of propane and butane, as well as other light hydrocarbons, may also be handled. For example, if the liquid content of tank 10 is a mixture 30% propane and 70% butane, its boiling point will be about 0° F. at substantially atmospheric pressure or, as is contemplated herein, an absolute pressure of 1 or 2 p.s.i., above that value.

Due to the partial pressures of the two components of this material, vapor withdrawn from the space above the liquid in tank 10 through conduit 19 will contain more propane and less butane than the liquid from which it comes. In this particular case, the vapor would consist of about 70% propane and 30% butane. When this vapor is passed through compressor 20, compressed to about 180 p.s.i. and condensed at approximately 100° F., it will be reduced to a liquid state. Expansion of this liquid in flash drum 26 will cool the liquid to about -33° F. and about one-fourth of it will flash to vapor, which can be recycled to the suction vessel 21. The resulting liquid coming from flash cooler 26, to be returned either to tank 10 or to the cooling tubes 15, will be the same composition as the vapor originally evaporated from the tank, namely, 70% propane and 30% butane, and this will have a boiling point at 1 atmosphere pressure of -33° F. The vapor from this flashed material that goes back to the suction compressor will contain about 91% propane and 9% butane.

For the mixture described there will be enough temperature difference in the cooling coil 15 so that it will not be necessary to operate the suction drum 21 for compressors 20 at sub-atmospheric pressure, as may be required for some pure liquids.

Generally speaking, it is not desirable to return this liquefied material directly to the liquid 14 in tank 10, because of its lower temperature than that in tank 10. It will immediately start to boil off the excess proportion of propane it contains, and will thus agitate the entire contents of the tank. For this reason it is contemplated that such condensed material will be returned to cooling tubes 15 and recirculated in a closed circuit to

the refrigerating system comprising the compressors 20 and associated cooling and condensing chambers 22, 23, 24 and 26.

One of the problems involved, if the vapors formed by heat leakage are released in the main tanks and are taken to the compressors of a central compression system is that of returning to each tank the same amount of liquid that left it in vapor form, to maintain its liquid level. It would be difficult to provide liquid level controllers for this redistribution that would be dependable under the conditions of movement in the sea.

This problem becomes more complex if the liquid is a mixture of several components. In this case the composition of the vapor is not the same as that of the original liquid, and will not necessarily be the same from all of the tanks. It would be very difficult to insure that each component of the mixture would be returned to each tank in the same amount that leaves it in vapor form.

With the separate cooler shown, the surface of the liquid will be maintained at the boiling point of the liquid at the pressure that has been fixed, while the bulk of the tank will be below this temperature. There will therefore be an equilibrium, with no vapor to be removed from the tank, but only from the closed system, of fixed composition. This eliminates the problem of returning to tanks exact amounts and/or compositions the same as the vapor removed, since no vapor will be removed.

In conclusion, it will be appreciated that there are disclosed herein improved methods of filling, transporting, and emptying liquefied petroleum gas (LPG) chosen from the group consisting of methane, ethane, propane, and butane and similar hydrocarbons in refrigerated tanks maintained at a constant absolute pressure which is slightly above normal variations of atmospheric pressure. An arrangement is also disclosed of a closed circuit refrigerating system, desirably supplied from product evaporated during the transporting, loading, or emptying of these tanks.

Although specific examples have been given of operating conditions, it is apparent that numerous changes and modifications could be made without departing from the essential features of the invention and all such methods that come within the scope of the appended claims are intended to be embraced thereby.

I claim:

1. In the bulk tank method of transporting refrigerated liquefied petroleum gas at substantially atmospheric pressure and at temperatures below about 0° F. to -40° F., in tanks having substantially vertical side walls the steps of minimizing the temperature difference between the upper and lower portions of the liquid by withdrawing vaporized product from the top of the tank above the liquid therein, condensing it to liquefied form at super-atmospheric pressure, cooling it by reducing its pressure to substantially atmospheric, separating the cooled liquefied portion, and passing said last-named portion in indirect heat exchange relation to the central portion of the liquid in said tank to induce downward circulation in said central portion and upward circulation along side walls in the peripheral portion of said tank.

2. In the bulk tank method of transporting refrigerated liquefied gas without further vaporization thereof, comprising the steps of circulating a refrigerant along the central vertical axis of said tank without mixing with liquid therein to maintain the temperature of the liquid at the bottom of said tank lower than that at the top thereof, providing an interface level in said tank between liquid and vaporized gas, detecting the absolute pressure in said vaporized gas, and maintaining said pressure at a predetermined absolute value according to said detector response.

3. In the bulk tank method of transporting a mixture of refrigerated liquefied gases comprising the steps of withdrawing a volatilized product differing in composi-

tion from that in the tank, compressing and condensing said withdrawn product to liquid state, flashing said last-named liquid to reduce substantially the percentage of the more volatile constituent in said liquid so that said liquid will have substantially the same composition as the liquefied mixture in the tank, and circulating said flashed liquid through said refrigeration system out of direct contact with the liquefied gases in said tank and at a temperature lower than the temperature of liquid in said tank to reduce evaporation of said original liquefied gases therein.

4. In the bulk tank method of transporting refrigerated liquefied petroleum gas at substantially atmospheric pressure and at temperatures below from about 0° F. to -40° F., the method of minimizing the temperature difference between the upper and lower portions of the body of liquefied petroleum gas during transport by the steps of withdrawing a limited portion of the vapor from said liquefied petroleum gas for use as a refrigerant, injecting said refrigerant into a substantially closed refrigeration loop which includes a heat-absorption zone comprising a tube bundle extending substantially vertically throughout the central portion of said bulk tank, and flowing said refrigerant from the lower portion of said tank to the upper portion of said tank to induce downward circulation in said central portion and upward circulation in the peripheral portion of the liquid in said tank substantially without modification of said liquefied petroleum gas by the portion thereof circulating as refrigerant.

5. In the bulk tank method of transporting refrigerated liquefied petroleum gas at substantially atmospheric pressure and at temperatures below from about 0° F. to -40° F., the method of minimizing the temperature difference between the upper and lower portions of said liquefied petroleum gas during transport by the steps of providing a vapor space above said liquefied petroleum gas in said tank, withdrawing vapor from said space for use as a refrigerant, introducing said refrigerant into a circulating system including a laterally restricted central portion through said tank and closed to said vapor space to prevent mixing of said refrigerant with the liquefied petroleum gas in said tank, the direction of circulation of said refrigerant being such as to induce downward circulation of said liquefied petroleum gas in said central portion and upward circulation in the peripheral portion of said tank, and controlling the rate of circulation of said refrigerant in accordance with a predetermined absolute pressure in said vapor space, said absolute pressure being not more than about two pounds p.s.i. higher than but independent of atmospheric pressure.

6. In the method of transporting refrigerated liquefied gas in bulk tanks at substantially atmospheric pressure the steps of providing a vapor space above the liquid in said tank, circulating a portion of said liquefied gas to prevent the temperature at the bottom of said tank substantially exceeding that at the top thereof, said circulating including withdrawing a part of the vapor from said space, compressing and condensing said vapor and continuously circulating said condensed vapor in indirect heat exchange with the liquid in said tank from the bottom of said tank upwardly through a central portion thereof without mixing with said liquefied gas in said tank, whereby the temperature of the liquefied gas at the bottom does not exceed that at the top, and varying the rate of circulation of said condensed vapor in accordance with the absolute pressure in said space.

7. In the bulk tank method of transporting refrigerated liquefied gas, the method of maintaining the pressure in said tank at a substantially constant absolute value independently of and higher than atmospheric pressure while said tank is being emptied which comprises the steps of heating a portion of the vapors of said liquefied gas, withdrawing substantially, but not entirely, the liquid contents of said tank from the lower portion thereof, while simultaneously circulating said heated vapor in

heat exchange relation to the remaining liquid contents
in said tank, and controlling the rate of circulation of
said heated vapor to maintain substantially constant the
pressure in said tank at said absolute pressure value
and independently of the rate of withdrawal of said liq- 5
uid contents.

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