METHOD OF HANDLING NATURAL GAS

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This invention relates to the containment and handling of natural gas hydrocarbon mixtures and, more particularly, to a method and apparatus for loading and unloading pressure vessels with a natural gas hydrocarbon mixture while maintaining it in a single-phase state of moderate refrigeration and compression. The inventors, employees of The Lumms Company, made the invention while engaged in development work undertaken by that organization in techniques of natural gas transportation.

In many populated areas throughout the world the demand for natural gas is increasing at a far greater rate than the supply available from pipelines. The industry is responding to this by intensive development in techniques for transporting natural gas by ship so that regions of increased demand remote from sources of supply need not rely solely on pipelines. One of the more important advances in this field has been the concept of maintaining the natural gas cargo mixture in a single-phase state of moderate refrigeration and compression throughout the voyage from the first of the loading steps to the completion of loading. The method generally involves refrigerating the gas but not to the very low cryogenic temperatures characteristic of LNG processes, and compressing the gas but not to the very high pressures characteristic of static storage processes at ambient temperature. By the use of moderate refrigeration and compression, advantage is taken of optimum processing costs per unit of gas transported so that the natural gas cargo can be delivered by ship more economically than by other methods.

It is a primary purpose of the present invention to provide a method and apparatus for carrying out the actual loading and unloading operations for natural gas cargo mixtures maintained in the optimum state of moderate compression and refrigeration described above. One of the most important objectives is to insure that the cargo mixture does not depart substantially in pressure or temperature from that operating state at any time during loading and unloading. A further object is to permit of substantially continuous loading and unloading of a ship without significant interruption so that, if desired, the cargo mixture may be directed immediately into pipelines at the dockside facilities to the regions of demand. To achieve this uninterrupted displacement of the cargo, the new method and apparatus are adapted specifically to successive loading and unloading of one ship after another without significant idle time at the ports of embarkation and destination. All of these objects and several others which will be made clear hereinafter, are to be attained under conditions of strict safety and cost control.

Broadly stated, the new method of handling a hydrocarbon mixture is a plurality of pressure vessels in series is applicable both to the loading and the unloading thereof while the mixture is maintained in a single-phase refrigerated and compressed operating state. In loading the pressure vessel means, a cushion fluid is forced into the first pressure vessel means at a regulated temperature until it is filled at substantially the operating pressure of the hydrocarbon mixture. The hydrocarbon mixture is then forced into the first pressure vessel while the cushion fluid is expelled therefrom at a regulated flow rate so that said first pressure vessel means is filled with the hydrocarbon mixture. Thereafter, the expelled cushion fluid is directed into the next pressure vessel means in the series and it is filled with the hydrocarbon mixture by the foregoing steps. The process is repeated in succession until all of the pressure vessel means are filled with the hydrocarbon mixture in the operating state and the cushion fluid is expelled from the last pressure vessel means. In unloading the pressure vessel means by the new method, a displacement fluid at a pressure greater than the operating pressure of the hydrocarbon mixture is forced into the first pressure vessel means while the hydrocarbon mixture is expelled therefrom at a regulated flow rate so that the first pressure vessel means is emptied of the hydrocarbon mixture and filled with displacement fluid. Thereafter, the displacement fluid is directed into the next pressure vessel means in the series to empty it of the hydrocarbon mixture by the foregoing step and the process is repeated in succession until all of the pressure vessel means are emptied of the hydrocarbon mixture and filled with displacement fluid. Finally, at least part of the displacement fluid is removed from all the pressure vessel means in succession.

For carrying out this method, the invention also provides apparatus for handling the hydrocarbon mixture maintained in the single-phase refrigerated and compressed operating state. The apparatus includes a multiplicity of pressure vessel means each including first and second access conduits communicating with the lower and upper regions respectively thereof and means for separately controlling the flow of fluids through each of the access conduits. First and second sub-headers interconnect the first and second access conduits respectively of all of the pressure vessel means. A main header system is included which comprises first main header means interconnecting all of one of the two sub-headers. Second main header means are also included interconnecting all of the other sub-headers.

Preferred embodiments of the method and apparatus of the invention are described hereinafter with reference to the accompanying drawings, wherein

FIG. 1 is a pressure-temperature phase diagram illustrating the limits generally contemplated for the operating state of the hydrocarbon mixture;

FIG. 2 is a schematic layout of a three-header system, including shipboard and dockside facilities, for loading the cargo mixture by gas displacement;

FIG. 2A is a fragmentary schematic layout of dockside facilities to be associated with the shipboard facilities of FIG. 2 for unloading the cargo mixture by gas displacement;

FIG. 3 is a schematic layout of a six-reader system, including shipboard and dockside facilities, for loading the cargo mixture by gas displacement;

FIG. 3A is a fragmentary schematic layout of dockside facilities to be associated with the shipboard facilities of FIG. 3 for unloading the cargo mixture by gas and liquid displacement;

FIG. 4 is a schematic layout of a four-header system, including shipboard and dockside facilities for loading the cargo mixture by liquid displacement;

FIG. 4A is a fragmentary schematic layout of dockside facilities to be associated with the shipboard facilities of FIG. 4 for unloading the cargo mixture by liquid displacement.

THE CARGO MIXTURE

Various natural gases are suitable for use with the method and apparatus of the invention. In general, they
may be described as hydrocarbon gas mixtures containing at least 30 mol percent methane and at least 75 mol percent methane-plus-ethane, the remaining being heavier hydrocarbons. The second access conduits 15, 15a, and 15b are provided with the respective upper and lower limits of the various bottles to control the flow of fluids into and out of each bottle at a predetermined rate. The contractions generally vary in size from one bottle to the next in accordance with variations in the size of the bottles and other factors, so that the bottles of relatively large capacity have relatively large contractions and high flow rate. The object of the flow-control contractions is to assure that all of the bottles in each battery are filled or emptied substantially simultaneously when subjected to the same fluid pressure in their respective second access conduits. Each contraction may be defined by a plate in the appropriate passage with a round orifice formed in it of a size which may be calculated in accordance with theories of fluid flow well known in the art.

In each of the respective batteries, first sub-headers 17a to 17h and second sub-headers 18a to 18n interconnect the first and second access conduits 12a to 12h and 13a to 13h, respectively, of the bottles. Each sub-header may be disposed laterally in the ship over the tops of the bottles in the respective batteries. The system also includes a board on the ship a first main header 20 interconnecting all of the first sub-headers 17a to 17h for conveying the cargo mixture into and out of the bottles. First valves 21 to 21h are located at the respective interconnections between the first main header 20 and the first sub-headers 17a to 17h. A second main header 22 interconnects all of the first sub-headers 17a to 17h through second valves 23a to 23h, in a similar manner. Finally, a third main header 25 interconnects all of the second sub-headers 18a to 18n through third valves 26a to 26n. The function of dotted line 27 and third main headers 22 and 25 is to convey cushion and displacement gas into and out of the bottles. Conventional detection means 27a to 27h and 28h to 28n are located adjacent the bottle-side of the respective first and second valves 21, 21h and 26h to 26n to recognize and respond to the arrival of an interface between differing fluids from the bottles of their respective batteries. By interface is meant a sharp or gradual change in the recognizable properties, composition or other characteristics of the fluid passing the detection means. Such detection means, which are commercially available, may operate the various valves in the manner described by the other characteristics of the fluid system. Also, it will be apparent from the description of the operation below that one detection device may suffice at the end of each main header 20, 22 and 25 where they are attachable to shore facilities.

FIGURE 2 SYSTEM

In FIGS. 2 and 2A, a system is illustrated for loading and unloading a cargo mixture by gas displacement. It is particularly suited to a cargo mixture maintained at an operating temperature below the cricondenbar point C, the mixture is less dense and may therefore be handled easily in a manner as described hereafter. At temperatures in the operating range between the critical point B and the cricondenbar point C it may be possible to handle the mixture in accordance with any of the techniques discussed hereafter.

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residual gaseous mixture in its bottles at a moderately high pressure, perhaps between 100 and 300 p.s.i.g. The temperature of the bottles will be at about the level of the refrigerated cargo mixture carried in the previous voyage, for example —50° F., if adequate insulation surrounds them in the hold of the ship. The system is linked to the dockside facilities by the conduits 35, 36 and 37 as shown in FIG. 2. A source of the cargo mixture is in the operating state ready for loading through the header 41. In the header 43 a supply of cushion gas is available at about the operating state pressure of the cargo mixture and at about ambient temperature. The cushion gas usually is less dense at substantially the pressure and temperature of the cargo mixture operating state. The cushion gas is advantageously a leaner natural gas mixture than the cargo mixture but otherwise similar to it in composition or it may be hydrogen, nitrogen or some other gas quite different from the cargo mixture.

At the beginning of the loading cycle, all the shipboard valves 21a to 21m, 23a to 23p, and 26a to 26q are closed and all the other valves 29 to 31, 44 to 46, 49, 53 and 54 are open. Cushion gas proceeds from its source through the header 43 and the by-pass conduit 48 into the header 42 and the second main header 22. To start the cycle the second valve 23, in the first battery 11, is opened. Valve 23 opens the path from the header 43, the by-pass conduit 48, the header 42, the conduit 36 and the second main header 22. Passing through the open valve 31a, the cushion gas proceeds into the first sub-header 17a to enter all of the first access conduits 12a of the various bottle in battery 11a. The cushion gas flows into the bottom region of each bottle 10a in this manner and proceeds to fill the respective bottles. Since the pressuring medium is a gas, the flow is automatically distributed correctly with more flow going to the larger bottles so that all of the bottles 10a approach capacity at substantially the same time. As the pressure, in the bottle 10a increases, heat of compression causes the cushion gas temperature to rise. The temperature of the bottle walls will rise but at a much slower rate since heat transfer under such conditions is relatively poor. In order to have the cushion gas enter the bottle 10a at the optimum temperature, i.e., perhaps about the refrigerated temperature of the operating state of the cargo mixture, it may be desirable to pass all or part of the cushion gas through the heat exchanger 52 before it enters the ship instead of solely through the by-pass conduit 48. When the pressure of the cushion gas in battery 11a has been raised to slightly less than the operating state pressure of the cargo mixture, for example 950 p.s.i.g., the second valve 23a and the by-pass valve 49 are closed while the second valve 23p, the third valve 26p, and the first valve 21a are open, since the requisite amount of cushion gas has been put into the system. The cargo mixture, in an operating state of 1000 p.s.i.g. and —50° F., for example, therefore begins to enter the ship from the header 41 through the flexible conduit 35 and into the first main header 20. It proceeds through the open valve 21a into the first sub-header 17a and hence into the bottom region of the various bottles 10, of battery 11a through their respective access conduits 12a. As the dense cargo mixture enters the bottom of the bottles through the first access conduits 12a, the compressed cushion gas is forced out of the top of the bottles in the battery 11a through the respective constrictions 15a and second access conduits 13a into the sub-header 18a. The constrictions 15a prevent the cushion gas from escaping from the small bottles in the battery 11a as fast as it is displaced by the dense cargo mixture. The rate of flow of the dense cargo mixture entering the bottom of the bottles. By suitable correlation of the size of the constrictions 15a to the volume of the respective bottles, it can be assured that the bottles 10a in the battery 11a are all filled with the dense cargo mixture at the same time.

The cargo mixture entering the bottles 10a forces the cushion gas out through the second sub-header 18a and into the third main header 25 through the open valve 26a. Since all of the third valves 26a to 26q are closed, the cushion gas proceeds along the third main header 25 through the valves 31a and 45a and into the header 43 where it started from in the shore facilities. The header 43 is otherwise closed off from the source of cushion gas (not shown) so that the cushion gas can continue on its way only through the by-pass conduits 48 or 51. The by-pass valve 49 may be closed so that the cushion gas passes through the pressure control valve 54 which holds back a pressure on the first battery 11a, and thereby maintains the pressure of the cargo mixture entering the bottles 10a of that battery at a constant level.

If the cushion gas were delivered directly into the bottles 10a of the next battery 11a in its compressed and therefore warm state, the cushion gas would be heated still further by heat of compression. When the pressure in the battery 11a rises, the temperature could eventually become excessively high. Therefore, it is desirable for the cushion gas to enter each battery at as low a temperature as practical so that it will not become any warmer than necessary after it is compressed. The cushion gas is too cold when it enters a battery it might chill portions of the bottles thereof to such a low temperature that the bottle walls would lose their ductility. To guard against these dangers, the cushion gas is passed through the heat exchanger 52 before it is sent back through the header 42 and the valves 45 and 30 into the second main header 22. If the expansion of the cushion gas as it leaves the second control valve 53 cools it to too great an extent, a portion of the cushion gas upstream from the heat exchanger can be drawn off by the by-pass valve 49 through the by-pass conduit 48 to mix with the cooled cushion gas passing through the header 42 back into the second main header 22. Alternatively, the passage of the cushion gas through the first control valve 54 before entering the heat exchanger 52 may eliminate any expansion cooling after the gas leaves the heat exchanger 52. With these alternatives available, either one of the two control valves 53 or 54 can suffice in a given installation without including both of them.

Since the second valve 23a has been opened previously, the cushion gas at its regulated temperature proceeds from the second main header 22 into all the bottles 10a of the battery 11a through the respective first access conduits 12a, thereof to fill the second sub-header 18a in the manner that it had previously filled the first battery 11a. As soon as all of the bottles 10a in the first battery 11a, are filled with the cargo mixture as described, the interface between the denser cargo mixture and the lighter cushion gas reaches the detection device 28a. When this occurs, the detection device automatically closes the first valve 21a and third valve 26a in the battery 11a and opens the first valve 23a to direct the cargo mixture into the second battery 11a without interruption. The detection device 28a, also closes the second valve 23a, and opens the second and third valves of the third battery (not shown) and the third valve 26a of the second battery 11a. All of the bottles 10a in the battery 11a are filled in precisely the same manner as were the bottles 10a in the previous battery 11a. This continues throughout the ship as one battery after another is filled with the cargo mixture.

Since there was some gas in each battery when the ship arrived at the loading port and this gas is completely displaced by the dense cargo mixture, some of it must be bled off. This could be done by removing the gas either through the header 43 before the heat exchanger 52 or through the header 42 after the heat exchanger. It could be removed either continuously throughout the loading
cycle or at the end of the loading cycle after the pressure of the cargo mixture in the bottles has become as high as desired. As the last battery 11a on the ship is being filled with the cargo mixture, the cushion gas leaves through the second sub-header 18a, the third valve 26a, the main header 25, the valves 31 and 46, and the heat exchanger 52 as before. However, instead of returning to the ship, the detection device 26a, in the last battery has the additional function of closing the valve 46 so that the cushion gas exits through the header 42. The header 42 may direct the cushion gas to the next ship or at the end of the loading cycle after the pressure of the cargo mixture in the bottles has become as high as desired. The third valve 26a, the main header 25, the valves 31 and 46, and the heat exchanger 52 as before. However, instead of returning to the ship, the detection device 26a, in the last battery has the additional function of closing the valve 46 so that the cushion gas exits through the header 42. The header 42 may direct the cushion gas to the next ship, or if no other ship is yet ready to receive it, the cushion gas may go to storage facilities on shore or to flare. When the loading cycle is completed in this manner, all the valves are closed and the connecting conduits 35, 36 and 37 are removed from their associated couplings to permit the ship to proceed on its delivery voyage.

When the ship arrives at the unloading port, it is moored alongside dock facilities such as those shown in FIG. 2A. The flexible conduits 35, 36 and 37 are attached to the coupling means 56, 57 and 58 of the headers 59, 60 and 61 respectively. The header 61 communicates with a source of displacement gas, the choice of which is similar in all respects to that of the cushion gas used in the loading process. This displacement gas is at a pressure higher than that of the cargo mixture in the bottles in the ship. All the valves 29 to 31 and 62 to 64 are initially opened, together with the first and third valves 21a and 26a in the first battery 11a.

The displacement gas proceeds into the ship through the main header 25 and the third valve 26a, into the first battery 11a, through the second sub-header 18a, and into each of the bottles 10a, through their respective second access conduits 13a. As the displacement gas enters the bottles 10a at the top region thereof in this manner at a regulated rate because of the flow control exerted by the constrictions 15a, the denser cargo is forced out the bottom of the bottles 10a through their respective first access conduits 12a. The cargo mixture proceeds through the first sub-header 17a through the open first valve 21a and down the main header 25, so that it exits from the ship through the header 59 in the shore facilities where suitable back pressure is maintained to prevent its decompression. When the cargo mixture has been removed from all of the bottles of the first battery the interface between the displacement gas and the cargo mixture arrives at the detection device 27a, adjacent the first valve 21a, and in response thereto the third valve 26a and first valve 21a, gas is removed from the lower region of the bottle, the gas remaining in the bottles expands and therefore becomes cooler, and to prevent this remaining gas from becoming too cold it is desirable that the original displacement gas used to push the cargo mixture out of the ships be relatively warm.

FIGURE 3 SYSTEM

In FIGS. 3 and 3A, a system is shown which is similar in principle to that of FIGS. 2 and 2A. The first method of disconnecting the storage tank after the pressure of the cargo mixture in the bottles has become as high as desired is shown. The second battery 11b, is opened, and the detection device 27a adjacent the first valve 21a, and in response thereto the third valve 26a and first valve 21a, gas is removed from the lower region of the bottle, the gas remaining in the bottles expands and therefore becomes cooler, and to prevent this remaining gas from becoming too cold it is desirable that the original displacement gas used to push the cargo mixture out of the ships be relatively warm.

As shown in FIG. 3, there are certain elements not designated by prime reference numerals which are included in the system for use during unloading and it is to be understood that they have no function whatsoever during loading, the valves among them all being closed during the loading operation. These are the four-way valves 71, 72, 73a, 74a, 75, 76, 77, 78, and 79, 80, 81, 82, and flexible conduits 83, 84 and 85 associated with the fourth, fifth and sixth main headers respectively; flow-controlling constrictions 87, to 87a, in the first access conduits 12a, to 12a, of the respective batteries of bottles; and detection means 88, to 88a, and 89, to 89a, adjacent the respective fourth and sixth valves 71a, to 71a, and 75a, to 75a, designed to actuate various of the valves in response to the arrival of an interface between differing fluids. The double-side facilities to the right of the dot-dash line L associated with this system at the unloading port are shown in FIG. 3A. They consist of headers 90, 91, 92, 93, 94 and 95 equipped with valves 96, 97, 98, 99, 100 and 101 and coupling means 102, 103, 104, 105, 106 and 107 respectively, with a by-pass conduit 108 and by-pass valve 109 connecting the headers 91 and 92.

To remove the displacement gas from the bottles at full pressure in accordance with the system of FIGS. 3 and 3A, it is forced out with a chilled displacement liquid having a low vapor pressure, such as methanol, acetone, calcium chloride, brine, or heavy naphtha. The latter is particularly advantageous and will serve as an illustrative liquid displacement medium in the following description of the operation of this system. After the displacement liquid has forced out the displacement gas at full pressure, it is replaced in all the bottles by a low pressure scavenging gas which may be similar in composition to the cargo mixture but perhaps somewhat lighter, in a manner described hereinafter.

When the loaded ship arrives at the unloading port, conduits 83, 84, 85, 35, 36 and 37 are connected to coupling means 102, 103, 104, 105, 106 and 107 respectively on the shore facilities shown in FIG. 3A. To start the unloading operation, all the valves 77 to 79, 29a to 31a, and 96 to 101 are open. The header 91 transmits to the ship a low high-pressure displacement gas which may be close to the operating temperature of the cargo mixture since it will remain at fairly constant pressure throughout the unloading process. In the first battery 11a, the fourth and fifth valves 71a, to 71a, and 73a, to 73a, are opened, and the displacement gas passes through the header 91 into the fifth main header 72, where it enters the second sub-header 18a, through the fifth valve 73a. From the second sub-header 18a, the displacement gas passes through the various second access conduits 13a and into all of the bottles
The liquid naphtha pushes the displacement gas and cargo mixture reaches the detection device 88, adjacent the fourth valve 71e, after all the bottles 10, in the first battery are emptied of cargo, the fourth valve 71e, and the fifth valve 73a, are closed to entrap the displacement gas momentarily in the first battery. At the same time, the sensing device 88, automatically opens the first and fifth valves 21a and 73a. Liquid naphtha pumped into the header 93 in the shore facilities therefore begins to flow through the first main header 20' and into the first battery 11a' through the first valve 21a' and the first sub-header 17a'. From there, the naphtha enters the bottom region of the bottles 10', in the first battery thereof through the second access conduits 12, to force the displacement gas out of the top of the bottles through the second access conduits 13a. The constrictions 87a in the respective bottles control the entry of naphtha so that all of the batteries are emptied of displacement gas at substantially the same time. The displacement gas is forced from the second sub-header 18', through the fifth valve 75a, and into the sixth main header 74. It then proceeds into the header 92 in the shore facilities where the greater portion of it is directed through the bypass conduit 108 and back into the ship through the header 91 and the fifth main header 72. Since the fifth valve 75a, in the second battery 11a', when previously opened, the displacement gas enters all of the bottles 10a' of the second battery in precisely the same manner as it had entered the bottles of the first battery.

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FIGURE 4 SYSTEM

In the system shown in FIGS. 4 and 4A, the hydrocarbon cargo mixture is loaded and unloaded by use of a liquid medium instead of a gas as in the previous system. The various liquids mentioned previously in regard to the system of FIGS. 3 and 3A may be used here, but again naphtha is employed for illustrative purposes because it is particularly advantageous. The system of FIGS. 4 and 4A is particularly suited to the transporta- tion of relatively lean cargo mixtures at temperatures above its critical point B and particularly above its cri- ondenbar point C in the operating state shown in FIG. 1. The cargo mixture is much less dense under such conditions than when its temperature is below the critical point B and for that reason there is too great a tendency.
for the cargo mixture to admix with cushion or displacement gases in direct contact with it as in the systems of FIGS. 2 and 3A. Therefore, the FIGS. 4 and 4A system contacts the less refrigerated, and therefore less dense, cargo mixture only with displacement and cushion liquids throughout all the steps of loading and unloading.

The physical arrangement of the system shown in FIGS. 4 and 4A need only be described briefly because it is generally similar to those described previously. Again, the shore facilities are to the right of the dotted line marked L and the shipboard facilities are to the left of that line. Bottles 120a to 120n are arranged in batteries 121a to 121b throughout the ship. The bottles are connected by first and second access conduits 122a to 122b, 123a to 123b, first and second subheaders 124a, 124b to 125a, 125b. Constrictions 126a to 126e are located in each of the respective second access conduits 123a to 123b.

A first main header 128 is connected to the various second subheaders 125a to 125b, by first valves 129a to 129b, associated with detection devices 130a to 130b. A second main header 131 is connected to the various first subheaders 124a to 124b, by second valves 132a to 132b. A third main header 133 is connected to the various first subheaders 124a to 124b, by respective third valves 133a to 133b. Lastly, a fourth main header 135 is connected to the various second subheaders 125a to 125b, by respective fourth valves 136a to 136b, associated with detection devices 137a to 137b. All of the headers 128, 131, 133 and 135 terminate with valves 138, 139, 140 and 141 respectively, together with coupling means 142, 143, 144 and 145, which respectively connect conduits 146, 147, 148 and 149 may be connected to the shore facilities.

Onshore at the loading port, headers 151, 152, 153 and 154 terminate in valves 155, 156, 157 and 158 respectively, together with coupling means 160, 161, 162 and 163 adapted to receive the respective conduits 146, 147, 148 and 149. Headers 152 and 153 are interconnected by a by-pass conduit 164 contacting a by-pass valve 165. They also include valves 166 and 167 respectively on the side of the by-pass conduit 164 remote from the ship and a pressure control valve 168 in the header 153 closer to the ship. At the unloading port the shore facilities comprise headers 169, 170, 171, and 172 associated with valves 173, 174, 175 and 176, together with coupling means 177, 178, 179 and 180 adapted to be connected to the respective conduits 146, 147, 148 and 149.

When the ship arrives at the loading port, its bottles contain some residual gaseous mixture at atmospheric pressure or somewhat higher. After the shipboard and dockside facilities have been connected as shown in FIG. 4, all of the valves 138 to 141, 155 to 158, 165 and 166 are opened. The first step is to direct a chilled cushion liquid, i.e., naphtha in this embodiment, through the header 152 and second main header 131. The cycle is commenced by opening the second valve 132a, and the fourth valve 136b, in the first battery 121a. As a result, the naphtha passes from the second main header 131 through the second sub-header 124a, and into the bottom of each of the bottles 120a through their respective first access conduits 122a. As the level of naphtha rises in the various bottles, the residual gas originally in the bottle is expelled through the various constrictions 126, so that all of the bottles are filled with naphtha at substantially the same time. The expelled residual gas escapes through the second sub-header 124a, and valve 136b, into the fourth main header 135, from which it passes to the header 154 in the shore facilities. As soon as the interface of naphtha and residual gas reaches the detection device 137a, adjacent the fourth valve 136b, in the first battery, the second valve 132a, and the fourth valve 136b, are closed, and valves 129a, 134a, 132b, and 136e are opened. The cargo mixture then enters from the header 151 through the main header 128, and the first valve 129a, to fill each of the bottles 120a, from the second sub-header 125a. As the cargo mixture enters at the top of the bottles, the liquid naphtha is forced out the bottom of each bottle through the respective first access conduits 122a, through the valve 134a, and along the third main header 133 to the header 153 in the shore facilities. Since the valve 167 in the header 153 is closed, the displaced naphtha enters the by-pass conduit 164 and returns to the ship from the header 152 to the second main header 131. From there, it passes, through the opened second valve 132a, into the first subheader 124a, of the second battery 121b, and on into the respective bottles 120b, through their first access conduits 122b, displacing the residual gas in the second battery out the fourth valves 136e, and through the fourth main header 135 to shore.

The flow rate of the various fluids is preferably controlled by the constrictions 126a, to 126n, that, for example, all of the bottles 120a, are filled with the cargo mixture at the same time all of the bottles 120b, of the secondary battery are filled with liquid naphtha. If not, additional detection devices may be employed in a manner which should be clear from the discussion of the previous system. This process continues until the last battery 121b, of bottles 120b, is filled with naphtha. At this time, the by-pass conduit 164, at that point the detection device 137a, in the last battery closes the valve 165 and opens the valve 167 in the shore facilities so that the liquid naphtha proceeds out the header 153 to the next ship or to storage instead of being cycled back into the second main header 131. After the couplings 160 to 163 have been disconnected, the ship proceeds on its delivery voyage with all the bottles filled with the cargo mixture and all of the shipboard valves closed.

When the ship arrives at the unloading port, the conduits 146 to 149 are connected to the coupling means 177 to 180 of the headers 169 to 172 on the shore facilities. To commence unloading, all of the valves 138 to 141 and 173 to 176 are first opened. Then, the third valve 134a, and the first valve 129b, in the first battery 121b, are opened. Naphtha or one of the other displacement liquids referred to previously is pumped to a pressure somewhat above that in the bottles and enters the third main header 133 through the header 171. It proceeds through the third valve 134a, and the first sub-header 124a, into each of the bottles 120b, in the first battery at the bottom thereof. This forces the cargo mixture out the top of the bottles through their respective second access conduits 123a, and on through the second sub-header 125a, into the first main header 128. The cargo mixture passes from there to the header 169 in the shore facilities. As soon as the interface of liquid and cargo mixture reaches the detection device 137a, adjacent the first valve 129a, the first valve 129a, and the third valve 134a, are closed while the valves 134a, 129b, 136a, and 132a are opened. This permits this displacement liquid to start entering the second battery of bottles 120b, through the third valve 134a, the first sub-header 124a, the various first access conduits 122a, into the bottom bottles 120b. As a result, the cargo mixture exits from the bottles 120b, through the second access conduits 123b, the second sub-header 125b, the first valve 129b, and along the first main header 128 to the header 169 in the shore facilities. At the same time, a pumping gas such as that mentioned in regard to FIG. 3A enters from the header 172 on the shore facilities along the fourth main header 135 through the fourth valve 136b, and the second sub-header 125b, into each of the bottles 120b, at the top thereof. This forces the liquid naphtha out of the bottom of the bottles through the first sub-header 124a, and the second valve 132a. The naphtha then proceeds along the second main header 131 to the header 170 in the shore facilities. Again, the rate of flow is preferably
controlled by the constrictions $126_b$ to $126_a$ so that, for example, the cargo is forced out of the bottles $120_b$ of the second battery $121_b$ at the same time the naphtha is forced out of the bottles $120_a$ of the first battery $121_a$ by the scavenging gas, so that the detection devices $130_b$ to $130_a$ suffice to operate all the valves in the proper sequence. However, if the batteries do not fill and empty with such precision, additional detection devices may be located adjacent the second valves $132_b$ to $132_a$ to divide the action of the valves in a manner which should be apparent from the description of the previous systems. Unloading proceeds in this manner until all of the bottles are emptied of the cargo mixture and displacement liquid and only residual scavenging gas remains in the ship.

We claim:

1. In the containment of a natural gas hydrocarbon mixture maintained in a refrigerated and compressed single-phase operating state, a method of handling the mixture in a plurality of pressure vessel means in series which comprises:

(I) loading said pressure vessel means by the steps of:
   (A) forcing a cushion fluid into the first pressure vessel means at a regulated temperature until it is filled with said cushion fluid at substantially the operating pressure of the hydrocarbon mixture,
   (B) forcing said hydrocarbon mixture into said first pressure vessel means while expelling said cushion fluid therefrom at a regulated flow rate so that said first pressure vessel means is filled with the hydrocarbon mixture,
   (C) thereafter directing the expelled cushion fluid into the next pressure vessel means in the series and filling it with the hydrocarbon mixture by the foregoing steps and repeating the process in succession until all of the series of pressure vessel means are filled with the hydrocarbon mixture in the operating state and the cushion fluid is expelled from the last pressure vessel means; and

(II) unloading said pressure vessel means by the steps of:
   (A) forcing a displacement fluid at a pressure greater than the operating pressure of the hydrocarbon mixture into all the vessels of said first battery while expelling said cushion fluid therefrom at a regulated flow rate so that all of said vessels of said first battery are emptied of the hydrocarbon mixture and filled with displacement fluid substantially simultaneously, and
   (B) thereafter directing the expelled cushion fluid into the next battery in the series and emptying it of the hydrocarbon mixture by the foregoing step and repeating the process in succession until all the pressure vessels are emptied of the hydrocarbon mixture and filled with displacement fluid, and
   (C) removing at least part of the displacement fluid from all the batteries in succession.

2. In the containment of a natural gas hydrocarbon mixture maintained in a substantially uniform refrigerated and compressed single-phase operating state, a method of handling the mixture in a multiplicity of batteries of pressure vessels, said batteries being in series and each containing a plurality of said vessels in parallel, which comprises:

(I) loading said pressure vessels by the steps of:
   (A) forcing a cushion gas simultaneously into the lower region of all vessels of a first battery thereof at a regulated temperature so that all vessels of said first battery are filled substantially simultaneously at substantially the operating pressure of the hydrocarbon mixture,
   (B) forcing said hydrocarbon mixture simultaneously into the lower region of all vessels of said first battery while expelling said cushion gas from the upper region thereof at a regulated flow rate so that all of said vessels of said first battery are filled with the hydrocarbon mixture substantially simultaneously, and
   (C) thereafter directing the expelled cushion gas into the next battery in the series and filling it with the hydrocarbon mixture by the foregoing steps and repeating the process in succession until all of the vessels are filled with the hydrocarbon mixture in the operating state and the cushion gas is expelled from the last battery of vessels; and

(II) unloading said vessels by the steps of:
   (A) forcing a displacement gas at a pressure greater than the operating pressure of the hydrocarbon mixture simultaneously into the upper region of all vessels of said first battery while expelling said hydrocarbon mixture from the lower region thereof at a regulated flow rate so that all of said vessels of said first battery are emptied of the hydrocarbon mixture and
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founded with displacement gas substantially simultaneously,

(B) thereafter directing the displacement gas into the next battery in the series and emptying it of the hydrocarbon mixture by the foregoing step and repeating the process in succession until all the vessels are emptied of the hydrocarbon mixture and filled with displacement gas, and

(C) removing at least part of the displacement gas from all the batteries in succession.

4. The method according to claim 3 wherein during the loading steps the cushion gas is cooled as it is expelled from each battery and directed into the next battery.

5. The method according to claim 3 wherein the displacement gas is removed at the end of the unloading cycle by expending the greater part of the displacement gas in succession from each battery through the lower region of all the vessels thereof.

6. The method according to claim 3 wherein the displacement gas is removed at the end of the unloading cycle by the following steps:

(A) forcing a displacement liquid simultaneously into the lower region of all the vessels of each battery in succession while expelling said displacement gas from the upper region thereof at a regulated flow rate so that all the vessels in each successive battery are filled with said liquid substantially simultaneously, and

(B) forcing a scavenging gas at a lower pressure than that of said displacement gas simultaneously into the upper region of all the vessels of each battery in succession while expelling said displacement liquid from the lower region thereof at a regulated flow rate so that all the vessels in each successive battery are filled with said scavenging gas substantially simultaneously.

7. The method according to claim 6 wherein the operating temperature of the natural gas hydrocarbon mixture is below its cricondenbar temperature, the cushion, displacement and scavenging gases are hydrocarbon mixtures lighter than said natural gas hydrocarbon mixture, and said displacement liquid is naphtha.

8. The method according to claim 7 wherein the naphtha is forced into said vessels at a temperature greater than the operating temperature of the hydrocarbon mixture.

9. The method according to claim 7 wherein excess naphtha is forced into said vessels so that any admixture at the interface with the displacement gas is expelled with said displacement gas.

10. In the containment of a natural gas hydrocarbon mixture maintained in a single-phase state, at an operating temperature below ambient but above the critical temperature of methane and an operating pressure above its bubble point-dew point cricondenbar pressures, a method of loading the mixture into a multiplicity of batteries of pressure vessels, said batteries being in series and each containing a plurality of said vessels in parallel, which comprises:

(A) forcing a cushion gas simultaneously into the lower region of all vessels of each battery thereof at a regulated temperature so that all vessels of said first battery are filled substantially simultaneously at substantially the operating pressure of the hydrocarbon mixture,

(B) forcing said hydrocarbon mixture simultaneously into the lower region of all vessels of said first battery while expelling said cushion gas from the upper region thereof at a regulated flow rate so that all of said vessels of said first battery are filled with the hydrocarbon mixture substantially simultaneously, and

(C) thereafter directing the expelled cushion gas into the next battery in the series and filling it with the hydrocarbon mixture by the foregoing steps and repeating the process in succession until all of the vessels are filled with the hydrocarbon mixture in the operating state and the cushion gas is expelled from the last battery of vessels.

11. The method according to claim 10 wherein the cushion gas is cooled as it is expelled from each battery and directed into the next battery.

12. The method according to claim 10 wherein the operating temperature of the natural gas hydrocarbon mixture is below its cricondenbar temperature and the cushion gas is a hydrocarbon mixture lighter than said natural gas hydrocarbon mixture.

13. In the containment of a natural gas hydrocarbon mixture maintained in a single-phase state at an operating temperature below ambient but above the critical temperature of methane and an operating pressure above its bubble point-dew point cricondenbar pressures, a method of unloading the hydrocarbon mixture from a multiplicity of batteries of pressure vessels, said batteries being in series and each containing a plurality of said vessels in parallel, which comprises:

(A) forcing a displacement gas at a pressure greater than the operating pressure of the hydrocarbon mixture simultaneously into the upper region of all vessels of said first battery while expelling said hydrocarbon mixture from the lower region thereof at a regulated flow rate so that all of said vessels of said first battery are emptied of the hydrocarbon mixture and filled with displacement gas substantially simultaneously,

(B) thereafter directing the displacement gas into the next battery in the series and emptying it of the hydrocarbon mixture by the foregoing step and repeating the process in succession until all the vessels are emptied of the hydrocarbon mixture and filled with displacement gas, and

(C) removing at least part of the displacement gas from all the batteries in succession.

14. The method according to claim 13 wherein the displacement gas is removed by expending the greater part of the displacement gas in succession from each battery through the lower region of all the vessels thereof.

15. The method according to claim 13 wherein the displacement gas is removed by the following steps:

(A) forcing a displacement liquid simultaneously into the lower region of all the vessels of each battery in succession while expelling said displacement gas from the upper region thereof at a regulated flow rate so that all the vessels in each successive battery are filled with said liquid substantially simultaneously, and

(B) forcing a scavenging gas at a lower pressure than that of said displacement gas simultaneously into the upper region of all the vessels of each battery in succession while expelling said displacement liquid from the lower region thereof at a regulated flow rate so that all the vessels in each successive battery are filled with said scavenging gas substantially simultaneously.

16. The method according to claim 15 wherein the operating temperature of the natural gas hydrocarbon mixture is below its cricondenbar temperature, the displacement and scavenging gases are hydrocarbon mixtures lighter than said natural gas hydrocarbon mixture, and said displacement liquid is naphtha.

17. The method according to claim 16 wherein the naphtha is forced into said vessels at a temperature greater than the operating temperature of the hydrocarbon mixture.
18. The method according to claim 16 wherein excess naphtha is forced into said vessels so that any admixture at the interface with the displacement gas is expelled with said displacement gas.

19. In the containment of a natural gas hydrocarbon mixture maintained in a single-phase state at an operating temperature below ambient but above the critical temperature of methane and an operating pressure above its bubble point-dew point-critical temperature pressures, a method of handling the cargo mixture in a multiplicity of batteries of pressure vessels, said batteries being in series and each containing a plurality of said vessels in parallel, which comprises:

(I) loading said vessels by the steps of:
(A) forcing a cushion liquid simultaneously into the lower region of all vessels of a first battery thereof at a regulated temperature so that all vessels of said first battery are filled substantially simultaneously at substantially the operating pressure of the hydrocarbon mixture,
(B) forcing said hydrocarbon mixture simultaneously into the upper region of all vessels of said first battery while expelling said cushion liquid from the lower region thereof at a regulated flow rate so that all of said vessels of said first battery are filled with the hydrocarbon mixture substantially simultaneously, and
(C) thereafter directing the expelled cushion liquid into the next battery in the series and filling it with the hydrocarbon mixture by the foregoing steps and repeating the process in succession until all of the vessels are filled with the hydrocarbon mixture in the operating state and the cushion liquid is expelled from the last battery of vessels; and

(II) unloading said vessels by the steps of:
(A) forcing a displacement liquid at a pressure greater than the operating pressure of the hydrocarbon mixture simultaneously into the lower region of all vessels of said first battery while expelling said displacement liquid from the upper region thereof at a regulated flow rate so that all of said vessels of said first battery are emptied of the hydrocarbon mixture and filled with displacement liquid substantially simultaneously;

(B) thereafter directing the displacement liquid into the next battery in the series and emptying it of the hydrocarbon mixture by the foregoing step and repeating the process in succession until all the vessels are emptied of the hydrocarbon mixture and filled with displacement liquid, and

(C) removing substantially all of the displacement liquid from all of the batteries in succession.

20. The method according to claim 19 wherein the displacement liquid is removed at the end of the unloading cycle by forcing a scavenging gas simultaneously into the upper region of all the vessels of each battery in succession while expelling said displacement liquid from the lower region thereof at a regulated flow rate so that all the vessels in each successive battery are filled with said scavenging gas substantially simultaneously and substantially at the same time the vessels of the next battery are filled with said displacement liquid.

21. The method according to claim 20 wherein the operating temperature of the natural gas hydrocarbon mixture is above its critical temperature and its operating pressure is above its dew point-critical temperature pressures, the cushion and displacement liquids are naphtha, and the scavenging gas is a hydrocarbon mixture lighter than said natural gas hydrocarbon mixture.

22. The method according to claim 20 wherein the displacement liquid is pumped from each battery in succession and drawn said scavenging gas in thereafter.

23. In the containment of a natural gas hydrocarbon mixture maintained in a single-phase state at an operating temperature below ambient but above the critical temperature of methane and an operating pressure above its bubble point-dew point-point-critical-temperature pressures, a method of loading the mixture into a multiplicity of batteries of pressure vessels, said batteries being in series and each containing a plurality of said vessels in parallel, which comprises:

(A) forcing a cushion liquid simultaneously into the lower region of all vessels of a first battery thereof at a regulated temperature so that all vessels of said first battery are filled substantially simultaneously at substantially the operating pressure of the hydrocarbon mixture,

(B) forcing said hydrocarbon mixture simultaneously into the upper region of all vessels of said first battery while expelling said cushion liquid from the lower region thereof at a regulated flow rate so that all of said vessels of said first battery are filled with the hydrocarbon mixture substantially simultaneously, and

(C) thereafter directing the expelled cushion liquid into the next battery in the series and filling it with the hydrocarbon mixture by the foregoing steps and repeating the process in succession until all of the vessels are filled with the hydrocarbon mixture in the operating state and the cushion liquid is expelled from the last battery of vessels.

24. The method according to claim 21 wherein the operating temperature of the natural gas hydrocarbon mixture is above its critical temperature and its operating pressure is above its dew point-critical temperature pressures, and the cushion liquid is naphtha.

25. In the containment of a natural gas hydrocarbon mixture maintained in a single-phase state at an operating temperature below ambient but above the critical temperature of methane and an operating pressure above its bubble point-dew point-point-critical temperature pressures, a method of unloading the mixture from a multiplicity of batteries of pressure vessels, said batteries being in series and each containing a plurality of said vessels in parallel, which comprises:

(A) forcing a displacement liquid at a pressure greater than the operating pressure of the hydrocarbon mixture simultaneously into the lower region of all vessels of said first battery while expelling said displacement liquid from the upper region thereof at a regulated flow rate so that all of said vessels of said first battery are emptied of the hydrocarbon mixture and filled with displacement liquid substantially simultaneously;

(B) thereafter directing the displacement liquid into the next battery in the series and emptying it of the hydrocarbon mixture by the foregoing step and repeating the process in succession until all the vessels are emptied of the hydrocarbon mixture and filled with displacement liquid substantially simultaneously.

26. The method according to claim 25 wherein the displacement liquid is removed by forcing a scavenging gas simultaneously into the upper region of all the vessels of each battery in succession while expelling said displacement liquid from the lower region thereof at a regulated flow rate so that all the vessels in each successive battery are filled with said scavenging gas substantially simultaneously and substantially at the same time the vessels of the next battery are filled with said displacement liquid.

27. The method according to claim 26 wherein the operating temperature of the natural gas hydrocarbon mix-
The temperature is above its critical temperature and its operating pressure is above its dew point-critical-temperature pressures, the cushion and displacement liquids are naphtha, and the scavenging gas is a hydrocarbon mixture lighter than said natural gas hydrocarbon mixture.

28. The method according to claim 26 wherein the displacement liquid is pumped from each battery in succession and draws said scavenging gas in thereafter.

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MORRIS O. WOLK, Primary Examiner.
JAMES H. TAYMAN, Jr., Examiner.
Dedication


Hereby dedicates to the Public the entire remaining term of said patent.
[Official Gazette December 28, 1971.]