Dec. 20, 1966 J. D. LEWIS ET AL 3,293,011

METHOD OF HANDLING NATURAL GAS

Filed Dec. 20, 1963 3 Sheets-Sheet 1

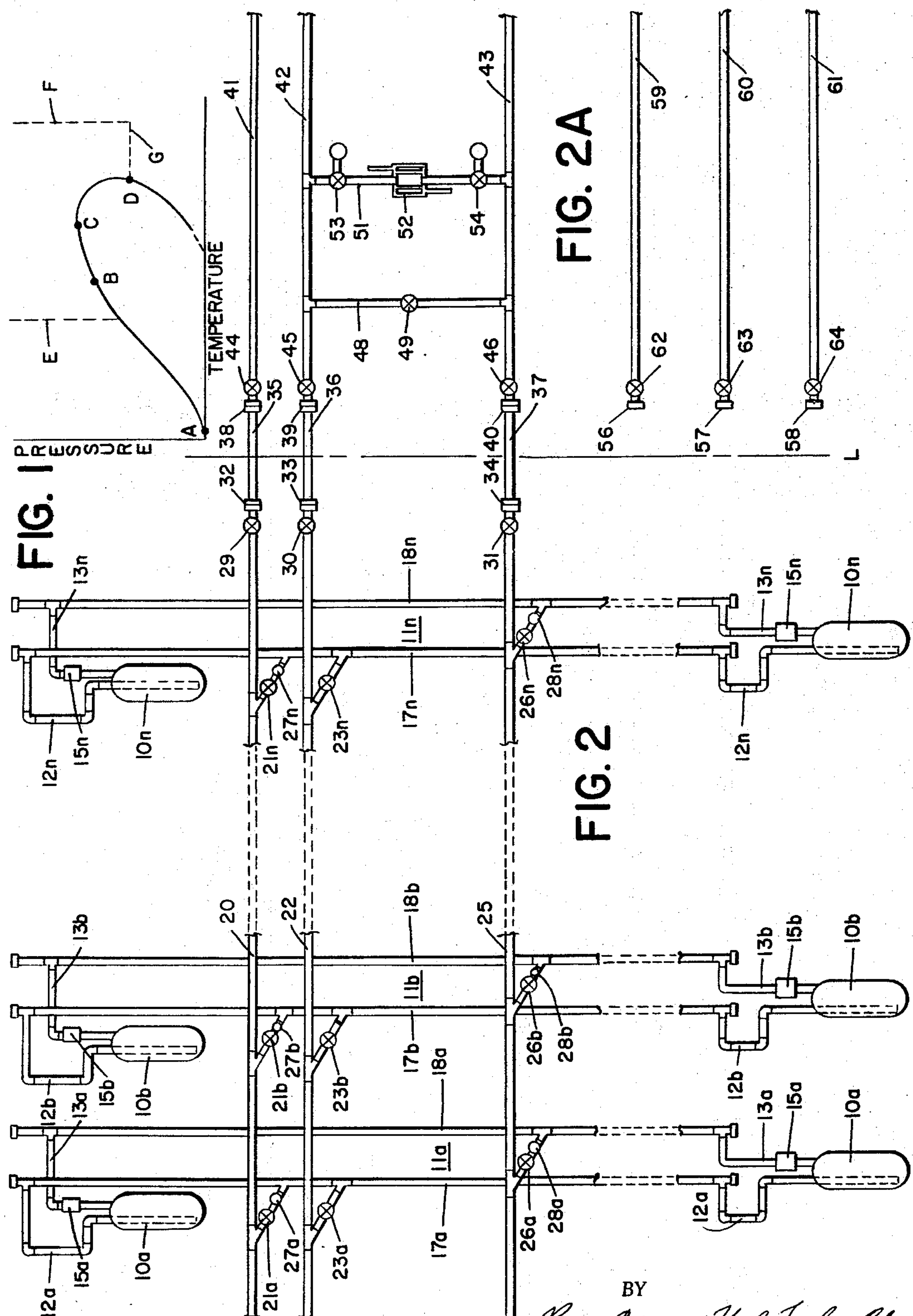


FIG. 1

FIG. 2A

FIG. 2

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Filed Dec. 20, 1963 3 Sheets-Sheet 2

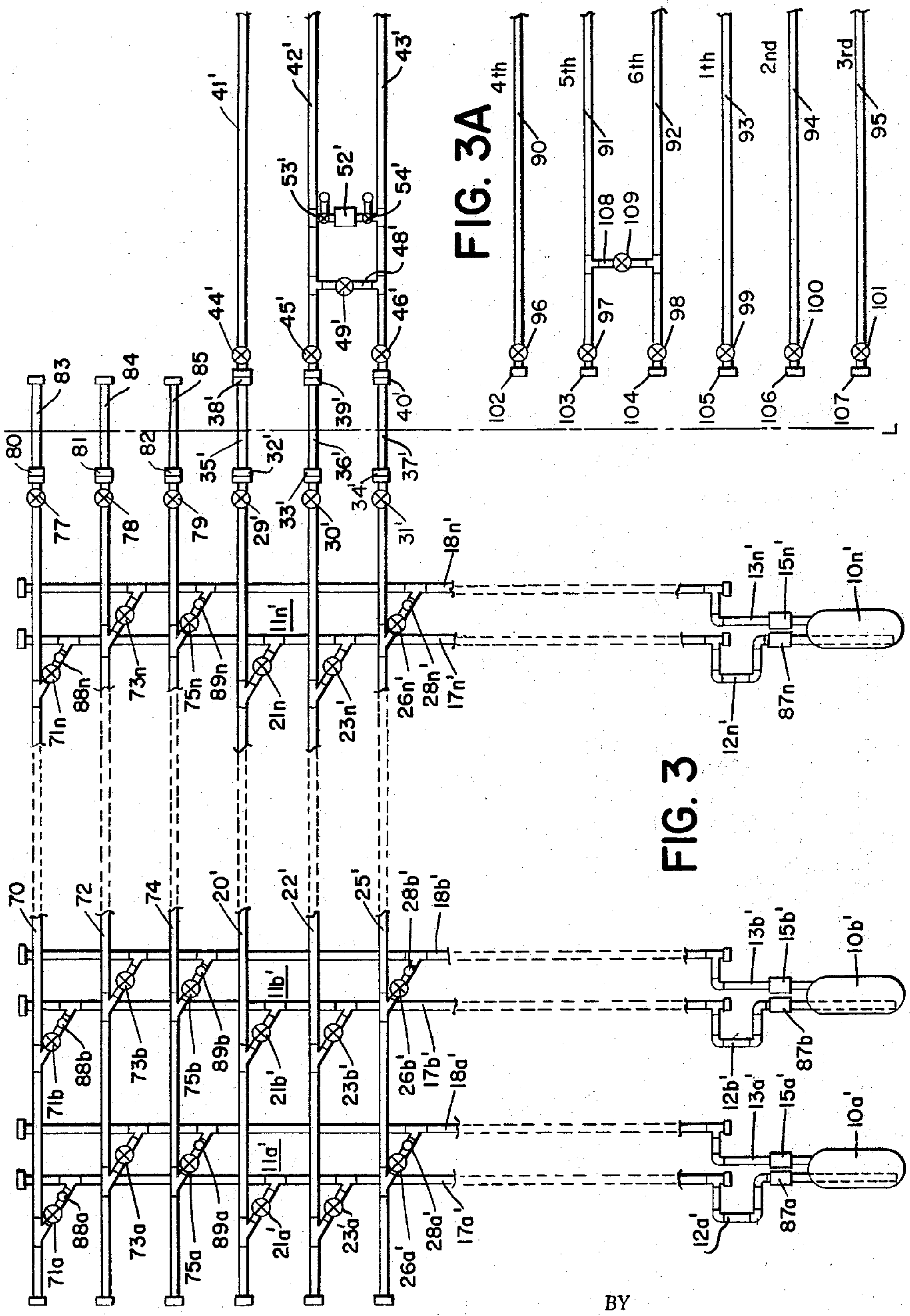

FIG. 3A

FIG. 3

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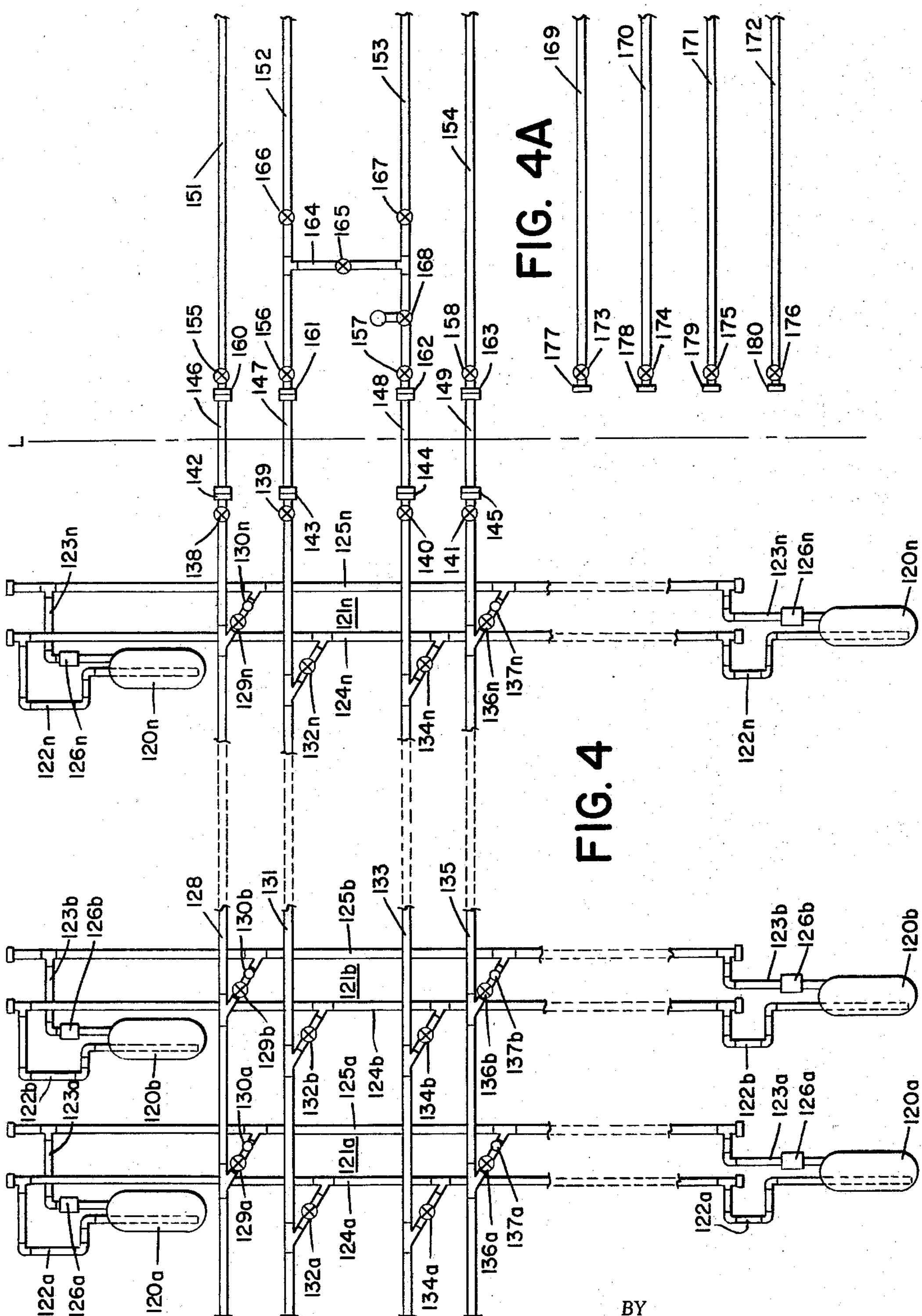


FIG. 4A

FIG. 4

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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 Lummus 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 objects 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 in a plurality of pressure vessel means 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 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. 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 hereinbelow 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; and

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 50 mol percent methane and at least 75 mol percent methane-plus-ethane, the remainder being heavier hydrocarbons and up to 20 mol percent inert constituents, and having a higher calorific value from 800 B.t.u./s.c.f. to 1800 B.t.u./s.c.f. The approximate limits of the operating state in which such cargo mixtures are to be maintained in accordance with this invention can best be described with reference to FIG. 1. This phase diagram shows a typical envelope curve within which the gas mixture exists in two-phase state, part liquid and part vapor. Point A indicates the liquification temperature of the mixture at atmospheric pressure, and in absolute terms it might be about −258° F. Point B is the true critical point of the gas at which the various lines of liquid and vapor concentrations within the two-phase region of the envelope converge. Point C is the cricondenbar point of the gas and it indicates the point of highest pressure, regardless of temperature, at which the two-phase condition can exist. Point D is the cricondentherm point of gas and it indicates the point of highest temperature, regardless of pressure, at which the two-phase condition can exist.

When the cargo mixture is moderately refrigerated and compressed to achieve optimum density at minimal compression and refrigeration costs, the mixture is within the region of the FIG. 1 diagram defined by the dotted line E on one side, the dotted lines F and G on the other, and the interconnecting portion of the envelope curve. The lower temperature limit marked by the dotted line E is the critical temperature of the methane content of the gas, about −116° F., and the maximum temperature indicated by the dotted line F is ambient temperature. The minimum pressure is indicated by the bubble point-dew point line of the envelope and by the dotted line G, the latter being the pressure of the gas at its cricondentherm point D. Thus, the cargo mixture should be refrigerated below ambient temperature but not below the critical temperature of methane, and it should be compressed above the bubble point-dew point-cricondentherm pressure of the mixture.

When the cargo mixture is refrigerated within this operating range to below its critical point B, it is especially dense and approaches a liquid in its behavior. At temperatures in the operating range above the cricondenbar point C, the mixture is less dense and may therefore be handled differently in a manner to be discussed hereinafter. 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 hereinafter.

## 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 thereof as indicated in the FIG. 1 phase diagram, but it is also applicable to a less dense cargo mixture above the cricondenbar temperature.

The shipboard facilities are to the left of the dot-dash line L in FIG. 1 and the shore facilities are to the right thereof. The ship carries a multiplicity of elongated bottles $\mathbf{10}_a$ to $\mathbf{10}_n$ in a plurality of respective batteries $\mathbf{11}_a$ to $\mathbf{11}_n$. A given ship may include twenty-four batteries of this type disposed laterally in its hold and there may be about one hundred bottles in each battery. Each bottle is made of a suitable alloy resistant to low temperatures and may be three or four feet in diameter and at least about twenty feet long. They are preferably arranged vertically in the hold of the ship. Each bottle in each battery is closed at both ends except for first and second access conduits $\mathbf{12}_a$ to $\mathbf{12}_n$ and $\mathbf{13}_a$ to $\mathbf{13}_n$ which extend through the respective upper ends of the bottles and communicate with the bottom and top regions respectively of the interior thereof. In the FIG. 2 system, constrictions $\mathbf{15}_a$ to $\mathbf{15}_n$ are provided in the respective second access conduits $\mathbf{13}_a$ to $\mathbf{13}_n$ of the various bottles to control the flow of fluids into and out of each bottle at a predetermined rate. The constrictions 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 a relatively large constriction and high flow rate. The object of the flow-control constrictions is to insure 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 constriction 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 $\mathbf{17}_a$ to $\mathbf{17}_n$ and second sub-headers $\mathbf{18}_a$ to $\mathbf{18}_n$ interconnect the first and second access conduits $\mathbf{12}_a$ to $\mathbf{12}_n$ and $\mathbf{13}_a$ to $\mathbf{13}_n$ respectively of all 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 on board the ship a first main header **20** interconnecting all of the first sub-headers $\mathbf{17}_a$ to $\mathbf{17}_n$ for conveying the cargo mixture into and out of the bottles. First valves $\mathbf{21}_a$ to $\mathbf{21}_n$ are located at the respective interconnections between the first main header **20** and the first sub-headers $\mathbf{17}_a$ to $\mathbf{17}_n$. A second main header **22** interconnects all of the first sub-headers $\mathbf{17}_a$ to $\mathbf{17}_n$ through second valves $\mathbf{23}_a$ to $\mathbf{23}_n$ in a similar manner. Finally, a third main header **25** interconnects all of the second sub-headers $\mathbf{18}_a$ to $\mathbf{18}_n$ through third valves $\mathbf{26}_a$ to $\mathbf{26}_n$. The function of the second and third main headers **22** and **25** is to convey cushion and displacement gas into and out of the bottles. Conventional detection means $\mathbf{27}_a$ to $\mathbf{27}_n$ and $\mathbf{28}_a$ to $\mathbf{28}_n$ are located adjacent the bottle-side of the respective first and second valves $\mathbf{21}_a$ to $\mathbf{21}_n$ and $\mathbf{26}_a$ to $\mathbf{26}_n$ 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 a manner described hereinbelow by any suitable servo 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.

At one end of each of the main headers **20**, **22** and **25** are valves **29**, **30** and **31** and coupling means **32**, **33** and **34** respectively. When the ship is being loaded or unloaded at dockside, flexible conduits **35**, **36** and **37** may be attached to the coupling means **32**, **33** and **34** respectively to interconnect the three main headers to the shore facilities. When the ship is being loaded, the flexible conduits **35**, **36** and **37** are connected through coupling means **38**, **39** and **40** to dockside headers **41**, **42** and **43** through valves **44**, **45** and **46** respectively. The dockside loading facilities also include a by-pass conduit **48** containing a valve **49** between the headers **42** and **43**. Also, they include between those same leaders **42** and **43** a second by-pass conduit **51** which includes a heat exchanger **52** between pressure relief control valves **53** and **54**. During unloading at the port of destination, the flexible conduits **35**, **36** and **37** (or others like them, since counterparts would probably be available at each port) are connected by coupling means **56**, **57** and **58** to headers **59**, **60** and **61** through valves **62**, **63** and **64** respectively as shown in FIG. 2A.

When the system of FIGS. 2 and 2A is to be used, a ship will be returning to the loading facilities with some 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 while 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 $\mathbf{21}_a$ to $\mathbf{21}_n$, $\mathbf{23}_a$ to $\mathbf{23}_n$ and $\mathbf{26}_a$ to $\mathbf{26}_n$ 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 $\mathbf{23}_a$ in the first battery $\mathbf{11}_a$ is opened. This causes the cushion gas to pass through the header **43**, the by-pass conduit **48**, the header **42**, the conduit **36** and along the second main header **22**. Passing through the open valve $\mathbf{23}_a$, the cushion gas proceeds into the first sub-header $\mathbf{17}_a$ to enter all of the first access conduits $\mathbf{12}_a$ of the various bottles in battery $\mathbf{11}_a$. The cushion gas flows into the bottom region of each bottle $\mathbf{10}_a$ 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 $\mathbf{10}_a$ approach capacity at substantially the same time. As the pressure in the bottles $\mathbf{10}_a$ rises, 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 bottles $\mathbf{10}_a$ 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 $\mathbf{11}_a$ 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 $\mathbf{23}_a$ and the by-pass valve **49** are closed while the second valve $\mathbf{23}_b$, the third valve $\mathbf{26}_a$ and the first valve $\mathbf{21}_a$ are opened, 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 $\mathbf{21}_a$ into the first sub-header $\mathbf{17}_a$ and hence into the bottom region of the various bottles $\mathbf{10}_a$ of battery $\mathbf{11}_a$ through their respective first access conduits $\mathbf{12}_a$.

As the dense cargo mixture enters the bottom of the bottles through the first access conduits $\mathbf{12}_a$, the compressed cushion gas is forced out of the top of the bottles in the battery $\mathbf{11}_a$ through the respective constrictions $\mathbf{15}_a$ and second access conduits $\mathbf{13}_a$ into the sub-header $\mathbf{18}_a$. The constrictions $\mathbf{15}_a$ prevent the cushion gas from escaping from the small bottles in the battery $\mathbf{11}_a$ as fast as from the larger bottles, thereby controlling the rate of flow of the dense cargo mixture entering the bottom of the bottles. By suitable correlation of the size of the constrictions $\mathbf{15}_a$ to the volume of the respective bottles, it can be assured that the bottles $\mathbf{10}_a$ in the battery $\mathbf{11}_a$ are all filled with the dense cargo mixture at the same time.



The cargo mixture entering the bottles $\mathbf{10}_a$ forces the cushion gas out through the second sub-header $\mathbf{18}_a$ and into the third main header **25** through the open valve $\mathbf{26}_a$. Since all of the third valves $\mathbf{26}_b$ to $\mathbf{26}_n$ are closed, the cushion gas proceeds along the third main header **25** through the valves **31** and **46** 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 $\mathbf{11}_a$ and thereby maintains the pressure of the cargo mixture entering the bottles $\mathbf{10}_a$ of that battery at a constant level.

If the cushion gas were delivered directly into the bottles $\mathbf{10}_b$ of the next battery $\mathbf{11}_b$ 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 $\mathbf{11}_b$ 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. However, if 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 proceeding 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 $\mathbf{23}_b$ has been opened previously, the cushion gas at its regulated temperature proceeds from the second main header **22** into all the bottles $\mathbf{10}_b$ of the battery $\mathbf{11}_b$ through the respective first access conduits $\mathbf{12}_b$ thereof to fill the second battery $\mathbf{11}_b$ in the same manner that it had previously filled the first battery $\mathbf{11}_a$. As soon as all of the bottles $\mathbf{10}_a$ in the first battery $\mathbf{11}_a$ are filled with the cargo mixture as described, the interface between the denser cargo mixture and the lighter cushion gas reaches the detection device $\mathbf{28}_a$. When this occurs, the detection device automatically closes the first valve $\mathbf{21}_a$ and third valve $\mathbf{26}_a$ in the battery $\mathbf{11}_a$ and opens the first valve $\mathbf{21}_b$ to direct the cargo mixture into the second battery $\mathbf{11}_b$ without interruption. The detection device $\mathbf{28}_a$ also closes the second valve $\mathbf{23}_b$, and opens the second and third valves of the third battery (not shown) and the third valve $\mathbf{26}_b$ of the second battery $\mathbf{11}_b$. All of the bottles $\mathbf{10}_b$ in the battery $\mathbf{11}_b$ are filled in precisely the same manner as were the bottles $\mathbf{10}_a$ in the previous battery $\mathbf{11}_a$. 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 $11_n$ on the ship is being filled with the cargo mixture, the cushion gas leaves through the second sub-header $18_n$, the third valve $26_n$, 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 $28_n$ in the last battery has the additional function of closing the valve **45** so that the cushion gas exits through the header **42**. The header **42** may direct the cushion gas to the next ship immediately, 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 somewhat higher than that of the cargo mixture in the ship. All the valves **29** to **31** and **62** to **64** are initially opened, together with the first and third valves $21_a$ and $26_a$ in the first battery $11_a$.

The displacement gas proceeds into the ship through the third main header **25** and the third valve $26_a$ into the first battery $11_a$. It then forces its way through the second sub-header $18_a$ and into each of the bottles $10_a$ through their respective second access conduits $13_a$. As the displacement gas enters the bottles $10_a$ at the top region thereof in this manner at a regulated rate because of the flow control exerted by the constrictions $15_a$, the denser cargo is forced out the bottom of the bottles $10_a$ through their respective first access conduits $12_a$. The cargo mixture proceeds through the first sub-header $17_a$ through the open first valve $21_a$ and down the first main header **20**, 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 the bottles of the first battery the interface between the displacement gas and the cargo mixture arrives at the detection device $27_a$ adjacent the first valve $21_a$, and in response thereto the third valve $26_a$ and first valve $21_a$ are closed and the third valve $26_b$ and first valve $21_b$ in the next battery $11_b$ are automatically opened, allowing the displacement gas to push the dense cargo mixture from the second battery $11_b$. At the same time, the second valve $23_a$ is opened to allow the displacement gas to expand out the bottom of the bottle $10_a$ in the first battery $11_a$ through the respective first access conduits $12_a$, the first sub-header $17_a$, the second valve $23_a$, the second main header **22**, the valves **30** and **63**, and the header **60**. The displacement gas continues to flow out until the pressure in the first battery $11_a$ is reduced to the desired level for the return voyage, perhaps 100 to 300 p.s.i.g.

When the cargo mixture is displaced out the bottom of the bottles as described, some of it may remain in the bottom of a few of the bottles. Such remaining cargo mixture would flash during decompression of the displacement gas and would lower the temperature locally below the permitted design factor for the bottle construction. However, this is avoided because any substantial amount of the dense cargo mixture left in the bottom of the bottles will be pushed out first before the pressure of the displacement gas is appreciably reduced. As the displacement gas is removed from the lower region of the bottles 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 except that in the unloading procedure it provides for removal of the displacement gas at full pressure without expanding it out of the ship after the successive batteries are emptied. Only the unloading operation in the FIGS. 3 and 3A system differs from what has been described previously in regard to FIGS. 2 and 2A, and not the loading operation. Therefore, everything said previously in regard to the loading procedure applies by reference here, and primed reference numerals are used to designate all those elements of the loading means in FIG. 3 which are identical in form and function to their counterparts in FIG. 2.

As shown in FIG. 3, there are certain elements not designated by primed 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 loading operation. These are a fourth main header **70** interconnecting all of the first sub-headers $17_a'$ to $17_n'$ through respective fourth valves $71_a$ to $71_n$; a fifth main header **72** interconnecting all of the second sub-headers $18_a'$ to $18_n'$ through respective fifth valves $73_a$ to $73_n$; a sixth main header **74** interconnecting all of the second sub-headers $18_a'$ to $18_n'$ through respective sixth valves $75_a$ to $75_n$; valves **77**, **78** and **79**, coupling means **80**, **81** and **82**, and flexible conduits **83**, **84** and **85** associated with the four, fifth and sixth main headers respectively; flow-controlling constrictions $87_a$ to $87_n$ in the first access conduits $12_a'$ to $12_n'$ of the respective batteries of bottles; and detection means $88_a$ to $88_n$ and $89_a$ to $89_n$ adjacent the respective fourth and sixth valves $71_a$ to $71_n$ and $75_a$ to $75_n$ designed to actuate various of the valves in response to the arrival of an interface between differing fluids. The dockside 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 discussed hereinbelow.

When the loaded ship arrives in 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 of the valves **77** to **79**, **29'** to **31'**, and **96** to **101** are open. The header **91** transmits to the ship a lean 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 cycle. In the first battery $11_a'$ the fourth and fifth valves $71_a$ and $73_a$ are opened, and the displacement gas passes through the header **91** into the fifth main header **72**, where it enters the second sub-header $18_a'$ through the fifth valve $73_a$. From the second sub-header $18_a'$, the displacement gas passes through the various second access conduits $13_a'$ and into all of the bottles

$10_a'$ of the first battery $11_a'$ at the top thereof. This forces the cargo mixture out the bottom of the bottles through the second access conduits $12_a'$ with the flow rate of the displacement gas controlled by the respective constrictions $15_a'$ so that all of the bottles $10_a'$ are emptied of cargo substantially simultaneously. As the cargo mixture is removed from the bottles in this manner, it passes from the first sub-header $17_a'$ through the fourth valve $71_a$ and along the main header 70 to the header 90 in the shore facilities where it is confronted by sufficient back pressure to prevent decompression.

As soon as the interface between the displacement gas and cargo mixture reaches the detection device $88_a$ adjacent the fourth valve $71_a$ after all the bottles $10_a$ in the first battery are emptied of cargo, the fourth valve $71_a$ and the fifth valve $73_a$ are closed to entrap the displacement gas momentarily in the first battery. At the same time, the sensing device $88_a$ automatically opens the first and fifth valves $21_a'$ and $73_b$. 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 $11_a'$ through the first valve $21_a'$ and the first sub-header $17_a'$. From there, the naphtha enters the bottom region of the bottles $10_a'$ in the first battery thereof through the second access conduits $12_a'$ to force the displacement gas out of the top of the bottles through the second access conduits $13_a'$. The constrictions $87_a$ in the respective bottles control the entry of naphtha so that all of the bottles are emptied of displacement gas at substantially the same time. The displacement gas is forced from the second sub-header $18_a'$ through the fifth valve $75_a$ 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 $73_b$ in the second battery $11_b'$ was previously opened, the displacement gas enters all of the bottles $10_b'$ of the second battery in precisely the same manner as it had entered the bottles of the first battery.

Thus, the liquid naphtha pushes the displacement gas and the latter in turn pushes the cargo from one battery of bottles to the next to remove all of the cargo mixture from the ship. Flow rates may be adjusted so that the cargo mixture has been pushed out of a given battery of bottles at the same time that the displacement gas has been pushed out of the previous battery of bottles by the liquid naphtha. Thus, when the interface of naphtha and displacement gas reaches the detection device $89_a$ adjacent the sixth valve $75_a$ in the first battery causing it to close the sixth valve $75_a$ and the fifth valve $73_b$ in the next battery, the interface of displacement gas and cargo mixture should have just arrived at the detection device $88_b$ in the next battery. For this reason one detection device in each battery may be made to actuate the valves instead of employing the two detection devices shown.

To remove the naphtha from the bottles, there is a further sequential movement of fluid through the system which proceeds as all of the steps described above are being carried out. When the interface of naphtha and displacement gas reaches the detection device $89_a$ in the first battery, the sixth valve $75_a$ and the first valve $21_a'$ are closed to entrap the naphtha momentarily in the first battery $11_a'$. However, the fifth valve $23_a'$ and the third valve $26_a'$ are opened so that the naphtha begins to flow out of the battery $11_a'$ from the bottom of the bottles through the first sub-header $17_a'$ and along the second main header 22' to the header 94 on the shore facilities. This reduces the pressure of the naphtha in the bottles to between atmospheric pressure and about 200 p.s.i.g.

A low pressure scavenging gas, chosen with the same standard as the cushion and displacement gases mentioned previously, enters the ship from the header 95 through the third main header 25' and into the second sub-header $18_a'$, to the upper regions of the respective bottles $10_a'$ through their various second access conduits $13_a'$. The rate of flow of the scavenging gas into the bottles $10_a'$ should be such that the naphtha is removed from all of the bottles in the battery $11_a'$ substantially simultaneously and also at about the same time the displacement gas is emptied from the next battery $11_b'$ and the cargo mixture is emptied from the battery after that. Thus, the detection devices $89_b$ or the one in the third battery (not shown) corresponding to the devices $88_a$ and $88_b$ may be used to close the second and third valves $23_a'$ and $26_a'$ and to open corresponding valves $23_b'$ and $26_b'$ so that the scavenging gas will proceed to empty the naphtha from the next battery $11_b'$. From this description of the manner in which the detecting devices function, it should be apparent that yet another series of them may be located adjacent the second valves $23_a'$ if desired.

While the displacement gas is flowing, for example, into the top of the bottles of battery $11_b'$ to push the cargo out of the bottom, the flow to the individual bottles is controlled primarily by constrictions $15_a'$ and $15_b'$ and the corresponding constrictions in the next battery. The pressure drop through the constrictions $87_a$ and $87_b$ and the corresponding constrictions in the next battery is relatively low at this time. When the liquid naphtha enters into the bottom of, for example, the bottles of battery $11_a'$ pushing the displacement gas out of the top thereof, the constrictions $87_a$ and $15_a'$ are about equally effective. When the scavenging gas is entering the top of the bottles of the first battery $11_a'$ pushing the liquid naphtha out of the bottom, the distribution to the various bottles is controlled primarily by constrictions $87_a$ and $87_b$ and the corresponding constrictions in the next battery. The pressure drop in constrictions $15_a$ and $15_b$ and the corresponding constrictions in the next battery will be relatively low at that time.

As the naphtha leaves the ship it may be reprocessed and pumped back to high pressure to be returned to the same or the next ship through the header 93 to push displacement gas and cargo mixture out of another battery. A problem to be guarded against is admixture of any of the displacement gas into the liquid naphtha as a result of contact between the two fluids at the interface thereof. When the pressure is subsequently released so that the naphtha may be pushed from the ship with low-pressure scavenging gas, any substantial amount of the displacement gas previously dissolved in the naphtha may flash in the bottles and drop the temperature to a dangerously low level. In order to prevent this it may be desirable to bring the naphtha into the ship at a somewhat higher temperature than the cargo mixture. Alternatively, after the naphtha has pushed all of the displacement gas out of the bottles of the first battery, a small additional amount of naphtha may be sent into the bottles to push out that portion of the naphtha at the top of the bottles which may have been contaminated with an admixture of the displacement gas. This is done before the pressure of the naphtha is released so that the admixture moves out of the ship with the displacement gas rather than with the liquid naphtha.

## 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 systems. 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 transportation of relatively lean cargo mixtures at temperatures above its critical point B and particularly above its cricondenbar 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 2A or 3 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 dot-dash line marked L and the shipboard facilities are to the left of that line. Bottles $120_a$ to $120_n$ are arranged in batteries $121_a$ to $121_n$ throughout the ship. The bottles are connected by first and second access conduits $122_a$ to $122_n$ and $123_a$ to $123_n$ to first and second sub-headers $124_a$ to $124_n$ and $125_a$ to $125_n$. Constrictions $126_a$ to $126_n$ are located in each of the respective second access conduits $123_a$ to $123_n$.

A first main header **128** is connected to the various second sub-headers $125_a$ to $125_n$ by first valves $129_a$ to $129_n$ associated with detection devices $130_a$ to $130_n$. A second main header **131** is connected to the various first sub-headers $124_a$ to $124_n$ by second valves $132_a$ to $132_n$. A third main header **133** is connected to the various first sub-headers $124_a$ to $124_n$ by respective third valves $134_a$ to $134_n$. Lastly, a fourth main header **135** is connected to the various second sub-headers $125_a$ to $125_n$ by respective fourth valves $136_a$ to $136_n$ associated with detection devices $137_a$ to $137_n$. 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**, **145** by which respective 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 $132_a$ and the fourth valve $136_a$ in the first battery $121_a$. As a result, the naphtha passes from the second main header **131** through the second sub-header $124_a$ and into the bottom of each of the bottles $120_a$ through their respectively first access conduits $122_a$. As the level of naphtha rises in the various bottles, the residual gas originally in the bottles is expelled through the various constrictions $126_a$ so that all of the bottles are filled with naphtha at substantially the same time. The expelled residual gas passes through the second sub-header $125_a$ and valve $136_a$ 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 $137_a$ adjacent the fourth valve $136_a$ in the first battery, the second valve $132_a$ and the fourth valve $136_a$ are closed, and valves $129_a$, $134_a$, $132_b$, and $136_b$ are opened. The cargo mixture then enters from the header **151** through the first main header **128** and the first valve $129_a$ to fill each of the bottles $120_a$ from the second sub-header $125_a$. 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 $122_a$ through the valve $134_a$ 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 $132_b$ into the first sub-header $124_b$ of the second battery $121_b$ and on into the respective bottles $120_b$ through their first access conduits $122_b$, displacing the residual gas in the second battery out the fourth valves $136_b$ and through the fourth main header **135** to shore.

The flow rate of the various fluids is preferably controlled by the constrictions $126_a$ to $126_n$ that, for example, all of the bottles $120_a$ are filled with the cargo mixture at the same time all of the bottles $120_b$ 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 $121_n$ of bottles $120_n$ is filled with the cargo mixture, and at that point the detection device $137_n$ 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 $134_a$ and the first valve $129_a$ in the first battery $121_a$ 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 $134_a$ and the first sub-header $124_a$ into each of the bottles $120_a$ in the first battery at the bottom thereof. This forces the cargo mixture out of the top of the bottles through their respective second access conduits $123_a$ and on through the second sub-header $125_a$ 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 $130_a$ adjacent the first valve $129_a$, the first valve $129_a$ and the third valve $134_a$ are closed while the valves $134_b$, $129_b$, $136_a$ and $132_a$ are opened. This permits this displacement liquid to start entering the second battery of bottles $120_b$ through the third valve $134_b$, the first sub-header $124_b$, the various first access conduits $122_b$ and into the bottom of the bottles $120_b$. As a result, the cargo mixture exits from the bottles $120_b$ through the second access conduits $123_b$, the second sub-header $125_b$, the first valve $129_b$ and along the first main header **128** to the header **169** in the shore facilities. At the same time, a scavenging 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 $136_a$ and the second sub-header $125_a$ into each of the bottles $120_a$ at the top thereof. This forces the liquid naphtha out of the bottom of the bottles through the first sub-header $124_a$ and the second valve $132_a$. 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 $126_a$ to $126_n$ 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 $130_a$ to $130_n$ 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 $132_a$ to $132_n$ to divide the actuation 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, and

(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 the first pressure vessel means while expelling said hydrocarbon mixture therefrom at a regulated flow rate so that said first pressure vessel means is emptied of hydrocarbon mixture and filled with displacement fluid,

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

(C) removing at least part of the displacement fluid from all the pressure vessel means 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 fluid into all the vessels of a first battery thereof at a regulated temperature until all vessels of said first battery are filled at substantially the operating pressure of the hydrocarbon mixture,

(B) forcing said 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 filled with the hydrocarbon mixture substantially simultaneously, and

(C) thereafter directing the expelled cushion fluid 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 fluid is expelled from the last battery of pressure vessels; and

(II) unloading said pressure vessels 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 hydrocarbon mixture 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,

(B) thereafter directing the displacement 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.

**3.** 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 cricondentherm pressures, 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 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 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.

**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 expanding 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 temperaure 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 cricondentherm 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 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.

**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 cricondentherm 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 expanding 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 cricondentherm 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 hydrocarbon mixture 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 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 scavening 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-cricondentherm pressures, the cushion and displacement liquids are naphtha, and the scavening 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 draws said scavening 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-cricondentherm 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-cricondentherm 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-cricondentherm 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 hydrocarbon mixture 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 the batteries in succession.

26. The method according to claim 25 wherein the displacement liquid is removed by forcing a scavening 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 scavening 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-

ture is above its critical temperature and its operating pressure is above its dew point-cricondentherm pressures, the cushion and displacement liquids are naphtha, and the scavening 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 scavening gas in thereafter.

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**Dedication**

3,293,011.—*John D. Lewis*, Forest Hills, *Morgan Chuan-Yuan Sze*, Garden City, *Carroll O. Bennett*, Pelham Manor, and *Maurice E. Brooks*, Great Neck, N.Y., *Irvin H. Lutz*, Westfield, and *Howard B. Zasloff*, Rockaway, N.J. METHOD OF HANDLING NATURAL GAS. Patent dated Dec. 20, 1966. Dedication filed Sept. 16, 1971, by the assignee, *Vehoc Corporation*.

Hereby dedicates to the Public the entire remaining term of said patent.
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