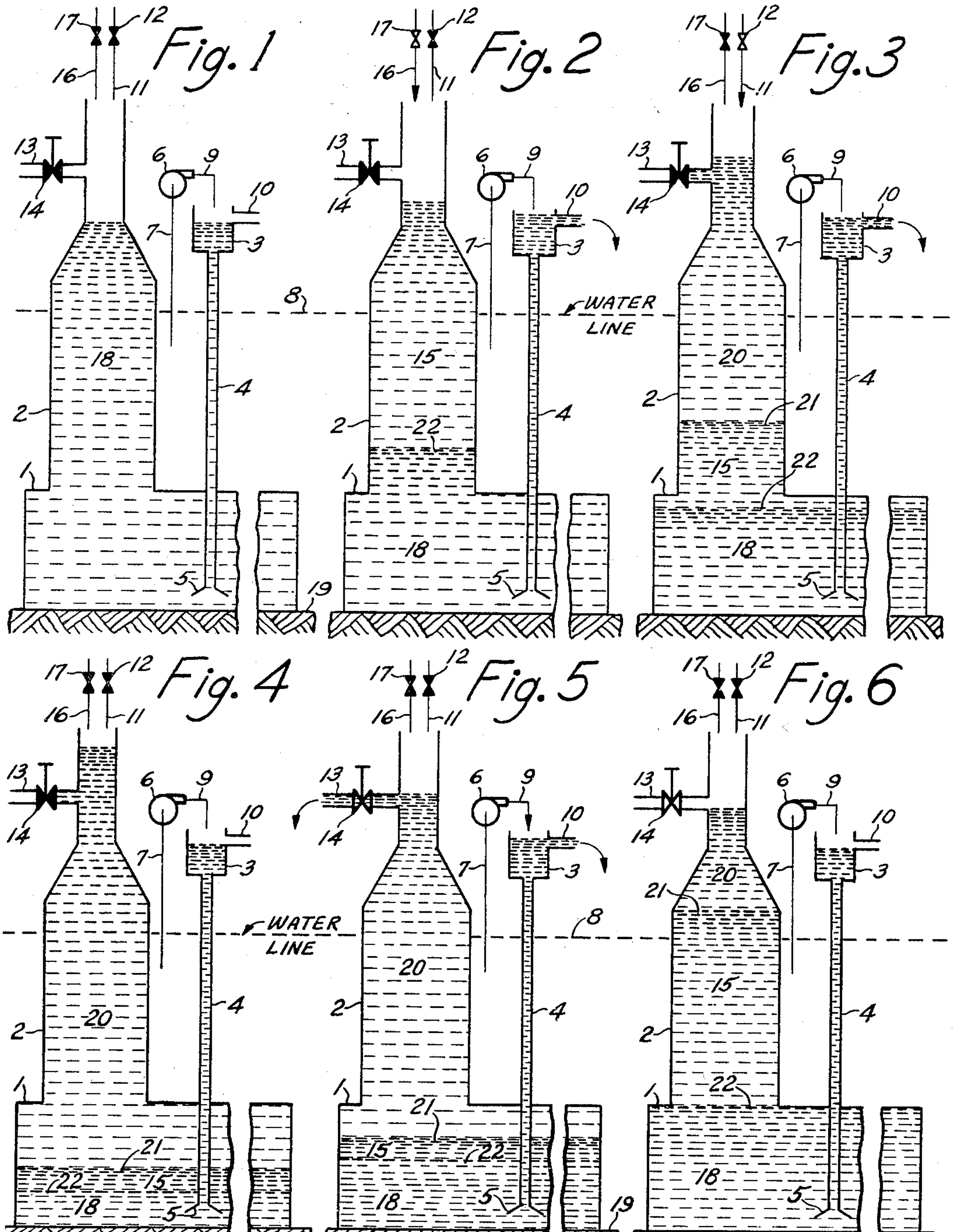
Jan. 13, 1970 R. S. LACY, JR **3,488,969**

APPARATUS FOR THE STORAGE OF PETROLEUM UNDER WATER

Filed Dec. 28, 1967 3 Sheets-Sheet 1



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APPARATUS FOR THE STORAGE OF PETROLEUM UNDER WATER

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FIG. 9

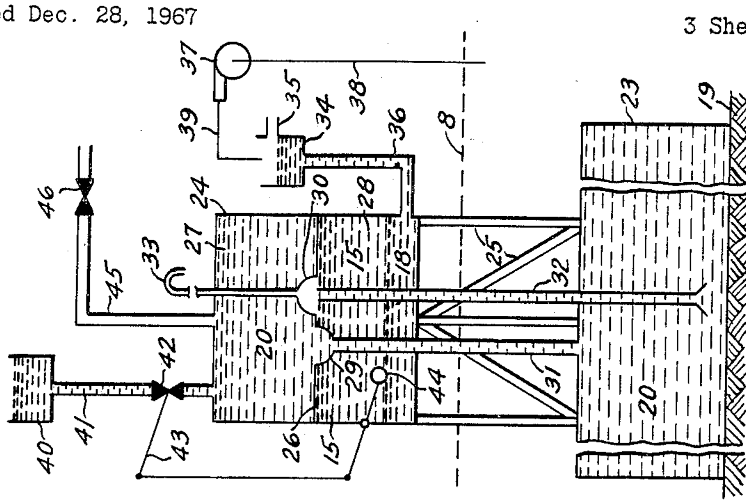


FIG. 7

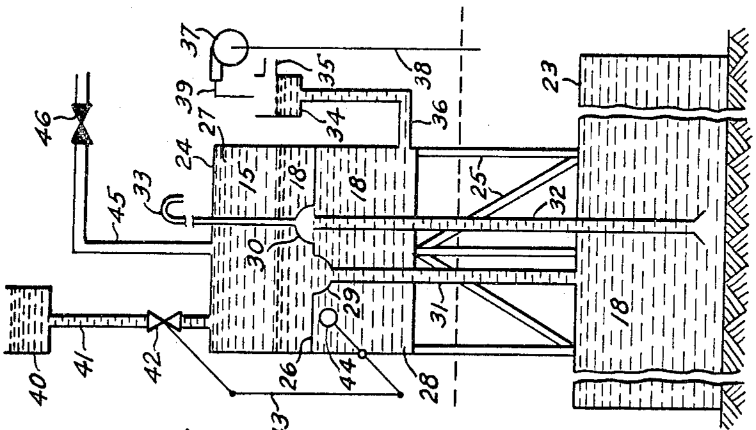
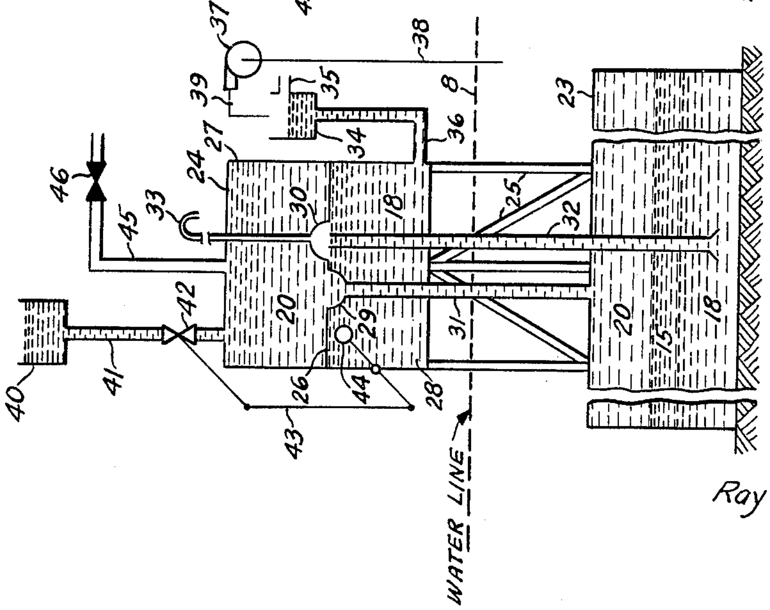


FIG. 8



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APPARATUS FOR THE STORAGE OF PETROLEUM UNDER WATER

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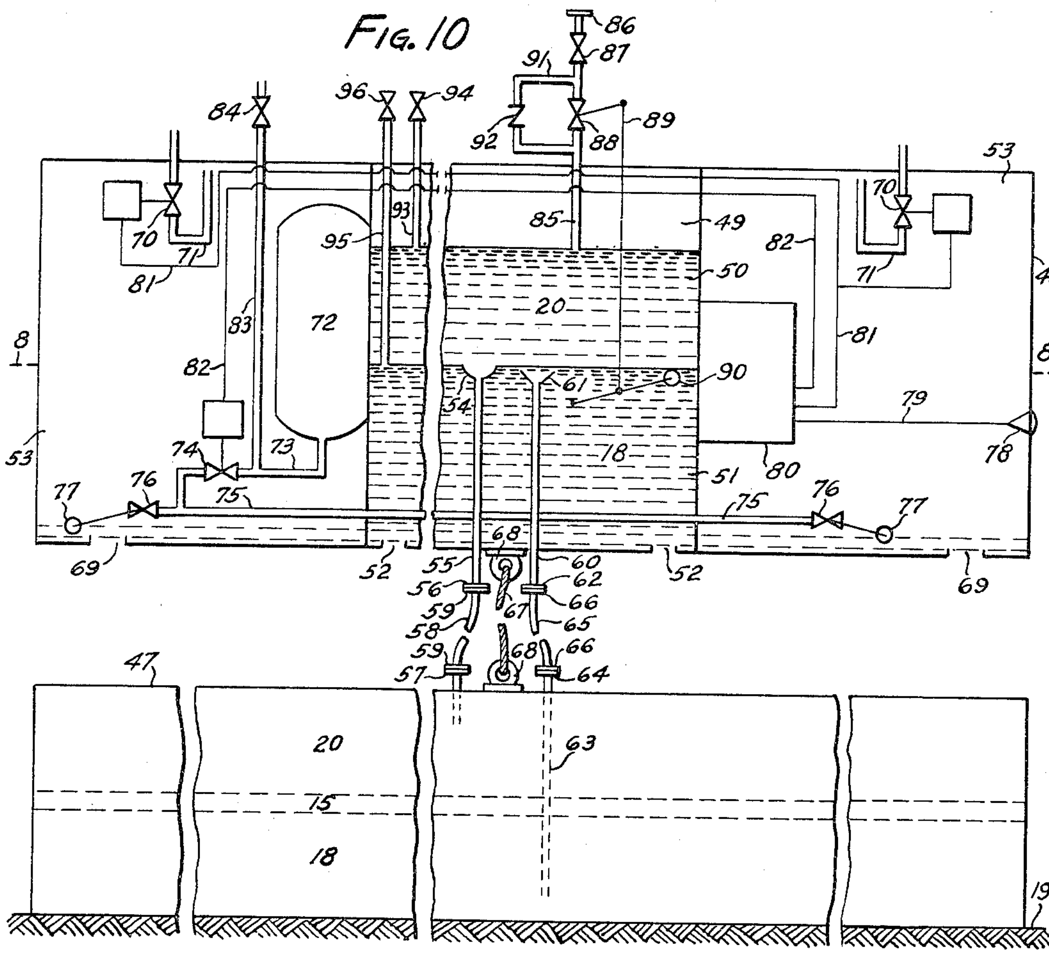
FIG. 10



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3,488,969

APPARATUS FOR THE STORAGE OF PETROLEUM UNDER WATER

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Continuation-in-part of application Ser. No. 478,697, Aug. 10, 1965. This application Dec. 28, 1967, Ser. No. 706,207
Int. Cl. E02b *17/00, 1/00*
U.S. Cl. 61—63 10 Claims

ABSTRACT OF THE DISCLOSURE

Separating liquid is interposed between petroleum and water in hydraulic-displacement type submerged storage apparatus. Water tank with overflow provides constant displacement head operating through separating liquid against petroleum. Compartments may be provided to hold all separating liquid at completion of discharging or charging operations to prevent escape of separating liquid to surrounding body of water or to tanker vessel. In a modification, sonar-operated submersible float associated with submerged tank contains compartments to hold separating liquid at either end of operating cycle, displacement head being provided by surrounding body of water.

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of copending application Ser. No. 478,697 filed Aug. 10, 1965 for Method and Apparatus for the Storage of Petroleum Under Water, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates generally to method and apparatus for the storage of petroleum under water. More specifically, this invention relates to method and apparatus for the storage of petroleum under water, employing hydraulic displacement principles and providing positive separation within the storage vessel of the petroleum and the displacement water.

Hydraulic displacement type underwater petroleum storage is well known in the art today, as shown for example in U.S. Patents 3,145,539 and 3,146,458. In conventional hydraulic displacement storage apparatus which will contain varying quantities of petroleum and displacement water, the petroleum and displacement water will be in physical contact with each other at an interface. Obviously, the interface will descend as petroleum is introduced for storage in the apparatus, and the interface will ascend as petroleum is removed from storage. Ordinarily, there are few problems arising from the physical contact between petroleum and water at the interface.

The term "petroleum" as employed herein with respect to the preferred embodiment is intended to comprise crude petroleum as well as refined petroleum products such as jet fuels, all having a density less than that of water. Sometimes, under certain circumstances and with certain stored liquids, particularly jet fuels, it is desirable to prevent a petroleum-water interface and to completely physically separate the petroleum and the displacement water.

There are a number of problems in providing and maintaining such complete physical separation while at the same time retaining the advantages inherent in underwater hydraulic displacement systems, which problems to date have not been completely resolved.

One attempt at solution of the above-mentioned problem is shown in French Patent 860,130. A solid septum of density intermediate that of the stored petroleum and the displacement water floats between these two liquids. However, this is not a practical solution. A considerable amount of clearance between the perimeter of the septum and the interior walls of the storage apparatus must necessarily be provided to permit free vertical movement of the septum in the apparatus as the relative quantities of stored petroleum and the displacement water change, and this clearance immediately results in physical contact between the stored petroleum and the displacement water. Also, the horizontal cross-section of the storage apparatus is usually different at various horizontal planes through the apparatus, and the rigid septum would obviously not be capable of free vertical movement over anything more than a closely limited range. Further, the French patent assumes that the interior of the storage apparatus is clear of stiffeners and other structural members, but in practice, this is not true. For at least the foregoing reasons, the French patent provides no solution to the stated problem.

Another attempt at solution of the stated problem involves the installation of a flexible rubber-like membrane or diaphragm in the storage vessel, as proposed by several workers in this field and as shown, for example, in U.S. Patent 2,731,168. There are several drawbacks inherent in this method of solution. The perimeter of the membrane being fixed to the interior of the tank, the vertical movement of the membrane with changes in relative quantities of stored petroleum and displacement water is quite limited. Entrainment of air or gases in the storage apparatus will modify the shape of the membrane creating filling and emptying difficulties and loss of storage volume. Installation of the membrane makes for construction problems. The membrane is subject to mechanical damage and maintenance of the membrane and repairs thereto are difficult if not impossible while the storage apparatus is submerged. The membrane does not lend itself to metering the stored liquid during load and unloading.

SUMMARY OF THE INVENTION

One of the objects of this invention is to provide improved method and apparatus for the storage of petroleum under water.

Another of the objects of this invention is to provide improved hydraulic displacement type method and apparatus for storing petroleum under water.

A specific object of this invention is to provide hydraulic displacement type method and apparatus for storing petroleum under water, with means for positively and effectively separating the petroleum and the displacement water.

Still another object of this invention is to provide hydraulic displacement type method and apparatus adapted to concealment below the surface of a body of water.

Other and further objects of this invention will become apparent during the course of the following description and by reference to the accompanying drawings and the appended claims.

Briefly, it has been discovered that the foregoing objects can be attained by establishing and maintaining in the storage apparatus between the body of petroleum and the body of displacement water a layer or body of a third liquid of density intermediate the density of the stored petroleum and the density of the displacement water, which third liquid is substantially insoluble or immiscible in and inert to the said stored petroleum and the displacement water; by providing compartments of size sufficient to hold all of the third liquid at either end of the operating cycle; and by providing a submersible float which can be sunk below the surface of the surrounding body of water, for concealment, in response to sonar signals, and which can be refloated to the surface of the surrounding body of water, in response to sonar signals, and charging or discharging operations conducted therethrough in respect to a submerged storage tank.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 represents diagrammatically a vertical section of storage apparatus which has just been filled with water and sunk to rest on the marine floor.

FIGURE 2 represents diagrammatically a vertical section of the storage apparatus towards the end of the initial introduction of separating liquid.

FIGURE 3 represents diagrammatically a vertical section of the storage apparatus as petroleum is being introduced therein for storage.

FIGURE 4 represents diagrammatically a vertical section of the storage apparatus after it has been filled with petroleum.

FIGURE 5 represents diagrammatically a vertical section of the storage apparatus as petroleum is being discharged therefrom by hydraulic displacement.

FIGURE 6 represents diagrammatically a vertical section of the storage apparatus at the end of the petroleum discharge cycle.

FIGURE 7 represents diagrammatically a vertical section of a modified storage apparatus filled with water and separating liquid and resting on the marine floor.

FIGURE 8 represents diagrammatically a vertical section of the modified storage apparatus of FIGURE 7 as petroleum is being introduced therein for storage.

FIGURE 9 represents diagrammatically a vertical section of the modified storage apparatus of FIGURE 7 after it has been filled with petroleum.

FIGURE 10 represents diagrammatically a vertical view, partially in section, of a further modified storage apparatus showing the hull stably supported on the marine floor and the float at the surface of the body of water, the said apparatus being partially filled with petroleum.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention, in the preferred embodiment, includes the structure disclosed in U.S. Patent 3,145,539. While all details of the present structure necessary to a clear and complete understanding of the present invention are described herein, it is intended that the person to whom this specification is addressed will refer to the said U.S. Patent 3,145,539 for an understanding of those details not bearing on the present invention, and the disclosure of said U.S. Patent 3,145,539 is incorporated herein by reference.

The underwater petroleum storage apparatus as shown in FIGURES 1–6 is seen as comprising a liquid-tight hull **1** (corresponding to hull **1** of U.S. Patent 3,145,539) and column **2** (corresponding to column **13** of U.S. Patent 3,145,539) communicating therewith. While only one column **2** is shown in the drawing, it will be understood that more than one such column may be employed. Also, in the drawing, hull **1** may be of much larger horizontal dimension than column **2**, and this is indicated diagrammatically by the break in hull **1**.

Salt water receiver **3** (corresponding with salt water receiver **42** of U.S. Patent 3,145,539) communicates with the lower portion of hull **1** through salt water line **4** (corresponding with any of salt water lines **62–68** of U.S. Patent 3,145,539) terminating in inverted funnel **5**. Deep well pump **6** has its intake end connected to deep pump well **7** communicating with the surrounding body of water **8**, and discharges to salt water receiver **3** through salt water supply line **9**. Salt water receiver **3** has an overflow **10**.

For the purpose of clarity, salt water receiver **3** has been indicated diagrammatically as outside the column **2**. It should be understood that the said salt water receiver **3** may be mounted within column **2** as shown in the preferred embodiment of U.S. Patent 3,145,539; alternatively, salt water receiver **3** may be supported outside column **2**.

The upper portion of column **2** is provided with petroleum loading line **11**, having valve **12** therein, which may communicate with a source of petroleum such as a receiver compartment **34** as shown in U.S. Patent 3,145,539. The upper portion of column **2**, below petroleum loading line **11**, is provided with petroleum unloading line **13**, having valve **14** therein, communicating with a tanker vessel.

The present invention contemplates the interposition between petroleum and water in the underwater petroleum storage apparatus of a separating liquid **15** substantially insoluble in and inert to the petroleum and water and having a density intermediate the density of the stored petroleum and water. Line **16**, having valve **17** therein, communicates between a source of separating liquid (which may, for instance, be a tank mounted on the deck structure of the apparatus, not shown) and the upper portion of column **2**, whereby said separating liquid **15** may be introduced into the said underwater petroleum storage vessel as hereinafter described.

By way of example, and not of limitation, a suitable separating liquid **15** would be a castor oil, particularly of the grade known in the trade as "blown" or oxidized. As shown in the 1955 catalog of The Baker Castor Oil Company, blown or oxidized castor oils having specific gravities of about 0.97 are commercially available. The specific gravity of sea water is about 1.02. The specific gravity of typical jet fuels is about 0.80 and may range between about 0.83–0.90 for typical petroleum crudes (30° A.P.I.–25.5° A.P.I.). Therefore, these castor oils will float on sea water below a stored petroleum and can effectively separate the two last-mentioned liquids.

The operation of the underwater petroleum storage apparatus shown in FIGURES 1–6 will now be described. It will be understood that the structure, in the preferred embodiment, is marine stable and can be transported on its own buoyancy to the desired location. Thereafter, the structure is ballasted with water **18**, through conventional ballast piping (not shown) or through salt water receiver **3**, and submerged to rest on the marine floor **19**. If desired, piles, well-known in the art, may be employed to anchor the structure to marine floor **19**. Also, the structure may be submerged to a position intermediate the surface of the sea **8** and marine floor **19** and stably supported in such position as by conventional piles.

The structure is now ready for the introduction of the separating liquid **15**. Valve **17** is opened and separating liquid **15** flows from the source of separating liquid into the upper portion of column **2** and onto the surface of water **18**. As the level of separating liquid **15** rises in column **2**, water **18** in the structure will be discharged through overflow **10** of salt water receiver **3**. A sufficient quantity of separating liquid **15** is introduced into the structure to provide a layer of adequate thickness when the said separating liquid **15** is subsequently displaced to those parts of the structure having a greater horizontal cross section as hull **1**.

The structure is now ready for the introduction of petroleum **20**. Valve **12** is opened and petroleum **20** flows from the source of petroleum into the upper portion of column **2** and onto the surface of separating liquid **15**. As the level of petroleum **20** rises in column **2**, water **18** in the structure will be discharged through overflow **10** of salt water receiver **3**. When the structure has been filled with petroleum **20**, separating liquid **15** will extend completely from one side to the other of hull **1**, and will function as a total barrier between water **18** and petroleum **20**.

When it is desired to remove from storage petroleum in the structure, deep well pump **6** is operated to introduce water **18** from the surrounding body of water **8** into salt water receiver **3**, and valve **14** is opened. Water **18** passes through salt water line 4 into hull 1, and petroleum is displaced from the structure through unloading line 13. Any water 18 in excess of that required to displace petroleum 20 at the desired rate is discharged from salt water receiver 3 through overflow 10.

Means such as float controls responsive to the petroleum-separating liquid interface 21 and the separating liquid-water interface 22 may be employed to shut down deep well pump 6 when the petroleum-separating liquid interface 21 approaches the level of unloading line 13, and to close valve 12 when the separating liquid-water interface 22 approaches funnel 5, so as to prevent loss of separating liquid 15 through overflow 10 or unloading line 13.

The underwater petroleum storage apparatus may be deballasted by suitable conventional means and refloated to another site.

It may be desired to eliminate altogether column 2, and to employ only hull 1 for storage of petroleum 20. Such a structure would be completely submerged in the body of water 8 except for those elements which may be desired to be operated from the surface of the said body of water 8. Thus, petroleum loading line 11 and unloading line 13 and separating liquid line 16 can communicate directly with hull 1. If a salt water receiver 3 is to be employed, salt water line 4 can communicate with hull 1 as in the preferred embodiment shown in the drawings. Alternatively, salt water receiver 3 can be eliminated, and also hull 1 can communicate directly with the body of water 8, if this is desired.

It will be understood that FIGURES 1–6 are essentially diagrammatic, and the levels of the various liquids in the structure are illustrative only. Also, the present invention is capable of use with other liquids not classified as "petroleum" but lighter than and insoluble in the separating liquid, and the use of the term "petroleum" in the appended claims is intended to cover these other liquids.

Some of the advantages accruing from the present invention are:

(1) The separating liquid 15 is not susceptible to mechanical damage, unlike the solid septum or flexible membrane earlier referred to.

(2) The separating liquid 15 is easily introduced into the structure when the latter is bottomed on the marine floor 19. In the unlikely event that separating liquid 15 is lost due to malfunctioning interface-responsive control means, or in the event it becomes ineffective, it may easily be replaced without having to gain entrance to the interior of the structure and without having to refloat the structure.

(3) Should free water or other heavy contaminant be introduced into the structure along with petroleum 20, such constituents would pass through the separating liquid 15 and into the water 18.

(4) Accurate metering of petroleum 20 is assured.

The underwater petroleum storage apparatus as shown in FIGURES 7–9 is seen as comprising a liquid-tight storage hull 23 adapted to be submerged below the surface of the surrounding body of water 8 and stably supported, as by grounding, on marine floor 19, and a chamber 24 adapted to be supported at or above the surface of the surrounding body of water 8. One means of supporting chamber 24 is shown diagrammatically in FIGURES 7–9 as comprising structural members 25 extending between the said chamber 24 and hull 23.

Chamber 24 is divided by wall 26 into an upper compartment 27 and a lower compartment 28. A sump 29 and a dome 30 are provided in wall 26. Conduit 31 communicates between upper compartment 27 through sump 29, and the upper portion of hull 23. Conduit 32 communicates between the upper portion of lower compartment 28, through dome 30, and the lower portion of hull 23. A vent conduit 33 communicates between lower compartment 28, through dome 30, and the atmosphere.

Salt water receiver 34, having overflow 35, communicates with the lower portion of lower compartment 28 through salt water conduit 36. Deep well pump 37 has its intake end connected to deep pump well 38 communicating with the surrounding body of water 8, and discharges to salt water receiver 34 through salt water supply line 39.

Petroleum receiver 40, suitably supported above chamber 24 by means not shown, communicates through petroleum loading conduit 41 with the upper portion of upper compartment 27. Valve 42 in conduit 41 is opened or closed by means of linkage 43 indicated diagrammatically in FIGURES 7–9, the said linkage 43 being actuated by float 44 in a manner to be described. Petroleum unloading conduit 45, having valve 46 therein, communicates between the upper portion of upper compartment 27 and a tanker vessel (not shown).

The object of the modification of FIGURES 7–9 is to provide sufficient volume in upper compartment 27 at the proper elevation relative to overflow 35 to prevent the accidental discharge of separating liquid 15 along with petroleum 20 through petroleum unloading conduit 45, during the operation of discharging petroleum 20 to a tanker vessel, and to provide sufficient volume in lower compartment 28 to prevent the accidental discharge of separating liquid 15 along with water 18 through overflow 35, during the operation of filling the storage apparatus with petroleum.

In order to attain the first objective mentioned in the preceding paragraph, the elevation of overflow 35 should not provide such a head as would be in excess of the head of water 18 and separating liquid 15 present in upper compartment 27 at the conclusion of the operation of discharging petroleum 20 from the storage apparatus. If the head provided by overflow 35 were in excess of this amount, then, at or before the conclusion of this operation, separating liquid 15 would be forced upwardly and into petroleum unloading conduit 45 and assuming that the volume of petroleum unloading conduit 45 is negligible, thence into the tanker vessel. Specifically, upper compartment 27 should be large enough to contain all of the separating liquid 15 at the conclusion of the operation of discharging petroleum 20 from the storage apparatus, when the head provided by overflow 35 balances the head of separating liquid 15 and water 18 in upper compartment 27.

In order to attain the second objective mentioned in the paragraph preceding the foregoing paragraph, the volume of that portion of lower compartment 28 lying above the top of the opening communicating with conduit 36 should be larger than the volume of separating liquid.

Under the foregoing conditions, separating liquid 15 cannot be discharged with either the petroleum 20 or the water 18 at the conclusion of either cycle of operation (i.e., discharging or storing petroleum 20).

Float 44 is responsive to the interface between water 18 and separating liquid 15 in that the said float 44 floats on water 18 and sinks in separating liquid 15 and therefore always moves vertically in response to vertical excursions of the separating liquid-water interface. Float 44 is positioned in lower compartment 28 at such a level as to close valve 42, through linkage 43, when a predetermined quantity of separating liquid 15 has entered the lower compartment 28 (i.e., when the separating liquid-water interface has descended to a predetermined point which will be slightly above the opening communicating between lower compartment 28 and conduit 36). At this point in the operating cycle, the storage apparatus is considered filled to capacity with petroleum 20.

It will be understood that the relative heights of overflow 35, petroleum receiver 40 and petroleum unloading conduit 45 are as described in U.S. Patent 3,145,539, so as to permit the apparatus to be operated on hydraulic displacement principles. Briefly, in filling the storage apparatus with petroleum 20, the height of petroleum receiver 40 is sufficient to permit petroleum 20 to displace water 18 from the storage apparatus out through overflow 35, and in discharging petroleum 20 from the storage apparatus, the height of overflow 35 is sufficient to permit water 18 to displace petroleum 20 out through petroleum unloading conduit 45, it being understood that the petroleum 20 and water 18 are never in contact but rather are always separated by separating liquid 15.

The operation of the underwater petroleum storage apparatus shown in FIGURES 7–9 will now be described, it being understood that this operation generally follows that described for the species of FIGURES 1–6.

The apparatus is filled with water 18 and stably supported on marine floor 19. Separating liquid 15 is then introduced in the proper quantity into upper compartment 27, through petroleum receiver 40 if desired or through another suitable conduit. The apparatus is now generally in the condition shown in FIGURE 7, except, of course, there will be no petroleum 20 in the petroleum receiver 40 at this time.

The apparatus is ready to receive petroleum 20 which is introduced into petroleum receiver 40, valve 42 being open. The petroleum 20 displaces separating liquid 15 from upper compartment 27 to hull 23, and water 18 out through overflow 35. In the intermediate portion of this operation, the apparatus is in the condition shown in FIGURE 8. This operation is continued until the separating liquid 15 has been displaced to the lower compartment 28 and float 44 has dropped to operate linkage 43 and thereby to close valve 42. It will, of course, be understood that vent conduit 33 is of sufficient height to prevent separating liquid 15 from being displaced out of the top of said vent conduit 33. The apparatus is now in the condition shown in FIGURE 9.

When it is desired to discharge petroleum 20 from the apparatus, valve 46 is opened and pump 37 is operated to introduce water to salt water receiver 34. Water 18 displaces separating liquid 15 from lower compartment 28 to hull 23 and petroleum 20 to upper compartment 27 and thence to petroleum unloading conduit 45. In the intermediate portion of this operation, the apparatus is in the condition shown in FIGURE 8. This operation is continued until the separating liquid 15 has been displaced to the upper compartment 27 and the head of water 18 and separating liquid 15 in upper compartment 27 balances the head provided by overflow 35. The apparatus, now in the condition shown in FIGURE 7, is discharged of petroleum 20.

The underwater petroleum storage apparatus as shown in FIGURE 10 is seen as comprising a liquid-tight-storage hull 47 adapted to be submerged below the surface of the surrounding body of water 8 and stably supported, as by grounding, on marine floor 19, and a submersible float 48 adapted to be floated to the surface of the body of water 8 or selectively to be submerged below the surface of said body of water 8. It will be understood that the dimensions of the hull 47 may be many times the dimensions of the hull 48.

Float 48 comprises permanent buoyancy compartment 49 adjacent the upper portion of float 48, an upper liquid tank 50 below the buoyancy compartment 49, and a lower liquid tank 51 below the upper liquid tank 50. Lower liquid tank 51 is provided with apertures 52 in the bottom thereof communicating with the body of water 8. Variable buoyancy compartments 53 are located at the ends of float 48. Variable buoyancy compartments 53 are so proportioned that, when they are ballasted or filled with water, float 48 will sink below the surface of the body of water 8, and when the said variable buoyancy compartments 53 are deballasted or emptied of water, float 48 will float to the surface of the body of water 8 with the bottom of upper liquid tank 50 at or closely adjacent the surface of the body of water 8. The volume of the upper liquid tank 50 is greater than the volume of separating liquid 15, and specifically, can hold the entire volume of separating liquid 15 plus any water 18 that might enter upper liquid tank 50 when float 48 is at the surface of the body of water 8. Similarly, the volume of lower liquid tank 51 is greater than the volume of separating liquid 15. Sump 54 is provided in the partition between upper and lower liquid tanks 50 and 51, and conduit 55 extends from sump 54 to beyond the bottom of float 48, the extremity of conduit 55 being provided with a flanged fitting 56.

Flanged fitting 57 is provided on the top of hull 47, in communication with the upper portion thereof. Flexible conduit 58, provided with flanged fittings 59 at both ends thereof, is mounted between flanged fittings 56 and 57, thereby to place the lower portion of upper liquid tank 50 in communication with the upper portion of hull 47.

Conduit 60, the upper end of which is provided with funnel 61, communicates between the upper portion of lower liquid tank 51 and a point beyond the bottom of float 48, terminating in flanged fitting 62. Conduit 63 communicates between the lower portion of hull 47 and flanged fitting 64 on the top of hull 47. Flexible conduit 65, provided with flanged fittings 66 at both ends thereof, is mounted between flanged fittings 62 and 64, thereby to place the upper portion of lower liquid tank 51 in communication with the lower portion of hull 47.

Cable 67 is secured between ears 68 mounted to float 48 and hull 47, the length of said cable 67 preferably being less than the lengths of flexible conduits 58 and 65, whereby to prevent said flexible conduits 58 and 65 from being stressed in tension.

Each variable buoyancy compartment 53 is provided with an aperture 69 in the bottom thereof communicating with the body of water 8. Each variable buoyancy compartment 53 is also provided with a solenoid-operated valve 70 in a vent conduit 71 communicating between the upper portion of said compartments 53 and the body of water 8.

A compressed gas tank 72 is mounted in one of the variable buoyancy compartments 53, as shown in the drawings. Conduit 73, provided with solenoid-operated valve 74 communicates between compressed gas tank 72 and conduit 75, the latter communicating with both variable buoyancy compartments 53 through float controlled valves 76, the floats 77 being designed to float in water and open valves 76 and to sink in a gaseous atmosphere and close valves 76, thereby to follow the water-gas interface as hereinafter described.

Receiver 78, adapted to receive coded sonar signals, is mounted in an external wall of variable buoyancy compartment 53, and is electrically connected through line 79, to activating device or relay 80, also mounted within the variable buoyancy compartment 53. Activating device 80 is adapted to produce electrical signals in response to the coded sonar signals received by receiver 78, the electrical signals so produced being fed through lines 81 and 82 to solenoid-operated valves 70 and 74, whereby to operate said valves 70 and 74 in a manner to be described hereinafter. Receiver 78 and activating device 80, energized by a battery (not shown) are regularly commercially available, as is known to those familiar with this art, and need not be described herein in detail.

Conduit 83 communicates with conduit 73 between solenoid-operated valve 74 and compressed gas tank 72, and extends above the top of float 48, terminating in valve 84. Conduit 83 is used to recharge compressed gas tank 72 with gas as required.

The distribution of weight and the disposition and volume of the several buoyancy compartments in float 48 are selected so that the center of buoyancy of the float 48 is always above the center of gravity of the float 48. Thus, float 48 will always maintain an upright position whether afloat or submerged.

Conduit 85 communicates between the upper portion of upper liquid tank 50 and a point above the top of float 48, terminating in flanged fitting 86. Valves 87 and 88 are provided in conduit 85, valve 88 being opened or closed through linkage 89 operated by float 90 in lower liquid tank 51, indicated diagrammatically in FIGURE 10. Float 90 is designed to sink in separating liquid 15 and to float in water 18, closing valve 88 as the water-separating liquid interface falls to a predetermined level. Float 90 is preferably positioned in lower liquid tank 51 at such a level as to close valve 88 when all of the separating liquid 15 has been displaced to lower liquid tank 51 and the apparatus is, at this point in the operating cycle, considered filled with petroleum 20. Conduit 91 bypasses valve 88 and is provided with check valve 92 adapted to permit flow around valve 88 in a direction leading from upper liquid tank 50 to flanged fitting 86, and to block flow in the reverse direction.

Vent conduit 93 extends from the upper portion of upper liquid tank 50 to a point above float 48, and is provided with valve 94 at its upper end. Similarly, vent conduit 95 extends from the upper portion of lower liquid tank 51 to a point above float 48, and is provided with valve 96 at its upper end.

The operation of the underwater storage apparatus shown in FIGURE 10 will now be described.

Hull 47 is brought to location, either on its own buoyancy or by means of another vessel. Hull 47 is then filled with water through flanged fitting 64 and conduit 63, the air within hull 47 being vented through flanged fitting 57, the said hull 47 sinking until it is stably supported on marine floor 19.

Float 48 is then floated over the submerged hull 47, all valves thereon being closed. Cable 67 is secured between ears 68 thereby to anchor float 48 over submerged hull 47, and permitting float 48 to function as a mooring buoy. Flanged fittings 59 of flexible conduit 58 are secured to flanged fittings 56 and 57 on float 48 and hull 47 respectively. Similarly, flanged fittings 66 on flexible conduit 65 are secured to flanged fittings 62 and 64 on float 48 and hull 47 respectively.

Valve 96 in vent conduit 95 may now be opened, permitting water 18 to enter float 48 through apertures 52 and to flood lower liquid tank 51, after which valve 96 is closed. It will, at this point, be noted that float 90 has risen in response to the introduction of water 18 into the lower liquid tank 51 and, through linkage 89, to open valve 88.

A conduit (not shown) communicating with a source of separating liquid 15 (on a tanker vessel, not shown, for instance) is connected to flanged fitting 86 of conduit 85. Valve 87 in conduit 85, and valve 94 in vent conduit 93 are opened. The required quantity of separating liquid 15 is now introduced through conduit 85 into upper liquid tank 50, any air in said upper liquid tank 50 venting through vent conduit 93. Valve 94 is then closed, and the heretofore mentioned conduit (not shown) communicating with the source of separating liquid is disconnected from flanged fitting 86.

A conduit (not shown) communicating with a source of petroleum 20 (on a tanker vessel, not shown for instance) is connected to flanged fitting 86 of conduit 85, and petroleum 20 is introduced into upper liquid tank 50, displacing separating liquid 15 through conduit 55 into hull 47, water 18 being displaced ahead of the separating liquid 15 up through conduits 63 and 65 into lower liquid tank 51 and out through apertures 52. The introduction of petroleum 20 through conduit 85 is continued until, in the preferred mode of operation, all of the separating liquid 15 has entered lower liquid tank 51 and the storage apparatus is now considered filled with petroleum 20. It will be particularly noted that, in this phase of operation, none of the separating liquid 15 can be displaced to the surrounding body of water, due to the capacity of lower liquid tank 51. Float 90 in lower liquid tank 51 has been positioned to respond to the descent of the water-separating liquid interface to a level indicating that all of the separating liquid 15 is in the lower liquid tank 51, and at this point the said float 90, through linkage 89, closes valve 88 and thus signals completion of the charging operation. Valve 87 is closed, and the heretofore mentioned conduit (not shown) communicating with the source of petroleum 20 is disconnected from the flanged fitting 86.

Float 48 is now ready to be submerged for concealment below the surface of the body of water 8. A coded sonar signal is generated by a transmitter located, for example, on the tanker vessel, and is received by receiver 78 which actuates activating device 80 to operate the solenoids of valves 70 to open the said valves 70, thus venting variable buoyancy compartments 53 and permitting water from the surrounding body of water 8 to enter the variable buoyancy compartments 53 through apertures 69. Variable buoyancy compartments 53 are proportioned so as to be capable of reducing the buoyancy of float 48 to a negative buoyancy when sufficiently ballasted. As water enters variable buoyancy compartments 53, the freeboard of float 48 is reduced and then the float sinks below the surface of the body of water 8 for concealment. The position of the center of buoyancy above the center of gravity in the float 48 assures that the float remains right-side-up even when submerged. A coded sonar signal is now transmitted to close vent valves 70, through the medium of receiver 78 and activating device 80.

Assume now that petroleum 20 is to be withdrawn from the apparatus and loaded onto a vessel. It is necessary to refloat float 48 before petroleum 20 can be withdrawn from hull 47. As variable buoyancy compartments 53 have been flooded with water, floats 77 have floated to their upward positions and their respective valves 76 are open. A coded sonar signal is generated by a transmitter located on the vessel (not shown) and is received by receiver 78 which actuates actuating device 80 to operate the solenoid of valve 74 to open the said valve 74. Gas from compressed gas tank 72 enters variable buoyancy compartments through conduits 73 and 75, under pressure, and displaces water from said variable buoyancy compartments 53 out through apertures 69 into the surrounding body of water 8. As this continues, and as the variable buoyancy tanks 53 are deballasted, float 48 assumes a positive buoyancy, rising to the surface of the body of water 8 and acquiring freeboard. When the variable buoyancy compartments 53 have been deballasted to the desired extent, so that the gas (or air)-water interfaces in the said compartments 53 have descended to a predetermined level, floats 77 having followed these interfaces down will, at the predetermined level, close valves 76 thus shutting off the flow of gas from compressed gas tank 72. In the interest of conserving gas, the floats 77 may be positioned to close valves 76 before the gas-water interface has descended to the desired level (i.e., before the variable buoyancy compartments 53 have been completely deballasted), the pressure of the gas in variable buoyancy compartments 53 being sufficient to expel water 18 through apertures 69 as the float 48 rises and hydrostatic head thereon decreases. A coded sonar signal is now generated by the transmitter on the vessel (not shown) and is received by receiver 78 which actuates activating device 80 to operate the solenoid of valve 74 to close the said valve 74. A conduit (not shown) communicating with the tanker vessel is connected to flanged fitting 86 on conduit 85. It will be recalled that float 90 has closed valve 88. Valve 87 is opened and the hydrostatic head of the body of water 8 exerted through apertures 52 is sufficient to displace separating liquid 15 from lower liquid tank 51 down through conduit 65 into hull 47, and petroleum 20 ahead of the separating liquid 15 from hull 47 up through conduit 58 into upper liquid tank 50 and thence through conduit 85 and check valve 92 to the tanker vessel. That is to say, the ratio of the depth of the body of water to the height above marine bottom 19 of the highest point in the petroleum loading system is greater than the ratio of petroleum density to water density. As this operation continues, the separating liquid-water interface in lower liquid compartment 51 will rise, carrying float 90 upwardly and thus opening valve 88, so that thereafter some of the flow of petroleum **20** outwardly from float **48** will be through valve **88.**

As heretofore mentioned, variable buoyancy compartments **53** are so proportioned that, when they are deballasted, float **48** will have such freeboard as to maintain the bottom of upper liquid tank **50** at or closely adjacent the surface of the body of water, and, also, that the volume of upper liquid tank **50** can hold the entire volume of separating liquid **15** as well as any water **18** that might enter upper liquid tank **50.** It is apparent, then, that the hydraulic displacement of petroleum **20** from the storage apparatus will automatically stop when all of the separating liquid **15** has been displaced to upper liquid tank **50** and the head of the surrounding body of water **8** is in equilibrium with the head of water **18** and separating liquid **15** in the storage apparatus. It will be particularly noted that none of the separating liquid **15** can be displaced to the tanker vessel in this phase of operation of the present invention, due to the capacity and elevation of upper liquid tank **50.** At the conclusion of this step, the heretofore mentioned conduit (not shown) communicating with the tanker vessel is disconnected from flanged fitting **86** and valve **87** is closed.

Vent valves **70** are opened by means of the coded sonar signal as hereinbefore described, through the receiver **78** and activating device **80**, and float **48** is submerged to a concealed position below the surface of the body of water **8**, after which vent valves **70** are closed by means of another coded sonar signal in the same manner.

When it is desired to refill the storage apparatus with petroleum **20**, float **48** is raised by a coded sonar signal, as hereinbefore described.

I claim:

1. Marine hydraulic-displacement petroleum storage apparatus comprising:

(a) a storage tank adapted to be floated to and submerged at a marine location and stably supported adjacent the marine bottom,
(b) a first chamber,
(c) a second chamber below said first chamber,
(d) support means mounted to said storage tank and supporting said first and second chambers above the surface of the surrounding water,
(e) first conduit means communicating with the upper portion of said first chamber to introduce a separating liquid having a specific gravity intermediate that of petroleum and water and substantially insoluble in said petroleum and water into said first chamber or selectively to introduce petroleum into said first chamber,
(f) second conduit means communicating between the lower portion of said first chamber and the upper portion of said storage tank,
(g) third conduit means communicating with the upper portion of said first chamber to withdraw petroleum from said first chamber,
(h) fourth conduit means communicating with the lower portion of said second chamber to introduce water into said second chamber or selectively to discharge water from said second chamber,
(i) fifth conduit means communicating between the upper portion of said second chamber and the lower portion of said storage tank,
(j) the volume of said first chamber being at least equal to the volume of separating liquid introduced into said storage apparatus,
(k) the volume of said second chamber being at least equal to the volume of separating liquid introduced into said storage apparatus,
(l) whereby said separating liquid forms a layer floating on the surface of the water in said storage apparatus and in contact with said petroleum, thereby forming a barrier between and completely separating said petroleum and water, said layer of separating liquid being further adapted to travel vertically in said storage apparatus through a major portion of the height thereof as the relative quantities of petroleum and water in said storage apparatus vary.

2. Apparatus as in claim **1**, further comprising:

(m) a valve in said first conduit means,
(n) means in said second chamber responsive to the level therein of the interface between said water and said separating liquid, said means being adapted to close said valve when said interface has fallen to a predetermined level within said second chamber.

3. Apparatus as in claim **2**, further comprising:

(o) a compartment containing said first and second chambers,
(p) a horizontal partition within said compartment separating said first and second chambers,
(q) a sump in said partition communicating with said first chamber,
(r) said second conduit means communicating with said sump,
(s) a dome in said partition communicating with said second chamber,
(t) said fifth conduit means communicating with said dome.

4. Marine hydraulic-displacement petroleum storage apparatus comprising:

(a) a storage tank adapted to be floated to and submerged at a marine location and stably supported adjacent the marine bottom,
(b) a float,
(c) means to float said float at the surface of the surrounding body of water or selectively to submerge said float below the surface of the surrounding body of water,
(d) a first chamber within said float,
(e) a second chamber within said float below said first chamber,
(f) first conduit means communicating with the upper portion of said first chamber to introduce a separating liquid having a specific gravity intermediate that of petroleum and water and substantially insoluble in said petroleum and water into said first chamber or selectively to introduce petroleum into said first chamber or selectively to withdraw petroleum from said first chamber,
(g) second conduit means communicating between the lower portion of said first chamber and the upper portion of said storage tank,
(h) third conduit means communicating between the lower portion of said second chamber and the surrounding body of water,
(i) fourth conduit means communicating between the upper portion of said second chamber and the lower portion of said storage tank,
(j) the volume of said first chamber being at least equal to the volume of separating liquid introduced into said storage apparatus,
(k) the volume of said second chamber being at least equal to the volume of separating liquid introduced into said storage apparatus,
(l) whereby said separating liquid forms a layer floating on the surface of the water in said storage apparatus and in contact with said petroleum, thereby forming a barrier between and completely separating said petroleum and water, said layer of separating liquid being further adapted to travel vertically in said storage apparatus through a major portion of the height thereof as the relative quantities of petroleum and water in said storage apparatus vary,
(m) and whereby said float may be submerged for concealment below the surface of the surrounding body of water.

5. Apparatus as in claim **4**, further comprising:

(n) a valve in said first conduit means,
(o) means in said second chamber responsive to the level therein of the interface between said water and

said separating liquid, said means being adapted to close said valve when said interface has fallen to a predetermined level within said second chamber.

6. Apparatus as in claim **5**, further comprising:

(p) a fifth conduit connected at both ends to said first conduit and bypassing the valve in said first conduit,

(q) a check valve in said fifth conduit adapted to permit the passage of fluid from said first chamber only.

7. Apparatus as in claim **4**, further comprising:

(n) a variable buoyancy compartment in said float,

(o) fifth conduit means communicating between the lower portion of said variable buoyancy compartment and the surrounding body of water,

(p) said means to float said float or selectively to submerge said float comprising:

first means to introduce gas into said variable buoyancy compartment to displace water therefrom through said fifth conduit means to said surrounding body of water,

second means to vent gas from said variable buoyancy compartment thereby to permit water from the surrounding body of water to enter said variable buoyancy compartment through said fifth conduit means,

third means responsive to a signal to actuate said first means or selectievly said second means thereby to float said float or selectively to submerge said float.

8. Apparatus as in claim **7**, further comprising:

(q) fourth means in said variable buoyancy compartment responsive to the level therein of the interface between said water and said gas, said fourth means being adapted to automatically deactivate said first means when said interface has fallen to a predetermined level within said variable buoyancy compartment.

9. Apparatus as in claim **4**, further comprising:

(n) a horizontal partition within said float separating said first and second chambers, said horizontal partition being at a level closely adjacent the surface of the surrounding body of water when said float has been floated to the surface of the surrounding body of water.

10. Apparatus as in claim **4**, further comprising:

(n) a permanently void compartment adjacent the upper portion of said float,

(o) the center of buoyancy of said float always being above the center of gravity of said float.

References Cited

UNITED STATES PATENTS

2,942,424	6/1960	Koble	61—.5
2,986,007	5/1961	Shook	61—.5
3,145,539	8/1964	Estes et al.	61—46.5

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61—.5, 46.5