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[54] **SUB-AQUEOUS STORAGE OF LIQUEFIED GASES**

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[51] **Int. Cl.** **F17c 1/00**
[58] **Field of Search** .... 62/45; 220/9 LG, 220/18; 61/0.5, 46; 114/0.5 T, 74 A; 222/386.5

[56] **References Cited**

UNITED STATES PATENTS

2,798,633	7/1957	Cornell et al.	220/18 X
2,924,350	2/1960	Greer	220/18 X
3,396,544	8/1968	Manning	61/46
3,471,349	10/1969	Cohen et al.	222/386.5 X
3,518,836	7/1970	Itokawa	61/0.5
3,599,590	8/1971	Rego	114/0.5 T

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[57] **ABSTRACT**

Liquefied natural gas is stored under water in a submerged, jacketed container the interior of which is coupled to a balancing fluid in another container, the balancing fluid being in turn coupled to the water surrounding both containers. The containers are fastened together, and the assembly is ballasted as appropriate, or required.

11 Claims, 2 Drawing Figures

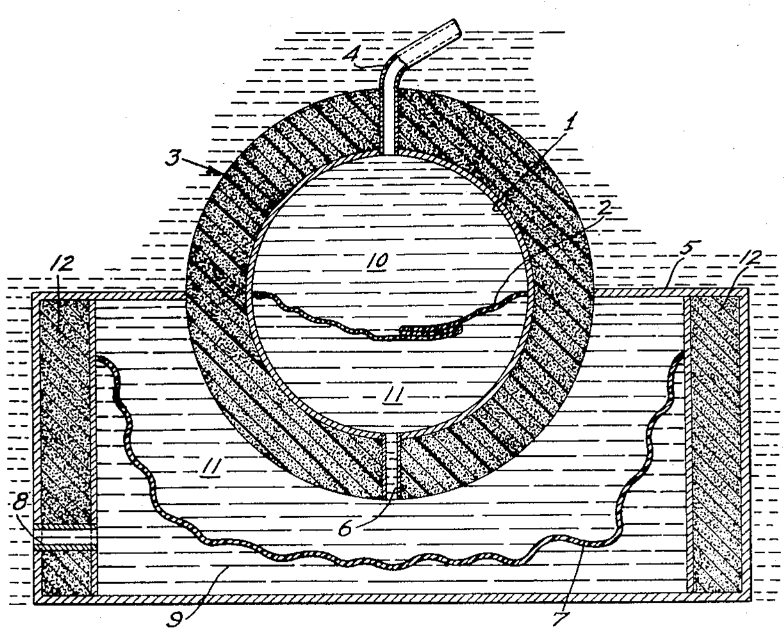


FIG. 1.

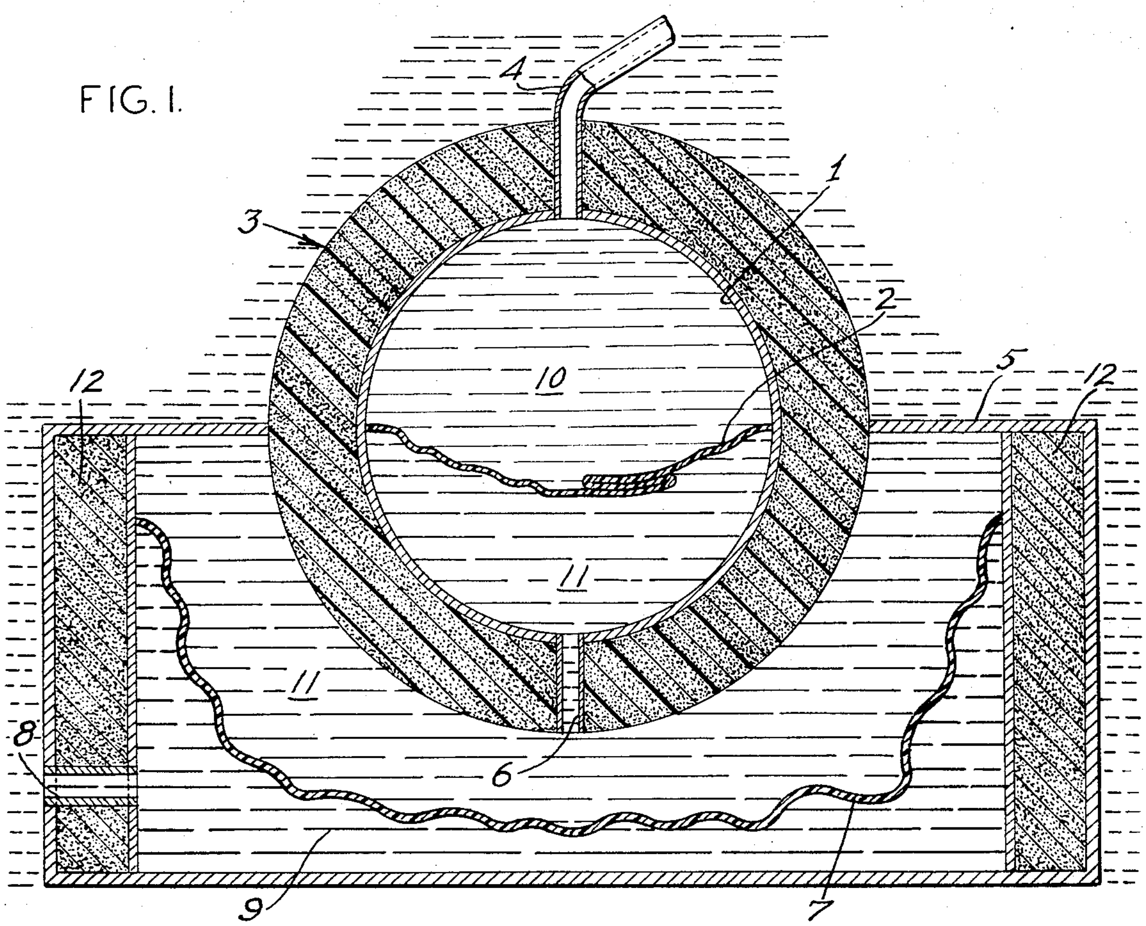
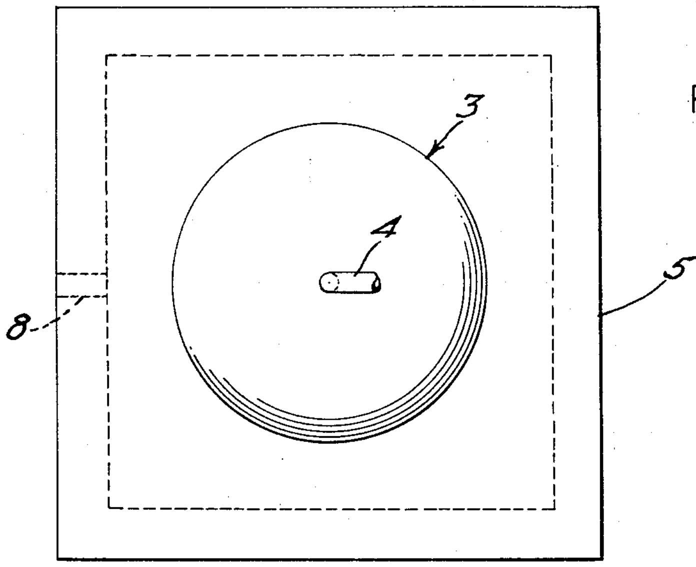


FIG. 2.



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SUB-AQUEOUS STORAGE OF LIQUEFIED GASES

This invention relates to the storage and/or transportation of liquefied gases under water, and more particularly to an arrangement for the sub-aqueous storage of liquefied natural gas (LNG).

A need for storage facilities for natural gas exists, near the major areas of distribution (which is to say, near the major markets which exist in large metropolitan and industrial areas in the north, northeastern, Gulf Coast, and Pacific Coast regions of the United States). A recent development for providing underground-storage capacity for natural gas involves freezing the earth and subsequent mining, to form underground caverns. However, this technique is quite expensive, and requires scarce and valuable real estate.

The present invention discloses the sub-aqueous storage of LNG, and has several advantages over the dry land method of storage previously mentioned. In the first place, a large amount of unused water space is available, it being noted that there are quantities of water areas located near most large centers of population. In the next place, such water space or areas are low in cost, and may be obtained perhaps even more inexpensively by simply excavating cheap swamp land. Furthermore, water space is relatively free from safety limitations, which is to say that water space inherently provides for safety in the case of any failures such as leaks, etc.

An object of this invention is to provide a novel apparatus for storage of liquefied gases, such as LNG.

Another object is to provide an apparatus for the sub-aqueous storage of liquefied gases.

A further object is to provide an apparatus which may be used for the underwater transportation of LNG.

A still further object is to provide an apparatus which will accomplish the above objects in an efficient, effective, and rather inexpensive manner.

The objects of this invention are accomplished, briefly, in the following manner: A storage arrangement for liquefied gases comprises a jacketed inner container secured to another container and containing the liquefied gas (product) to be stored. A suitable balancing fluid is contained in the second container and is coupled to the product stored in the first container. The entire arrangement or assembly is submerged in water, and the balancing fluid is coupled to the surrounding water. The assembly is ballasted, as required.

A detailed description of the invention follows, taken in conjunction with the accompanying drawing, wherein:

FIG. 1 is a view in vertical section of a storage arrangement according to this invention; and

FIG. 2 is a top or plan view of the arrangement of the invention, on a smaller scale.

Referring now to the drawing, a metallic inner container 1, which may be spherical in shape as illustrated, serves as the container for the product (LNG) which is to be stored and/or transported under water. A flexible, impervious separator member or membrane 2 is sealed at its edges to the inner wall of container 1, in a horizontal diametrical plane thereof. Member 2 is flexible and durable enough, and of sufficient size (area) to conform to the inner wall of container 1, as the relative quantities of the two liquids separated by this member vary. In FIG. 1, this member 2 is illustrated in an approximate mid-position in container 1. Membrane 2 is preferably made from a sheet material which can withstand cryogenic or near-cryogenic temperatures.

A heat-insulating jacket 3, which will be described in more detail hereinafter, surrounds the container 1, and a pipe or connector 4 extends through this jacket into fluid communication (at its lower end) with the upper portion of container 1. The connector 4 serves as a means whereby LNG (or in some cases, vaporized or gaseous natural gas) may be pumped into or out of container 1.

Another container 5, which may have the shape of a hollow prism (see FIG. 2), is fastened securely by any suitable means (not shown) to container 1. Container 5, for example, has a circular opening in its upper wall in which the jacket 3 sealingly fits. A pipe or connector 6 extends through jacket 3 at the lower portion of container 1, to provide fluid communication between the lower portion of container 1 and the interior of container 5. The connectors 4 and 6 communicate with container 1 on respective opposite sides of separator member 2.

A flexible, impervious separator member or membrane 7 (made of the same material as membrane 2, for example) is sealed at its edges to the inner wall of container 5, near the upper end thereof. The connector 6, it will be noted, is coupled at its lower end to the portion of container 5 above the separator member or partition member 7.

The two-container assembly of this invention, when in use, is entirely submerged in water. A connector 8, which extends through one of the side walls of container 5, below the point of attachment of member 7 to this container, provides fluid communication between the surrounding water and the interior of container 5, below member 7. Thus, when the assembly of the invention is in use (and is therefore submerged), water 9 fills the space in container 5, below membrane 7.

The upper end of connector or pipe 4 extends to a suitable pump (not shown), for pumping LNG into, and for removing LNG from, container 1. The LNG 10 is stored in container 1, above the membrane 2. Since methane, the principal constituent of natural gas, has a boiling point of about −160°C., the storage of natural gas in liquefied form (particularly if stored at atmospheric pressure) involves very low temperature or cryogenic storage.

The membrane 2 couples the LNG 10 to a quantity of a balancing fluid 11 which is contained between the two separator members 2 and 7 and which is adapted to flow into and out of container 1 (as dictated by the volume of fluid 10 in container 1), by way of connector 6. The quantity of fluid 11 is sufficient to fill the entire volume of container 1, if necessary, and the separator member 7 is of sufficient size to follow the balancing fluid 11 as it moves into and out of container 1. The membrane 7 couples the balancing fluid 11 to the water 9. Since the membranes 2 and 7 are both flexible, and both physically separate the respective adjacent pairs of liquids with no voids or air spaces, there is zero pressure gradient across each of these membranes, so they can be made from a relatively thin sheet material (film).

The balancing fluid 11 should be a liquid which does not freeze at the temperature of the LNG, which provides a negative buoyancy as compared to the LNG (that is, one which has a density greater than that of the LNG), and which has a density somewhat similar to those of hydrocarbon fluids. A liquid which has these characteristics is 2-methyl butane, also known as isopentane, or ethyldimethylmethane (density 621 grams per liter, as compared to the densities of liquid methane, **0.415** grams per liter, and of water, 1,000 grams per liter; melting point about −160°C).

As an example, LNG **10** may be pumped through connector **4** to the container **1**, causing the balancing fluid **11** to be displaced to the container **5** through connector **6**, and displacing water **9** from container **5** through connector **8**. The action just described takes place by way of the flexible impervious membranes **2** and **7**. The reverse action takes place when LNG is pumped out of container **1**. Thus, the volume of balancing fluid **11** remains constant, but the volumes of LNG **10** and water **9** in the storage arrangement of this invention vary, depending upon the volume of LNG being stored at any particular moment. The flexible members **2** and **7** follow the movements of the liquids, as required by conditions.

It is desirable, for purposes of LNG storage, that there be no ullage space in container **1**, to avoid the extra buoyancy which such space could entail. Suitable cooling equipment should be coupled to connector **4** to chill any natural gas that gasifies in the container **1**. Such equipment is commonly used in apparatus for handling LNG. The connector **4** thus provides for the removal of vaporized natural gas, for subsequent return.

Although the balancing fluid **11** has a much higher density than that of the LNG, both it and the LNG have densities less than that of water, so that they themselves provide a positive buoyancy effect when submerged in water. The weight of the various containers does of course provide a negative buoyancy effect, but in order to make sure that the assembly remains safely submerged even when there is a maximum of LNG **10** (and a minimum of water **9**) in the apparatus, ballast **12** (in the form of gravel, rock, or even sand), as appropriate, or as required, is provided in a compartment mounted at the periphery of container **5**.

It will be appreciated that the apparatus described utilizes an essentially balanced pressure approach, which keeps compressive or tensile forces low—in fact, practically non-existent.

The insulating jacket **3** preferably comprises a porous solid insulating material (e.g., polyurethane foam) through the pores of which water may penetrate when the apparatus is submerged. At the temperature of the LNG (about −160°C.), this water freezes, resulting in frozen water (ice) intermixed with the resilient compressible foam type material. The ice strengthens the foam material to a certain extent, but more importantly, it provides additional heat insulation. The thickness of the jacket **3** is preferably greater than that required for a temperature reduction from the LNG temperature to the freezing point of water. For example, if a 6-foot thickness of foam or sponge material were required to reduce the temperature from the LNG temperature to the freezing point of water, then a total thickness of say 10 ft. of foam material could be utilized at 3. The extra 4 feet of foam material on the outside (beyond the 6 feet mentioned) would then prevent erosion of the ice by water action. Alternatively, instead of this extra thickness of foam material, a substantially impervious flexible skin (such as a rubber cover), with holes to permit the flow of water in either direction through the skin (but at much reduced velocities), could be added on the outside of the foam-ice jacket, to prevent erosion of the icy material.

It would be possible to utilize the two-container assembly previously described for the underwater transportation of LNG. For this, the connector **4** would be removed, and a controlled ullage space (operating through a cooling or compression cycle, as required) would be established in the top of container **1**, to provide nearly zero buoyancy at all times. The transporting submarine and the weight of its equipment would be designed quite accurately to provide near zero buoyancy at all times. The difference in lift or buoyancy (as the volume of LNG in container **1** varies) between the water and natural gas would need to be taken into account (the relative quantities of these two liquids in the assembly varying as the volume of LNG varies, the volume of balancing fluid remaining constant, as previously mentioned). By an arrangement of buoyant tanks, with cooling and compression equipment, a near zero buoyancy could be maintained for the LNG submarine.

The thickness of container **1** could be minimal, since the water pressure existing at the depth whereat the assembly is submerged is applied both to the outside and inside of the container (the application to the inside being by way of the balancing fluid **11**).

The flexible impervious membrane **7** may not be required in some cases, except for ecological purposes or to preserve the environment; if membrane **7** is not used, the different densities of water **9** and of the isopentane **11** may be relied upon to provide the required separation of these two fluids.

Also, the container **5** does not necessarily need to have a solid bottom, as illustrated, except possibly for the prevention of impacts, etc.

The invention claimed is:

1. A sub-aqueous storage arrangement for liquefied natural gas (LNG), comprising a first closed submersible container, means for transferring LNG to and from the interior of said container, a second submersible container secured to said first container, means providing a fluid connection between said containers, a body of a balancing fluid in said second container and adapted to flow into and out of said first container through said fluid connection, a partitioning means between the LNG in said first container and said balancing fluid, and a partitioning means between the balancing fluid in said second container and the water surrounding both of said containers.

2. Arrangement according to claim **1**, wherein the first-mentioned partitioning means comprises a flexible impervious membrane mounted in said first container and physically separating said LNG from said balancing fluid.

3. Arrangement according to claim **1**, wherein the second-mentioned partitioning means comprises a flexible impervious membrane mounted in said second container and physically separating said balancing fluid from said water.

4. Arrangement defined in claim 1, wherein said balancing fluid is 2-methyl butane.

5. Arrangement of claim 1, including also a heat-insulating jacket on said first container.

6. Arrangement defined in claim 5, wherein said jacket comprises a porous solid insulating material containing frozen water in its pores.

7. Arrangement according to claim 1, wherein the first-mentioned partitioning means comprises a flexible impervious membrane mounted in said first container and physically separating said LNG from said balancing fluid; and wherein the second-mentioned partitioning means comprises a flexible impervious member mounted in said second container and physically separating said balancing fluid from said water.

8. Arrangement defined in claim 7, wherein said balancing fluid is 2-methyl butane.

9. Arrangement of claim 7, including also a heat-insulating jacket on said first container.

10. Arrangement defined in claim 9, wherein said jacket comprises a porous solid insulating material containing frozen water in its pores.

11. A sub-aqueous storage arrangement for liquefied natural gas (LNG), comprising a first closed submersible container, means for transferring LNG to and from the interior of said container, a second submersible container secured to said first container, means providing a fluid connection between said containers, a body of a balancing fluid in said second container and adapted to flow into and out of said first container through said fluid connection, and a partitioning means between the LNG in said first container and said balancing fluid, the upper portion of said second container being secured to and sealed to said first container but the lower portion of said second container communicating with the water surrounding both of said containers.

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