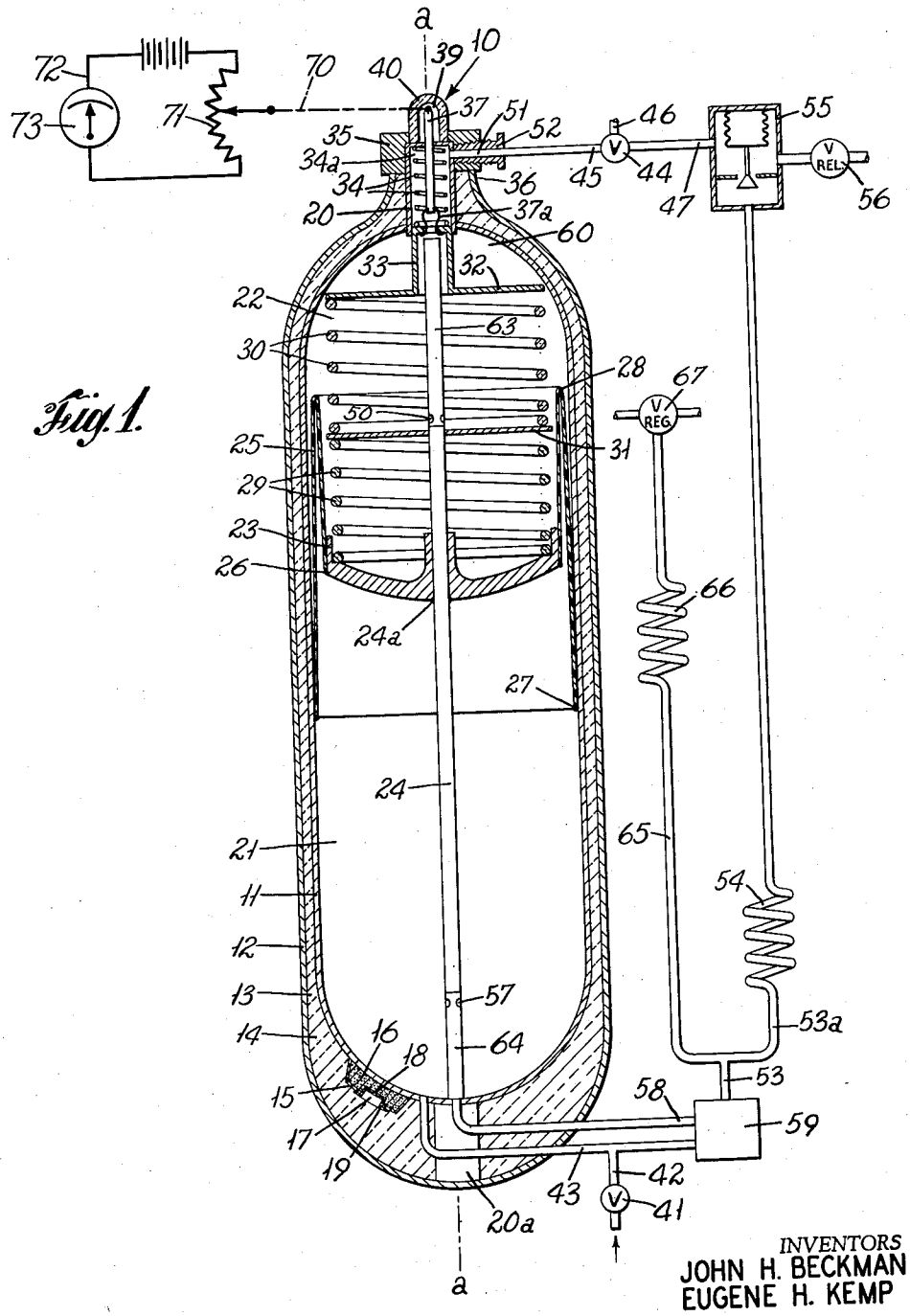
Feb. 7, 1961 J. H. BECKMAN ET AL 2,970,452

METHOD AND APPARATUS FOR SUPPLYING LIQUEFIED GAS

Filed April 1, 1959 2 Sheets-Sheet 1

Fig. 1.



INVENTORS
JOHN H. BECKMAN
EUGENE H. KEMP

BY William F. Messinger
ATTORNEY

Feb. 7, 1961 J. H. BECKMAN ET AL 2,970,452

METHOD AND APPARATUS FOR SUPPLYING LIQUEFIED GAS

Filed April 1, 1959 2 Sheets-Sheet 2

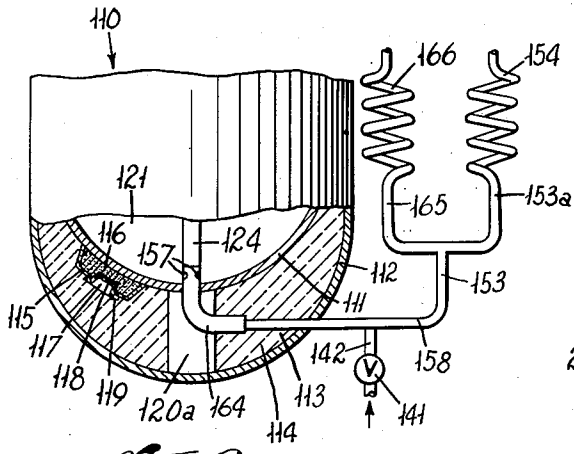


Fig. 2.

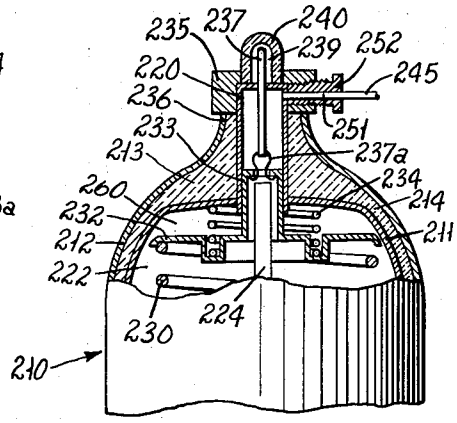


Fig. 3.

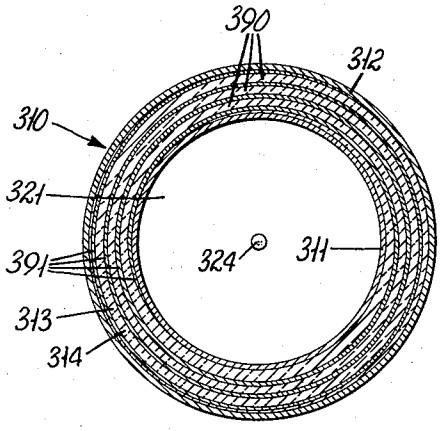


Fig. 5.

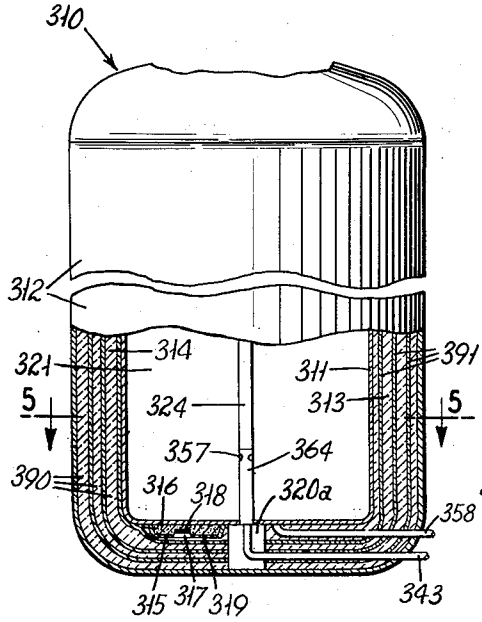


Fig. 4.

INVENTORS
JOHN H. BECKMAN
EUGENE H. KEMP
BY William F. Mesinger
ATTORNEY

United States Patent Office 2,970,452 Patented Feb. 7, 1961

2,970,452

METHOD AND APPARATUS FOR SUPPLYING LIQUEFIED GAS

John H. Beckman and Eugene H. Kemp, Indianapolis, Ind., assignors to Union Carbide Corporation, a corporation of New York

Filed Apr. 1, 1959, Ser. No. 803,466

14 Claims. (Cl. 62—51)

This invention relates to an improved method of and apparatus for supplying low-boiling liquefied gas, and more particularly to a portable double-walled container for carrying liquefied gas and discharging fluid therefrom when the container is in any position or under any gravity condition, as for example in aircraft or underseas.

Oxygen, nitrogen and air, for example, are widely used to provide breathing atmospheres or for pressurizing fuel systems and control mechanisms. These gases are conveniently stored in the liquefied form to reduce the total storage volume and vessel weight required to supply a given volume of gas. Many such systems must be portable, as for example where oxygen is to be supplied for high altitude and deep-sea breathing purposes. This need for portable, light-weight equipment emphasizes the potential advantages of liquid storage as contrasted from pressurized gas storage containers. Low boiling liquefied gas containers are usually constructed with double walls, the space between the inner and outer walls being provided to insulate the liquid in the inner vessel from the atmospheric heat. This is necessary because such liquefied gases are stored at very low temperatures, e.g. —183° C. for liquid oxygen, and without high quality insulation the liquid would vaporize very quickly.

Most prior art liquefied gas storage containers deliver the desired liquid outlet flow only when properly positioned and under the influence of gravity. When these containers are inverted or when gravity is eliminated, as would be encountered in space flight, the liquid delivery either becomes sporadic or ceases completely. Conventional pressure building circuits in which the liquid phase of the container is connected to the gas phase through a vaporizer could not be used to pressurize the liquid in the prior art containers for this type of service since these circuits rely on gravity as the pressure driving force. Also, the gas phase in these previously proposed containers has the disadvantage of being in direct contact with the liquid phase. When a pressure-building circuit is used, a portion of the vaporized liquid is returned to the gas phase. Hence, when liquid air, for example, is stored therein, a portion of the oxygen will be condensed from the gas phase to achieve equilibrium within the container. This phenomenon will result in the gas phase always being nitrogen-rich and the liquid phase being oxygen-rich with respect to air. Since the container may be operated in various positions and delivery may occur from either gas phase or liquid phase, the desired composition of the output gas would not be obtained at any moment. This is a serious problem when the stored fluid is used to supply breathing atmospheres to divers or crew members in aircraft, since for optimum functioning the human body requires oxygen and nitrogen in a relatively narrow concentration range.

One prior art method which attempts to maintain liquefied gas flow from a storage container in all positions or under zero-gravity conditions and which could also be used for liquid air breathing supplies, involves

positioning a flexible bladder inside the storage vessel. The bladder is inflated or collapsed with a gas having a lower boiling point than the stored liquid in order to pressurize the liquid. The main disadvantage with this system is the requirement of a separate pressure source to inflate or collapse the bladder and thus permit the application or sufficient pressure to the liquid for forcing such liquid out of the storage container.

Another previously proposed method of solving this difficult problem is to incorporate a separate energy source, such as a heating coil, within the storage container. Energy can be added in large amounts to vaporize additional liquid within the container and thus provide sufficient pressure to force out the liquid. A separate source of energy would involve an intricate, heavy and costly system. Also, such an arrangement has the additional critical disadvantage of unsuitability for use with liquid air for breathing purposes since the heat energy input would cause a composition change by vaporizing primarily nitrogen.

A principal object of the invention is to provide an improved liquefied gas storage container capable of dispensing any desired quantity of liquid from any container position and under any gravity condition.

Another object is to provide an improved liquefied gas storage container having the additional characteristics of lightweight and minimum heat inleak.

Still another object is to provide a method for dispensing any desired quantity of liquefied gas from a storage container when such container is in any position and exposed to any gravity condition.

These and other objects and advantages of the invention will become apparent from the following description and the accompanying drawings in which:

Fig. 1 is a schematic view, mainly in vertical cross-section of an exemplary double-walled cylindrical container construction embodying the principles of the invention;

Fig. 2 is a schematic view, mainly in vertical cross-section of the lower portion of an alternate double-walled container;

Fig. 3 is a schematic view, mainly in vertical cross-section of the top portion of an alternate double-walled container;

Fig. 4 is a view of a longitudinal cross-section of an exemplary double-walled cylindrical container embodying another form of the invention; and

Fig. 5 is a view of a horizontal cross-section taken along the line 5—5 of Fig. 4.

In the drawings similar elements in the several figures are designated by similar reference characters.

In accordance with one embodiment of the present invention, a portable container is provided for storing and dispensing from any container position a pressurized liquefied gas having a boiling point below 233° K. The container includes an inner vessel for storing a body of the pressurized liquefied gas, an outer shell enclosing and separating the inner vessel from the atmosphere, and an insulating space under a vacuum pressure between the inner vessel and the outer shell. A piston is transversely positioned across the cross-sectional area of the inner vessel so as to substantially fill such area. The piston is also arranged and constructed to slidably move in a direction parallel to the longitudinal axis of the container so as to separate the liquid and gas phases at all levels of the liquid in the inner vessel. Means are provided for sealing the outer periphery of the slidable piston against the inner wall of the inner vessel, and preferably such means constitute a concentrically positioned flexible cylindrical film having one end leak-tightly and circumferentially attached to the inner wall of the inner

vessel. The other end of the cylindrical film is leak-tightly and circumferentially attached to the outer periphery of the piston. The piston also serves as a thermal barrier between the stored liquid and gas phases preventing the gas from recondensing into the liquid, thus maintaining a substantially constant composition in the stored liquid and the product gas resulting therefrom. The liquid phase and the piston are maintained under a slight artificial gravity pressure at all container positions and gravity conditions, by at least one compressible spring transversely positioned across the inner vessel. The spring is longitudinally located between the upper end of the inner vessel and the top side of the slidable piston. This combination of interacting elements permits the use of a pressure building circuit even under zero-gravity conditions.

The term "vacuum" as used hereinafter is intended to refer to the vacuum pressure in the insulating space between the inner vessel and outer shell of the portable container of this invention. The term applies to sub-atmospheric pressure conditions not substantially greater than 1,000 microns of mercury, and preferably below 100 microns of mercury absolute.

In a preferred embodiment of the novel portable container, the insulating space contains an opacified insulating jacket, which is many times as efficient as the conventional powder-in-vacuum or highly polished reflective surfaces heretofore used in double-walled liquefied gas containers. The use of opacified insulation permits the fabrication of a liquefied gas container having a much narrower insulating space for a given rate of heat inleak, and consequently a smaller and lighter unit for a given liquid storage capacity. Alternatively, opacified insulation permits an increased liquid storage capacity for a given weight, as compared with a container insulated by conventional materials.

The term "opacified insulation" as used herein refers to a two-component insulating system comprising a low heat conductive, radiation-permeable material and a radiant heat impervious material which is capable of reducing the passage of infrared radiation rays without significantly increasing the thermal conductivity of the insulating system. Also, the term "radiant heat barrier" as used herein refers to radiation opaque or radiant heat energy impervious materials which reduce the penetration of infrared heat rays through the insulating system either by radiant heat reflection, radiant heat absorption or both. As defined, opacified insulation includes a mixture of finely divided low-conductive particles which substantially impede heat inleak by conduction and yield to heat passage by radiation, and finely divided radiant heat impervious bodies having a relatively high thermal conductivity. As more fully described and claimed in copending U.S. Serial No. 580,897, filed April 26, 1956 in the name of L. C. Matsch and A. W. Francis, the low conductive particles may be selected from the group consisting of silica, perlite, alumina, magnesia and carbon black, and the radiant heat impervious bodies are preferably either aluminum or copper, although copper paint pigments, alumina paint pigments, magnesium oxide, zinc oxide, iron oxide, titanium dioxide, copper coated mica flakes, carbon black, and graphite either alone or in combination with each other would give satisfactory results. Also, these bodies usually in the form of flakes or powder, preferably constitute between 1% and 80% of the total weight of the insulation.

The opacified insulation may also take the form of the combination of a low heat conductive material and a multiplicity of spaced radiation-impervious barriers. As more fully described and claimed in copending U.S. Serial No. 597,947, filed July 16, 1956 in the name of L. C. Matsch, the low heat conductive material may be the previously listed powderous materials or alternatively a fiber insulation which may be produced in sheet form. Examples of the latter include a filamentary glass material such as glass wool and fiber glass, preferably having fiber diameters of less than about 50 microns. Also such fibrous materials preferably have a fiber orientation substantially perpendicular to the direction of heat flow across the insulation space. The spaced radiation-impervious barriers may comprise either a metal, metal oxide, or metal coated material, such as aluminum coated plastic film, or other radiation reflective or radiation adsorptive material or a suitable combination thereof. Radiation reflective materials comprising thin metal foils are particularly suited in the practice of the present invention, for example, reflective sheets of aluminum foil having a thickness between about 0.2 millimeter and 0.002 millimeter. Other radiation reflective materials which are susceptible of use in the practice of the invention are tin, silver, gold, copper, cadmium or other metals. When fiber sheets are used as the low-conductive material, they may additionally serve as a support means for relatively fragile radiation impervious sheets. For example, an aluminum foil-fiber sheet insulation may be spirally wrapped around the inner liquefied gas holding vessel with one end of the insulation wrapping in contact with the inner vessel, and the other end nearest the outer shell, or in actual contact therewith.

It would normally be concluded by one skilled in the art that the aforedescribed opacified insulation could not be economically used in portable liquefied gas containers because of the relatively heavy nature of such insulation. For example, a 50%–50% by weight mixture of silica powder with finely divided copper flakes has a bulk density of about 12 lbs. per cubic ft. However, it has been found that opacified insulation preferably in combination with lightweight aluminum or aluminum alloy construction provides an improved liquified gas portable container which is substantially lighter than heretofore used containers having the same storage volume and the same insulating efficiency. This remarkable result is attainable in part because the opacified insulations used in this invention have a relatively high insulating efficiency at vacuums poorer in quality than those required for vacuum-polished metal surface insulation. Because of this characteristic, aluminum, which is known to produce porous welds, can be used instead of relatively heavier stainless steel or copper which can produce relatively leak-proof metal joints.

In addition the present novel container is also substantially lighter in weight and requires substantially less fluid storage volume than prior art containers storing compressed gases and supplying the same total volume of gas. For example, a container having a liquid storage volume equivalent to 160 cu. ft. gas capacity built in accordance with the preferred form of the present invention using aluminum or aluminum alloy material for both the inner vessel and outer casing weighs about 29 lbs. empty. This container has an outside diameter of about 7¼ inches and an overall length of about 29½ inches. The container provides about the same amount of gas as two compressed gas cylinders each of about the same physical size and each weighing about 34 lbs. empty, the cylinders being of a type commonly used in underwater breathing equipment.

The thermal insulating effectiveness of opacified insulation versus straight vacuum plus polished surfaces (no powder insulation) can be compared by using the example of to 1-square foot metal plates spaced ⅞ inch apart. When straight vacuum insulation was used, the inside surfaces of the plates were polished to an emissivity of 0.04. The outer plate was a room temperature (70° F.) and the inner plate was at liquid oxygen temperature (−297° F.). Under 50 microns pressure between the plates, an opacified insulation in this space consisting of 50%–50% by weight mixture of silica powder and finely divided copper metal flakes had a heat transmission of about 1.85 B.t.u./hr. In order for straight vacuum insulation to have a comparable effectiveness, the pressure

would have to be less than 0.01 micron. Under similar pressure conditions (50 microns) straight vacuum plus polished surfaces had a considerably higher heat transmission of about 43 B.t.u./hr. It can thus be seen that by using opacified insulation a highly efficient insulating system may be provided in aluminum liquefied gas portable containers even though the space between the inner vessel and the outer casing is maintained at a relatively poor vacuum because of the relatively porous nature of the aluminum-containing joints. While a preferred embodiment of this invention includes the above-described opacified insulation as one of several interacting elements, it is to be understood that an alternate embodiment of the present portable container may utilize straight vacuum-polished surface insulation.

Even though the previously described preferred opacified insulation is more effective than straight vacuum insulation at higher internal pressures (poorer vacuum), its effective thermal insulation life is extended if the pressure can be maintained at or below a desired level. A gas removing material such as an adsorbent, either in powder or pellet form, may be used in the insulation space to remove by adsorption the gas entering through the porous aluminum-containing joints. This is an extremely important feature since no provision is made in the relatively small portable container of the present invention for reevacuation of the insulating jacket. The adsorptive capacity of suitable adsorbents, such as natural and synthetic zeolites, silica gel and activated charcoal, generally rises with increased pressure. Therefore these adsorbents are more effective for removal of insulation jacket air leakage when opacified insulation is used than when straight vacuum is employed because of the higher vacuum space pressure involved. Furthermore, these adsorbents generally have higher adsorptive capacities at relatively lower temperatures. Consequently they are preferably mounted adjacent to the cold outer side of the inner vessel wall. Alternatively, the adsorbent may be randomly mixed in the opacified insulation. In particular, crystalline zeolitic molecular sieves having pores of at least about 5 Angstrom units in size, as disclosed in U.S. Patent No. 2,900,800, issued in the name of P. E. Loveday, are preferred as the adsorbent since they have extremely high adsorptive capacity at the temperature and pressure conditions existing in the insulating jacket and are chemically inert toward any gases which might leak into the insulating jacket. Such zeolites may be either natural or synthetic. This novel combination of opacified insulation and adsorbent thus facilitates construction of a liquefied gas portable container which is lighter in weight and has a longer effective life than previously proposed containers. Such an adsorbent is also used advantageously in combination with straight vacuum-polished surface insulation.

Referring now more specifically to Fig. 1, the portable liquefied gas container generally indicated at **10** includes a liquid holding inner vessel **11** which is illustrated as cylindrical in form although other shapes such as the spherical form would also be suitable. The preferred shape is primarily determined by the intended use of the container. For example, a cylindrically shaped container is preferred for underwater diving, because a cylinder is most conveniently attached to the diver's back. The inner vessel **11** is completely surrounded and separated from the atmosphere by outer casing **12**, both containers being preferably fabricated from aluminum alloy in order to take advantage of its lightweight characteristic. The low density of aluminum especially allows a relatively thick outer casing to be used which has more resistance to handling abuse than would a relatively thin casing of equivalent weight fabricated from denser material.

Space **13** under a vacuum separates the outer wall of the inner vessel **11** from the inner wall of the outer casing **12**, and is preferably filled with the previously described opacified insulation **14**. The preferred form

of the opacified insulation used with this invention comprises low heat conductive material such as glass wool or fiber glass having fiber diameters of less than about 50 microns, and a multiplicity of spaced radiation-impervious barriers, such as aluminum foil having a thickness between about 0.2 mm. and 0.002 mm. This layered insulation is conveniently assembled around cylindrical inner vessels and tends to hold the inner vessel in spaced relation to the outer shell. Alternatively, the opacified insulation **14** may be a mixture of finely divided low conductive particles and radiant heat impervious bodies having a relatively high thermal conductivity. For example, a 50%–50% by weight mixture of finely divided silica powder having particle sizes below about 75 microns, and copper flakes smaller than about 50 microns with a flake thickness less than about 0.5 micron gives best results, although opacified insulation mixtures having larger size particles have been tested with excellent results. It has been found that the powder type opacified insulations are particularly suitable for spherical containers because such insulation may be easily poured in the space **13** between the inner vessel **11** and the outer casing **12**.

Blister or chamber **15** secured to and in heat exchange relation with the bottom section of inner vessel **11** holds a gas-removing material **16** and preferably an adsorbent such as the previously described synthetic or natural zeolite to remove gas and vapors from the insulating jacket **14**. Adsorbent material **16** communicates with the opacified insulating jacket **14** through passages **17** in the walls of chamber **15**, the adsorbent material for example being retained in chamber **15** by glass cloth sheets **18** extending across the passages and held against the chamber walls by plates **19**. It is to be understood that glass cloth sheets **18** do not interfere with vapor and gas communication between the opacified insulating jacket **14** and adsorbent material **16** although they serve to retain the latter.

The inner vessel **11** is supported and stabilized against all relative movement (both vertical and lateral) by a suitable support system which may, for example, comprise upper suspension member **20** and the layered insulation jacket **14** acting in combination. Element **20** is preferably formed from material such as stainless steel, having the properties of relatively high compression and shear strengths, low thermal conductivity, and retention of such properties at temperatures from about −191° C. to 127° C.

An alternate form of the support system which is especially advantageous when opacified powder insulation is used comprises the combination of upper suspension member **20** and hollow lower support member **20*a***. The last mentioned member is also preferably formed from low thermal conductivity material having relatively high compression and shear strengths, such as phenol-formaldehyde resin reinforced with fabric or paper. Lower member **20*a*** may either be mounted in continuous compression or it may be fixedly mounted against the inside wall of the outer casing **12** and positioned so as to slidably and telescopically engage the lower portion of the inner vessel outer wall **11**.

The liquid phase zone **21** of the inner vessel **11** is separated from the gas phase zone **22** by piston **23** which is preferably annularly and concentrically positioned around member **24** extending in a longitudinal direction from one end to the other end of such inner vessel. Piston **23** is also preferably slidably mounted on elongated and longitudinally aligned member **24** so as to move in a direction parallel to the longitudinal axis *a*—*a* of the container, and substantially fill the cross-sectional area of inner vessel **11**. Member **24** is preferably constructed of a low thermal conductivity material such as organic plastics or stainless steel, and serves to guide the movement of piston **23** and thus prevent

any tipping thereof which might interfere with proper operation. The center section of longitudinal member 24 is solid, and the extremities thereof are hollowed to provide upper and lower end eductor tube sections 63 and 64, respectively.

The surface of piston 23 sliding on longitudinal member 24 is preferably sealed by sliding seal 24a which may be constructed of trifluorochloroethylene polymers, tetrafluoroethylene polymers, or polyethylene terephthalate resin. These materials have been found to be able to withstand temperatures as low as those of liquid oxygen (−183° C.) and liquid nitrogen (−196° C.) without becoming brittle. Piston 23 is preferably constructed of a low thermal conductive material such as the aforementioned organic polymers or stainless steel. This is because the heat transfer across the piston must be minimized to decrease boiling in the liquid phase 21 and condensation in the gas phase 22.

In order to completely separate the liquid and gas phases 21 and 22 respectively and thus prevent leakage of liquid around the piston into the gas phase, it is necessary to seal the outer periphery of the slidable piston 23 against the inner wall of the inner vessel. This is preferably accomplished through the provision of flexible film 25 which is cylindrically shaped and positioned in the annular space between the piston periphery and the vessel inner wall. One end 26 of the cylindrical film is leak-tightly and circumferentially attached to the outer periphery of piston 23, and the other film end 27 is leak-tightly and circumferentially attached to the inner wall of the inner vessel. Flexible film 25 is preferably of sufficient length so that it folds back on itself along circumference 28, and as piston 23 moves up and down the film furls or unfurls. Film 25 is preferably composed of polyethylene terephthalate resin or trifluorochloroethylene polymer since these materials retain their flexibility at low temperatures, as previously discussed. Since the pressure drop across film 25 is only about 1 p.s.i at the most, its thickness is governed mainly by the flexibility required; thicknesses of about 0.0005 to 0.003 inch are suitable. Alternatively, a ring-type sliding seal formed from a suitable plastic or metal may be provided instead of flexible film 25.

The liquid phase 21 and piston 23 are maintained under a slight artificial gravity pressure at all container positions and gravity conditions by a pair of compressible springs 29 and 30 separated by movable ring 31. The springs are longitudinally located between the upper end of the inner vessel 11 and the top side of the slidable piston 23. A single spring instead of lower and upper springs 29 and 30 respectively, could alternatively be provided, but the double spring arrangement is preferred from the standpoint of stability. It will be appreciated that a relatively long spring assembly is needed to apply pressure to piston 23 as it moves along the full longitudinal length of the inner vessel 11. If a single long spring were used, it might tend to buckle instead of evenly compressing as the piston moves upwardly in the container.

The top surface of upper spring 30 abuts against spring retainer 32 having raised center capped section 33 covering the open upper end of eductor tube section 63. The upper end of spring retainer capped section 33 is received in the lower end of inner vessel hollow upper suspension member 20, the latter being leak tightly sealed to the edges of an opening in the top header of such inner vessel. The top surface of capped section 33 abuts the lower end of relatively small back-up spring 34, and the upper end of such spring is retained in center cavity section 34a of collar 35. The collar member 35 is leak-tightly sealed to the walls of an opening in the elongated upper end 36 of outer casing 12.

Rod pointer 37 is secured at one end to spring retainer 32 by suitable means such as flexible prongs 37a, and extends in a longitudinal direction through the center section of back-up spring 34 into center cavity section 34a of collar 35. The upper end of rod pointer 37 extends through a hole in the top of collar 35, and is contained in a recessed central part 39 of sight cap 40 which is leak-tightly secured to the walls of the collar hole. Sight cap 40 is constructed of transparent material, such as plastic or glass. The assembly is provided with sufficient clearance between the rod pointer 37 and the surrounding elements for free longitudinal movement of such pointer. The position of piston 23 coincides with the liquid level in the inner vessel 11, controls the compression in springs 29 and 30, and thus determines in combination with back-up spring 34, the position of spring retainer 32 and rod pointer 37. This novel combination provides an improved liquid level gage by calibration of the pointer position with respect to the liquid level in inner vessel 11, the upper end of rod pointer being observable through transparent cap 40. Alternatively, if an indicating device remote from the container is required, rod pointer 37 may for example be mechanically connected by linkage 70 to variable resistor 71 in electrical indicating circuit 72, changes in liquid level being observed on meter 73.

The container 10 is filled with liquefied gas by introducing such liquid through filling valve 41, conduit 42 and communicating conduit 43 which extends through insulation jacket 14 and connects with the lower end of inner vessel 11. Prior to filling, the combination vent and pressure buildup valve 44 is placed in the vent position, connecting conduit 45 with vent port 46 and closing off conduit 47 on the opposite side of valve 44. When liquid filling is commenced, the pressure of the incoming liquid and resulting vapor forces piston 23 upward to a position above the orifices 50 in the top eductor tube 63. This allows the gas formed by the liquid vaporizing on the relatively warm walls of the inner vessel 11 to be vented through top orifices 50 back into top eductor tube 63 for discharge through hollow upper suspension member 20, collar cavity section 34a, and communicating transverse passageway 51 in adapter 52 which is leak-tightly thread connected to collar 35. The last-mentioned passageway 51 connects with conduit 45 so that the evaporation gas formed during liquid filling is passed therethrough to combination vent and pressure buildup valve 44 for venting through port 46 to the atmosphere. When the inner vessel is completely filled with liquid, the velocity of the gas venting through the top orifices 50 will carry entrained liquid with it, so that when the operator observes liquid being discharged through vent port 46, he will be notified that the container is full. After filling is complete, filling valve 41 is closed and combination vent and pressure buildup valve 44 is placed in the buildup position, connecting conduit 45 with conduit 47 and closing off vent port 46.

In a preferred embodiment of the present invention, means are provided for building gas pressure in the gas phase 22 of inner vessel 11, so as to facilitate the discharge of liquid from such vessel at any desired rate. The pressure building circuit includes conduit 53 and branch conduit 53a. Branch conduit 53a contains vaporizer 54, pressure closing valve 55, and relief valve 56 communicating with the downstream side of pressure closing valve 55. One end of conduit 47 also connects with the downstream side of pressure closing valve 55, the other end joining with combination vent and pressure buildup valve 44, as previously described.

Gas pressure is built up in the gas phase zone 22 in the following manner: Springs 29 and 30 exert a downward force on piston 23 which transmits the force to the liquefied gas liquid phase 21 causing liquid to enter orifices 57 in the lower eductor tube 64. This liquid flows consecutively through communicating conduit 58, three-way valve 59, conduit 53, and into branch conduit 53a. The withdraw liquid then passes through vaporizer 54 which is preferably heated by the atmosphere, although

other sources of heat, such as steam, warmed air, or water, would also be suitable. The resulting gas is discharged from vaporizer 54 and flows consecutively through pressure closing valve 55, conduit 47, combination vent and pressure buildup valve 44, conduit 45, passageway 51 in adapter 52, hollow upper suspension member 20, and finally through the annular space 60 between member 20 and spring retainer 32 into the gas phase zone 22 of inner vessel 11. When the gas pressure in zone 22 has reached the desired level, e.g. 120 p.s.i.g., pressure closing valve 55 closes and no additional gas enters. If the pressure in gas phase zone 22 becomes excessive, relief valve 56 will open. The preferred combination or spring compression and gas pressure in zone 22 maintains piston 23 at the liquid level between liquid phase zone 21 and zone 22, and thus keeps the stored liquid under continuous compressive pressure. This pressure not only forces the liquid out of the container when desired but also helps maintain an artificial gravity in the container.

A product gas delivery circuit is preferably provided, and includes conduit 65 branching from conduit 53. Branch conduit 65 contains vaporizer-superheater 66 which is preferably atmospherically heated, and gas regulator 67 at the discharge end of conduit 65. When product gas delivery is required, regulator 67 is opened, lowering the pressure in conduit 65. Liquid then flows consecutively through lower end eductor tube section orifices 57, eductor tube 64, conduit 58, three-way valve 59, conduit 53, and hence into branch conduit 65. The liquid then passes through vaporizer-superheater 66 and the resulting warmed gas is discharged through gas regulator 67 for use as desired. Expansion of springs 29 and 30 forces piston 23 to remain in contact with the remaining liquid and thus maintain the desired flow of liquid rather than gas from whatever position the container may lie. As previously discussed, this feature is extremely advantageous for underwater breathing apparatus since divers must work in various positions. The present invention also provides a continuous source of liquefied gas of constant composition to breathing systems for aircraft and space ships under inverted flight or zero-gravity conditions.

It is especially desired in underwater breathing apparatus that the diver have a reserve breathing supply to enable him to safely return to the surface. In the apparatus of the present invention, lower eductor tube orifices 57 may be located so that when piston 23 reaches a low level covering these orifices and thus preventing further liquid flow therethrough, the liquid remaining in inner vessel 11 below the orifices is equivalent to about five minutes breathing supply. After receiving this warning, the diver may turn three-way valve 59 to permit flow through conduit 43 connected to the lower end of inner vessel 11. The downward movement of piston 23 under spring and gas phase pressure then forces out the remaining emergency supply of liquid through bottom conduit 43, three-way valve 59, conduit 53, and the previously described product gas supply system.

Fig. 2 illustrates an alternate modification of the lower portion of the improved apparatus which is particularly appropriate when an emergency supply of liquid is not required. Lower eductor tube orifices 157 are positioned substantially at the bottom end of inner vessel 111, and conduit 158 is directly connected to liquid filling valve 141 and conduit 153. Vaporizers 154 and 166 serve the same purposes as do vaporizers 54 and 66, described above.

Fig. 3 illustrates a modification of the top portion of the novel apparatus in which the lower end of back-up spring 234 is positioned in the annular circular recessed section 285 of spring retainer 233 and the upper end of such spring abuts the upper end of the inner vessel 211. The most important advantage of this arrangement is a reduction in the diameter of hollow upper suspension member 220. This feature in turn decreases the heat transfer to inner vessel 211 from the atmosphere, and consequently reduces evaporation of the stored liquid. This arrangement also permits a reduction in the overall height of the container.

Figs. 4 and 5 illustrate still another embodiment of the invention in which the opacified insulation comprises low-conductive layers 390 preferably formed of fiber glass having fiber diameters of less than about 50 microns and radiation impervious layers 391 preferably formed of aluminum foil sheets having a thickness between about 0.2 millimeter and 0.002 millmeter. Such layers may be spirally wrapped around the inner vessel with one end of the insulation wrapping in contact with the inner vessel 311 and the other end nearest the outer casing 312. Alternatively, the layers may be mounted concentrically with respect to the inner vessel 311. In either embodiment, the fibers of layer 390 are preferably oriented substantially parallel to radiation impervious layers 391 and substantially perpendicular to the direction of heat flow across the insulation space. The tightness and number of wrapping turns may be varied to suit the insulating requirements of the particular container. Tightening of the insulation wrapping causes the low conductive and resilient fibrous material to be compressed into a smaller space. This action decreases the percentage voids in the fibrous material, and increases the cross-sectional area of the effective path of solid conduction. However, the voids are reduced in size, which results in the insulation being less sensitive to pressure changes in the vacuum space. On the other hand, wrapping the insulation too loosely decreases the number of turns of radiation shielding in the insulation space, and increases heat leak by radiation. Optimum results are obtained somewhere between these extremes when the sum of the heat leaks due to radiation and conduction is a minimum. By providing a large number of turns of insulation wrappings, the passage or radiative heat is substantially eliminated, while the conductive heat flow along the spiral path is effectively reduced due to the lengthened heat path. A further advantageous feature of the wrapped insulation embodiment is that when it completely fills the insulation space wall to wall, the insulation also provides a good degree of support for the inner vessel, particularly against lateral accelerations.

It will be apparent from the foregoing description and the accompanying drawings that the preferred form of the present invention combines a number of elements including a slidable piston, a flexible film forming a leak-tight seal around the piston, a longitudinal member with eductor tube portions at each end, a pressure building circuit, aluminum or aluminum alloy construction, an opacified insulating jacket, and a gas adsorbent, in a manner so as to provide an improved portable container for carrying low-boiling liquefied gases. This container permits discharge of liquid therefrom when the container is in any position or under any gravity condition, and has the characteristics of lighter weight, lower heat inleak and greater compactness and durability.

Although preferred embodiments of the invention have been described in detail, it is contemplated that modifications of the apparatus may be made and that some features may be employed without others, all within the spirit and scope of the invention.

What is claimed is:

1. A portable container for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K., comprising an inner vessel for storing a body of said pressurized liquefied gas; an outer shell enclosing and separating said inner vessel from the atmosphere to define an insulating space under a vacuum pressure between said inner vessel and said outer shell; a piston transversely positioned across

the cross-sectional area of the inner vessel so as to substantially fill such area, and being arranged and constructed to slidably move in a direction parallel to the longitudinal axis of such container so as to separate the liquid and gas phases of said pressurized liquefied gas in said inner vessel; means for separably and gas-tightly sealing said liquid phase from said gas phase while allowing substantially free sliding movement of said piston; means for maintaining said liquid phase under a slight artificial gravity pressure at all container positions and gravity conditions, said means comprising at least one compressible spring longitudinally positioned between the upper end of said inner vessel and the top side of said slidable piston.

2. A portable container for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K., comprising an inner vessel for storing a body of said pressurized liquefied gas; an outer shell enclosing and separating said inner vessel from the atmosphere; an insulating space under a vacuum pressure between said inner vessel and said outer shell; a piston transversely positioned across the cross-sectional area of the inner vessel so as to substantially fill such area, and being arranged and constructed to slidably move in a direction parallel to the longitudinal axis of such container so as to separate the liquid and gas phases of said pressurized liquefied gas in said inner vessel; means for sealing the outer periphery of the slidable piston against the inner wall of said inner vessel, including a concentrically positioned flexible cylindrical film having one end leak-tightly and circumferentially attached to the inner wall of said inner vessel and the other end leak-tightly and circumferentially attached to the outer periphery of said piston; means for maintaining said liquid phase under a slight artificial gravity pressure at all container positions and gravity conditions, said means comprising at least one compressible spring longitudinally positioned between the upper end of said inner vessel and the top side of said slidable piston.

3. A portable container according to claim 2 for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K. in which said flexible cylindrical film is sufficiently long in the longitudinal direction to transversely bend back on itself during movement of said slidable piston.

4. A portable container according to claim 1 for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below about 233° K. in which said inner vessel and said outer shell are constructed from a member of the group consisting of aluminum and aluminum alloys.

5. A portable container according to claim 1 for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K. in which said piston is slidably mounted on an elongated member extending the longitudinal length of said inner vessel, the upper portion of such member communicating with the gas phase of said pressurized liquefied gas as well as top gas conduit means, and the lower portion of said member communicating with the liquid phase of said pressurized liquefied gas as well as bottom liquid conduit means.

6. A portable container according to claim 1 for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K. in which said piston is slidably mounted on an elongated member extending the longitudinal length of said inner vessel, the upper portion of such member communicating with the gas phase of said pressurized liquefied gas as well as top gas conduit means, and the lower portion of said member communicating with the liquid phase of said pressurized liquefied gas as well as bottom liquid conduit means; a pressure building circuit external to said outer shell and communicating at opposite ends with said bottom liquid conduit and top gas conduit means, such circuit including a vaporizer for vaporizing the liquid withdrawn through said bottom liquid conduit means, and pressure closing valve means for controlling the fluid flow through said pressure building circuit.

7. A portable container according to claim 1 for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K. in which said piston is slidably mounted on an elongated member extending the longitudinal length of said inner vessel; such member having a solid center section extending in the longitudinal direction as well as upper and lower eductor tube end sections, the upper eductor tube section communicating with the gas phase of said pressurized liquefied gas as well as top gas conduit means, and the lower eductor tube section communicating with the liquid phase of said pressurized liquefied gas as well as bottom liquid conduit means.

8. A portable container according to claim 6 for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K. in which a product gas supply conduit communicates with said bottom liquid conduit means, said product gas supply conduit containing vaporizing and superheating means.

9. A portable container according to claim 1 for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K. in which said piston is slidably mounted on an elongated member extending the longitudinal length of said inner vessel, the upper portion of such member communicating with the gas phase of said pressurized liquefied gas; top gas conduit means communicating with the upper end of said member; at least one orifice in the lower portion of said member and positioned above the lower end of said inner vessel for communication with the liquid phase of said pressurized liquefied gas; first bottom liquid conduit means communicating with the lower end of said member for liquid withdrawal therethrough; second bottom liquid conduit means communicating with the lower end of said inner vessel for discharge therethrough of at least the last portion of the stored liquid when said orifice in said elongated member is sealed by the sliding piston.

10. A portable container according to claim 1 for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K. in which means are provided for monitoring and visually indicating the liquid level of such liquefied gas body in said inner vessel, such means comprising a retainer transversely arranged and supported against the upper end of said compressible spring to move in a longitudinal direction with the motion of such spring and said piston as actuated by the changing liquid level of said liquefied gas body; a second compressible spring longitudinally alinged between the top surface of said retainer and said upper end of said portable container; a rod pointer having one end associated with the retainer top surface for movement therewith and the other end longitudinally extending into the upper end of said portable container, the longitudinal movement of said pointer other end being observable as a visual indication of said liquid level.

11. In a double-walled vacuum insulated portable container for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K. the improvement comprising a piston transversely positioned across the cross-sectional area of the inner vessel so as to substantially fill such area, and being arranged and constructed to slidably move in a direction parallel to the longitudinal axis of such container so as to separate the liquid and gas phases of said pressurized liquefied gas in said inner vessel; means for sealing the outer periphery of the slidable piston against the inner wall of said inner vessel, including a concentrically positioned flexible cylindrical film having one end leak-tightly and circumferentially attached to the inner wall of said

inner vessel and the other end leak-tightly and circumferentially attached to the outer periphery of said piston; means for maintaining said liquid phase under a slight artificial gravity pressure at all container altitudes and gravity conditions, said means comprising at least one compressible spring transversely positioned across said inner vessel and longitudinally located between the upper end of said inner vessel and the top side of said slidable piston.

12. A method for supplying liquefied gas in any container position and under any gravity condition from a double-walled vacuum insulated portable container storing gas and liquid phases, comprising the steps of providing in the inner vessel, a body of pressurized liquefied gas having a boiling point below 233° K., applying a slight artificial gravity pressure to such liquid body so as to discharge liquid from the container bottom, the artificial gravity pressure being applied by a continuous force in addition to gas pressure acting on the entire liquid level surface of said liquid body, said force being applied in a direction parallel to the longitudinal axis of the container, maintaining separate the liquid and gas phases of the liquefied gas in said inner vessel, and supplementing said force by gas pressure of vapor from said liquid body.

13. A portable container according to claim 1 for storing and dispensing from any container position, a pressurized liquefied gas having a boiling point below 233° K., in which said means for sealing the outer periphery of the slidable piston against the inner wall of said inner vessel comprises a flexible film.

14. A portable container according to claim 1 for storing and dispensing from any container position a pressurized liquefied gas having a boiling point below 233° K. in which means are provided for monitoring and remotely indicating the liquid level of such liquefied gas body in said inner vessel, such means comprising a retainer transversely arranged and supported against the upper end of said compressible spring to move in a longitudinal direction with the motion of such spring and said piston as actuated by the changing liquid level of said liquefied gas body; a second compressible spring longitudinally aligned between the top surface of said retainer and the upper end of said portable container; a rod having one end associated with the retainer top surface for movement therewith and the other end longitudinally extending into the upper end of said portable container and forming a contact with an electrical indicating circuit, the longitudinal movement of said rod other end actuating the electrical circuit and causing the remote indicating device to register a change in liquid level.

References Cited in the file of this patent

UNITED STATES PATENTS

609,970	Lochmann	Aug. 30, 1898
1,122,710	Feit	Dec. 29, 1914
1,973,880	Moody	Sept. 18, 1934
2,396,459	Dana	Mar. 12, 1946
2,604,230	Payne	July 22, 1952
2,657,542	Wildhack	Nov. 3, 1953
2,861,715	Wissmiller et al.	Nov. 25, 1958
2,900,800	Loveday	Aug. 25, 1959