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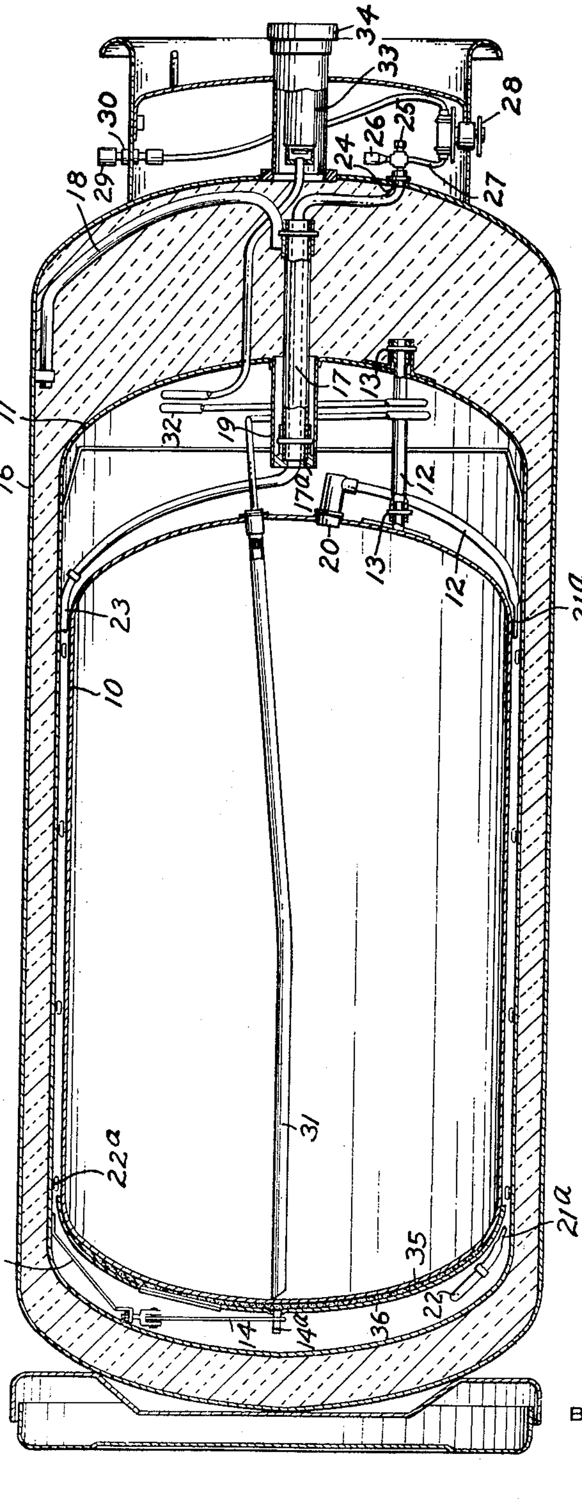

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CONTAINER FOR LOW-BOILING LIQUEFIED GASES

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This invention relates to apparatus for containing low-boiling liquefied gases. In particular this invention is a system for storing very low-boiling liquefied gases such as helium and hydrogen in a triple-walled, vacuum-insulated container.

Storing liquefied helium and hydrogen in a portable container has presented a vexing problem that until the present invention had escaped adequate solution. In the storage and preservation of such liquefied gases over a relatively long period of time, the prior art has used the technique of shielding the product liquid from external heat leakage by either partially or completely surrounding it with another more expendable liquefied gas, which may be either colder or warmer than the product liquid being stored. Since liquid helium and hydrogen even when pressurized to their critical pressure and temperature, or slightly above, are both still substantially colder than any other commercially available liquefied gas, it is thus usually only feasible to use a shielding or refrigerant liquid which is warmer than these stored product liquids. Therefore, the most that can be accomplished by shielding these very low-boiling product liquids with other warmer liquids is to retard evaporation of the product liquid by absorbing the heat leakage in the shielding liquid and thus preferentially evaporating that expendable liquid.

However, use of a warmer shielding liquid makes the resulting container unnecessarily large and bulky, which is especially undesirable for a portable container. Also, replenishment of the refrigerant liquid as may be required at rather frequent intervals is inconvenient and undesirable. Also, portable containers presently employed utilizing an insulating liquid have the further disadvantage of being quite sensitive to shocks experienced during common carrier shipment and handling.

It is an object, therefore, of the present invention to provide a system in which a very low-boiling gas such as helium or hydrogen can be preserved in the liquid state as a product. More specifically, it is an object of this invention to provide a portable system that is rugged in construction and convenient to use. A further object is to provide a system for the storing of a very low-boiling liquefied gas wherein the contents can be withdrawn at frequent intervals without appreciable loss of the contents through evaporation and without relying on the evaporation of an insulating liquid to prevent this loss.

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

The figure is a view of a longitudinal cross-section through a liquefied gas storage vessel embodying features of the present invention.

Although the invention will be described in terms of a system for storing helium in the liquefied state, it is to be understood that the invention is also suitable for storing other low-boiling liquefied gases with boiling points at atmospheric pressure below about 100° K., such as hydrogen and neon.

Very low-boiling gases such as helium and hydrogen are extremely difficult to store conveniently in rather substantial quantities, e.g. 100 liters or more, within a port-

able container. The desirability of transporting low-boiling industrial gases such as oxygen and nitrogen in liquid form is well known, and the need for such gases as well as for transporting even lower-boiling-gases is increasing. However, the problem of transporting and handling very low-boiling gases such as helium and hydrogen in liquid form is much more severe than that of transporting liquid oxygen and nitrogen. For example, the heat required to vaporize 1 liter of liquid helium is approximately 3 B.t.u., or about 1% of the heat required to vaporize 1 liter of liquefied oxygen. Consequently, great care must be taken to minimize the amount of heat that passes through the container into the liquid helium. The methods of limiting this heat inleak found in the prior art, however, partially offset the volumetric advantage of storing helium as a liquid rather than as a gas, since these methods require an extremely large insulation space between the helium storage vessel and the outer shell of the portable container thereby increasing the external dimensions of the container for a particular capacity and reducing the portability of the container.

It is not possible to completely eliminate the heat leak into a container and the present invention takes advantage of this fact to provide a portable container of minimum size. Heat leak by conduction and radiation has been minimized by providing a vacuum-insulated triple-walled liquefied gas storage container wherein at least one vapor-refrigerated metal thermal shield is situated between the outer shell and the inner liquefied-gas storage vessel.

An opacified insulating material is preferably placed between the outer shell and the inner vessel thereby substantially reducing the amount of heat leakage due to conduction and radiation that will pass through the enclosure formed by the outer shell and the thermal shield into the enclosure formed by the thermal shield and the inner vessel. The thermal shield is located such that the total heat leakage from it to the inner vessel comprising solid and gaseous conductive heat and radiant heat is quite small. The liquefied helium that is vaporized by the heat that passes through this inner enclosure between the thermal shield and the inner vessel is conducted, in heat exchange relationships with the thermal shield, out of the container into the surrounding atmosphere. Such vaporized helium is warmed by the heat transmitted through the outer enclosure, formed by the outer shell and the thermal shell, thereby cooling the thermal shield. With such a system, most of the heat transmitted through the outer enclosure is intercepted, thus permitting only a relatively small portion of the heat transmitted through the outer enclosure to enter the inner vessel. Due to the high specific heat of helium vapor in comparison to the latent heat of vaporization of liquid helium, this is a remarkably efficient method of restricting the amount of liquid helium that need be evaporated to carry off the heat passing across the thermal shield. By using such an insulating system to contain liquefied helium, not over about 10% of the heat reaching the thermal shield will usually be transmitted to the inner vessel.

The thermal shield is of sufficient strength to support the inner vessel in a rigid manner and to be attached to the outer shell. This two stage support system is constructed of relatively high strength-low thermal conductivity materials that effectively limit the amount of heat inleak by direct conduction.

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.

While a portable liquefied gas storage container will hereinafter be described in detail, it is to be understood that this invention is also applicable to larger containers of both mobile and stationary types. Such containers might, for example, be employed with trailers or tank cars.

With particular reference to FIGURE 1, a liquefied gas storage vessel 10 is preferably supported in a vertical position within the thermal shield 11 by spacers 12 and 14 which are rigidly attached to both vessel 10 and thermal shield 11. The spacers are preferably constructed from a material having a relatively high strength to thermal conductance ratio, such as reinforced plastic. A suitable plastic material is melamine or epoxy base resin with a reinforcing material such as glass fibers added to improve its tensile strength. An example of the latter is "Micarta" grade HY–180, obtainable from Westinghouse Corporation. Materials such as Micarta may be formed into relatively long members which are excellent for supporting an object where only a minimum amount of heat leakage by direct conduction can be tolerated but also where the object must be rigidly supported. Spacers 12 are preferably tubular shaped and are fixed to the upper end of vessel 10 and thermal shield 11 for example by pins 13. Vessel 10 is also stabilized at the lower end by spacers 14 which may be radially fixed to support ring 15, and support pin *14a*. Support ring 15 should also be constructed from a material having a relatively high strength to thermal conductance ratio such as austenitic stainless steel. Both spacers 12 and 14 should be located at uniform intervals about the central longitudinal axis of vessel 10 so that the preferred method of supporting vessel 10 by applying a tensile load to the spacers such that vessel 10 will be rigidly positioned will result in the load being evenly distributed.

Thermal shield 11 is located nearer the inner vessel than the outer shell, and preferably as close as possible without touching the inner vessel. This location of thermal shield 11 permits keeping the thickness of the outer enclosure and the overall physical size of storage container 10 to a minimum. Preferably, thermal shield 11 is supported from the upper end by means of a hollow support member 17 which is connected to the thermal shield 11 by connecting means *17a* disposed within reentrant tube 19. The upper portion of member 17 is supported by radial curved arms 18 extending from member 17 to the side wall of the outer shell 16. By extending member 17 down into re-entrant tube 19 and by attaching arms 18 to the side wall of the outer shell 16, maximum advantage is taken of their preferred construction from material having a relatively high strength to thermal conductance ratio. Therefore, the heat inleak by direct conduction through the support members to the thermal shield 11 is minimized without having to greatly enlarge the space between the top of thermal shield 11 and the upper end of outer shell 16. Also, by attaching curved arms 18 to the side of outer shell 16, the installation of the inner parts of the storage container is permitted prior to the final installation of the top portion of outer shell 16.

The liquefied gas storage vessel 10 is insulated from heat inleak preferably by an opacified insulation. In the preferred embodiment of this invention the opacified insulation employed is described more fully in copending U.S. application Serial No. 597,947 in the name of L. C. Matsch now U.S. Patent No. 3,007,596. It might comprise, for example, alternate parallel layers of a heat reflective foil such as aluminum separated by means of sub-micron glass fiber paper or mat. This insulation is preferably wrapped around the thermal shield 11 and substantially completely fills the space between the outer shell 16 and the thermal shield 11. Lateral support of the

fixed thermal shield-storage vessel combination is afforded by this insulation. Best insulating performance is obtained when the insulating space between the outer shell and the thermal shield is evacuated to less than about 25 microns of mercury.

An alternate insulating material which may be employed is the opacified powder-vacuum type described more fully in copending U.S. application Serial No. 580,897 in the name of L. C. Matsch now U.S. Patent No. 2,967,152 which might comprise, for example, equal parts by weight of copper flakes and finely divided silica. The latter material has a very low solid conductivity value but is quite transparent to radiation. The copper flakes serve to markedly reduce the radiant heat inleak.

The inner enclosure formed by the thermal shield 11 and storage vessel 10 may be filled with the powder-vacuum type opacified insulation or, alternately, evacuated to less than about 0.001 micron of mercury with no insulation added but with the surfaces enclosing this inner space being highly polished. However, such inner enclosure is preferably a portion of a space evacuated to a common low positive pressure of less than about 25 microns of mercury; the other portion of such space being the outer enclosure. In this preferred arrangement, the highly polished surfaces of thermal shield 11 and inner vessel 10 in combination with the evacuated inner enclosure serve to insulate inner vessel 10 from thermal shield 11. Absorbent material 35 such as silica gel or sodium zeolite A is located within enclosure 36 attached to the bottom of vessel 10 to assist in preserving the low vacuum pressure between the thermal shield and the vessel.

An alternate embodiment is a horizontally inclined liquefied gas storage vessel. The storage vessel could be supported with a two stage support system as indicated in the preferred embodiment of FIGURE 1 with tubular shaped spacers at one end and radially placed spacers at the other end. Also, the storage vessel could be supported at both ends by either arrangement. In this horizontal embodiment the thermal shield might be supported at each end by the support system employed in the preferred embodiment of FIGURE 1. Lateral support of the thermal shield could come from the insulation but should preferably come from a rigid support system as described above.

Evaporating gas from the liquid product contained in vessel 10 is withdrawn first through conduit 21 preferably having flattened section *21a*, between inner vessel 10 and thermal shield 11 directly to he bottom of the evacuated space between the thermal shield and the vessel. From here, the gas is conducted through conduit 22 having flattened section *22a*, which may be attached, for example, to the surface of thermal shield 11 in the shape of serpentine coils. The superheated vapor leaves the thermal shield at 23. If desired, conduit 22 may be directed through reentrant tube 19 and hollow support member 17 and emerge through the upper end of outer shell 16 at 24, at which point safety valve 25, which permits the passage of the evaporated gas to the atmosphere, and bursting disk 26 are installed. Conduit 27, the further extension of conduit 22, contains hand valve 28 and cap 29 on fitting 30. Hand valve 28 may be used for building pressure within the container from an external source if desired.

In the preferred embodiment, vapor conducting conduits 22 is attached to the surface of the metal thermal shield thereby allowing the vapor to refrigerate the thermal shield and the space between the thermal shield and the vessel to a desired low temperature which may be at about liquefied nitrogen temperatures; such vaporized gas being warmed to at least 150° K.

More particularly, thermal shield 11 must be maintained at a temperature such that the temperature difference between thermal shield 11 and inner vessel 10 is not greater than 50% of the temperature difference between the outer shell **16** and inner vessel **10**, and preferably within the range of 2–40%. Because the emissivity of the thermal shield is a function of the temperature to the fourth power, it is necessary to maintain the evacuated space between thermal shield **11** and inner vessel **10** at a low temperature in order to reduce the amount of radiant heat energy passing through such space to an acceptable value. It has been found that by maintaining the temperature difference between thermal shield **11** and inner vessel **10** below about 50% of the temperature difference between outer shell **16** and inner vessel **10** the emissivity factor is held within relatively low limits. The flattened portions of conduit **22**, i.e. **22***a*, allow thermal shield **11** to be positioned in the preferably close relationship with vessel **10** that results in a more adequately refrigerated evacuated space. This construction enables the thermal shield to be highly effective in intercepting heat inleak so that evaporation losses in helium service are restricted to less than about 2% of capacity per day for a 100 liter capacity storage container. In addition, vapor conducting conduits may also be located within the insulation space near the outer shell **16** in order to provide increased refrigerating effects from the evaporated gas. Further reduction in heat leak might be obtained by routing the vapor conduits near to or coiled around the major support members to refrigerate such members and thereby intercept some heat inleak by conduction.

Liquid filling and withdrawal is accomplished through fill-discharge conduit **31** located within vessel **10** and extending nearly to the bottom of the vessel. The upper end of conduit **31** is preferably attached to a helical conduit **32** coiled within the insulation space between the thermal shield **11** and inner vessel **10** and terminates in valve **33**, covered by cap **34**. For transferring a small portion of the contents of vessel **10** at one time, the normal operating gas pressure need be only slightly above atmospheric, such as 2–4 p.s.i.g. However, for transferring a greater quantity at one time, the gas pressure must initially be greater such as 4–15 p.s.i.g., since the gas pressure will decrease during withdrawn of liquid product. If it is desired to transfer all the liquid contents at one time, an external pressure source should be connected at fitting **30** to maintain a gas pressure of greater than about 4 p.s.i.g. during the entire transfer operation.

The preferred safety valve setting for helium will depend upon the usage of the container, and the choice of an optimum pressure for a particular application is based upon the following considerations:

(1) Adequate positive pressure must be maintained within the container to prevent back diffusion of air and its possible freezing therein, thus causing plugging of conduits and valves.

(2) A low saturation pressure is desirable to maintain the latent heat of vaporization of the liquid helium as great as possible to retard its loss by evaporation.

(3) The pressure setting must be sufficient to permit convenient transfer of at least some of the liquid contents, without requiring use of an external source of pressurizing gas.

This preferred pressure setting would be somewhat greater for higher-boiling liquefied gases.

An important feature of this container is that it not only has a very low heat leak as is required for liquid helium service and obtained principally by use of the special thermal shielding arrangement, but that it is also reasonably rugged and thereby particularly useful for transporting such liquefied gases.

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 liquefied gas storage container comprising in combination: a liquefied gas inner storage vessel; an outer shell surrounding the inner vessel and outwardly spaced therefrom to provide an evacuable insulation space therebetween; a metal thermal shield positioned within said evacuable insulation space such that the outer surface of the thermal shield and the inner surface of said outer shell define an outer enclosure and the inner surface of said thermal shield and the outer surface of the inner vessel define an inner enclosure; support means for positioning said thermal shield within said outer shell which comprises a re-entrant tube connecting to an opening in the upper part of said thermal shield and depending into said inner enclosure, and a hollow support member connecting to an upper section of said outer shell and depending into said re-entrant tube and connecting thereto; support means for positioning said inner vessel within said thermal shield; such support means being constructed from materials characterized by high strength-to-thermal-conductance ratios; liquefied gas fill-discharge means providing liquid communication within the interior of said inner vessel; vapor vent means providing gaseous communication with the interior of said inner vessel for the continuous venting therefrom of vapor evaporated by ambient atmospheric heat unavoidably transmitted thereinto, said vapor vent means being constructed and arranged to thermally cooperate with said thermal shield such that said thermal shield is substantially uniformly cooled to and maintained at a substantially constant low temperature by heat exchange with the vented vapor continuously passing through said vapor vent means.

2. Apparatus according to claim 1 wherein opacified insulation material is contained within and substantially completely fills the insulating space between said outer shell and said thermal shield.

3. Apparatus according to claim 4 wherein said opacified material comprises alternate parallel layers of heat reflective foil separated by sub-micron heat resistant paper or mat, such insulation being wrapped around said thermal shield.

4. Apparatus according to claim 2 wherein the insulation material comprises a powdered opacified heat reflective insulation.

5. A low-boiling liquefied gas storage container comprising in combination a liquefied gas storage vessel; an exterior shell completely surrounding the storage vessel and forming an evacuable space therebetween; a thin metal thermal shield positioned within said exterior shell such that the outer surface of the thermal shield and the inner surface of said exterior shell define a first outer enclosure and the inner surface of said thermal shield and the outer surface of said storage vessel define a second inner enclosure; said thermal shield and said storage vessel being joined by first support means contained within said second enclosure connecting the upper end of said thermal shield and the upper end of said storage vessel which comprises a plurality of tubular shaped spacers; and by second support means contained within said second enclosure connecting the lower end of said storage vessel and the lower end of said thermal shield; third support means within said first enclosure connecting said exterior shell with the upper end of the thermal shield which comprises a re-entrant tube connecting to an opening in the upper part of said thermal shield and depending in the second enclosure, a hollow support member connecting to an upper section of said outer shell and depending into said re-entrant tube and connecting thereto, and a plurality of curved arms connecting said hollow support member to the upper section of said outer shell; the first, second and third support means being constructed from materials characterized by high strength-to-thermal conductance ratios; liquefied gas fill-discharge means entering the upper end of said exterior shell and

extending to the bottom of said storage vessel thereby passing through said first enclosure, the upper end of said thermal shield, said second enclosure, and the upper end of said storage vessel; low-boiling liquefied gas vapor vent means attached to the upper end of said storage vessel and extending from the upper end of said second enclosure to the lower end, wherefrom the vent means extends spirally upward between the walls of said storage vessel and said thermal shield through the upper end of said thermal shield, said first enclosure, and the upper end of said exterior shell into the surrounding atmosphere said vent means being so constructed and arranged to thermally cooperate with said thermal shield such that said thermal shield is substantially uniformly cooled to and maintained at a substantially constant low temperature by heat transfer with the vented vapor passing through said vapor vent means; and an opacified insulation material substantially reducing the heat inleak to said storage vessel contained within said evacuable space.

6. Apparatus according to claim 5 wherein said vent means, being directed spirally upward between the walls of said storage vessel and said thermal shield, is a conduit attached to the inner surface of said thermal shield.

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