

- [54] **CRYOGENIC STORAGE AND
EXPULSION MEANS**
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Louis, Mo.
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- [51] Int. Cl. **F17c 7/02**
- [58] Field of Search..... **62/45, 50, 51, 52, 54**

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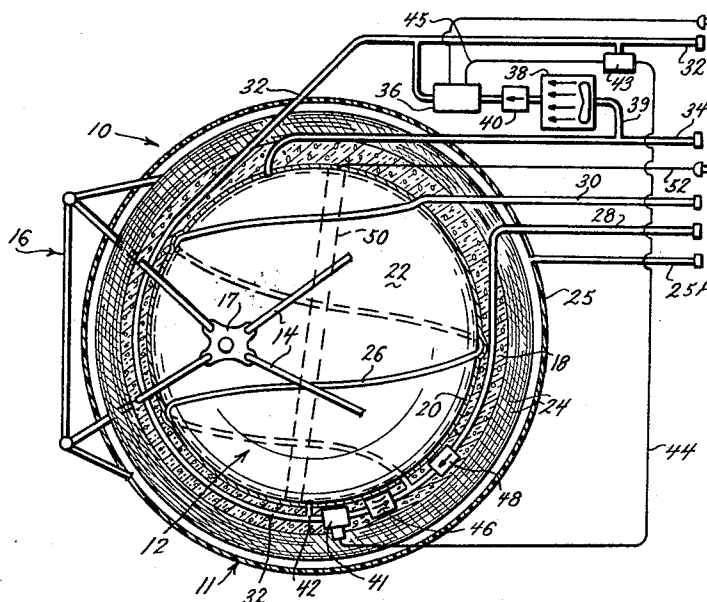
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[57] **ABSTRACT**

A system for storing cryogen in either a super-critical or a two phase state and for delivering the cryogen therefrom as desired. The system employs a storage vessel with external cooling coils which keep the storage vessel cold either by having isenthalpically expanded cryogen from the vessel vent therethrough when the cryogen is being stored in its super-critical state and/or by having a secondary cooling fluid pumped therethrough especially when the cryogen is being stored in its two phase state. The system also has means to prevent stratification of the super-critical cryogen and to pump heat into the vessel to maintain the super-critical state of the cryogen even when cryogen delivery is at relatively high rates of flow.

17 Claims, 2 Drawing Figures



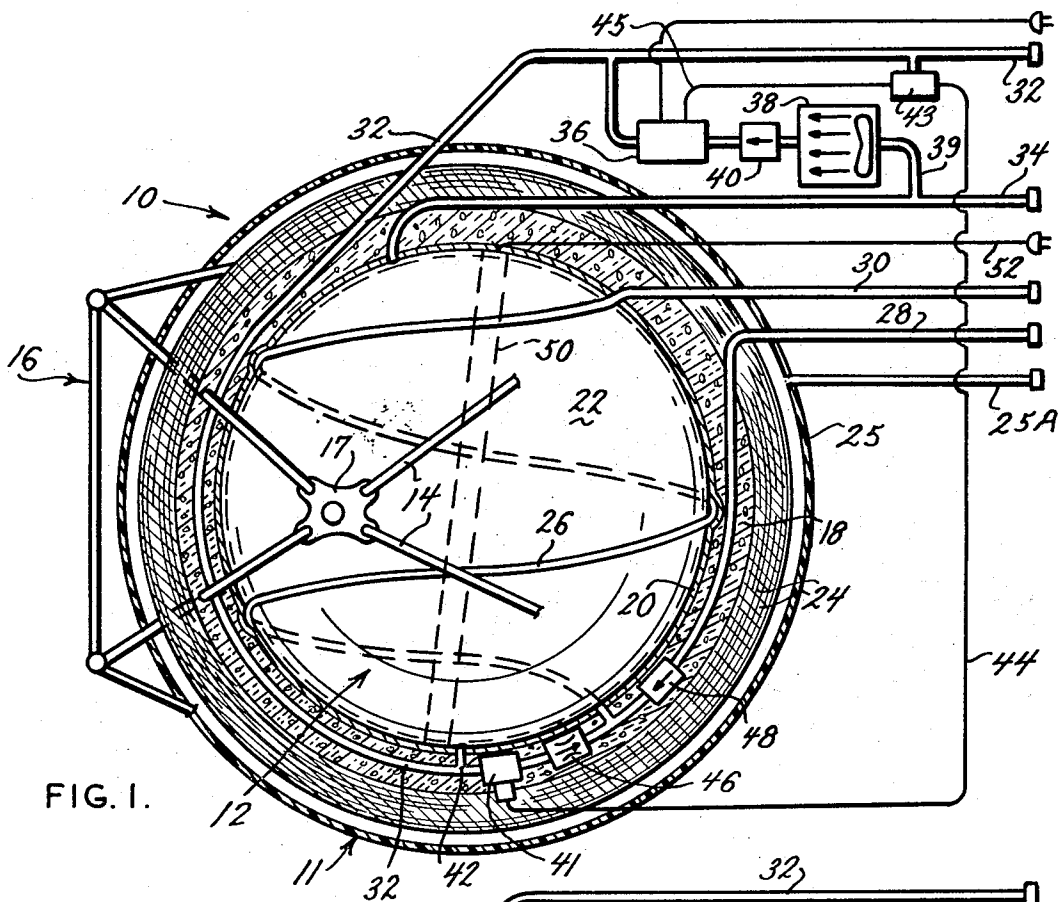


FIG. 1.

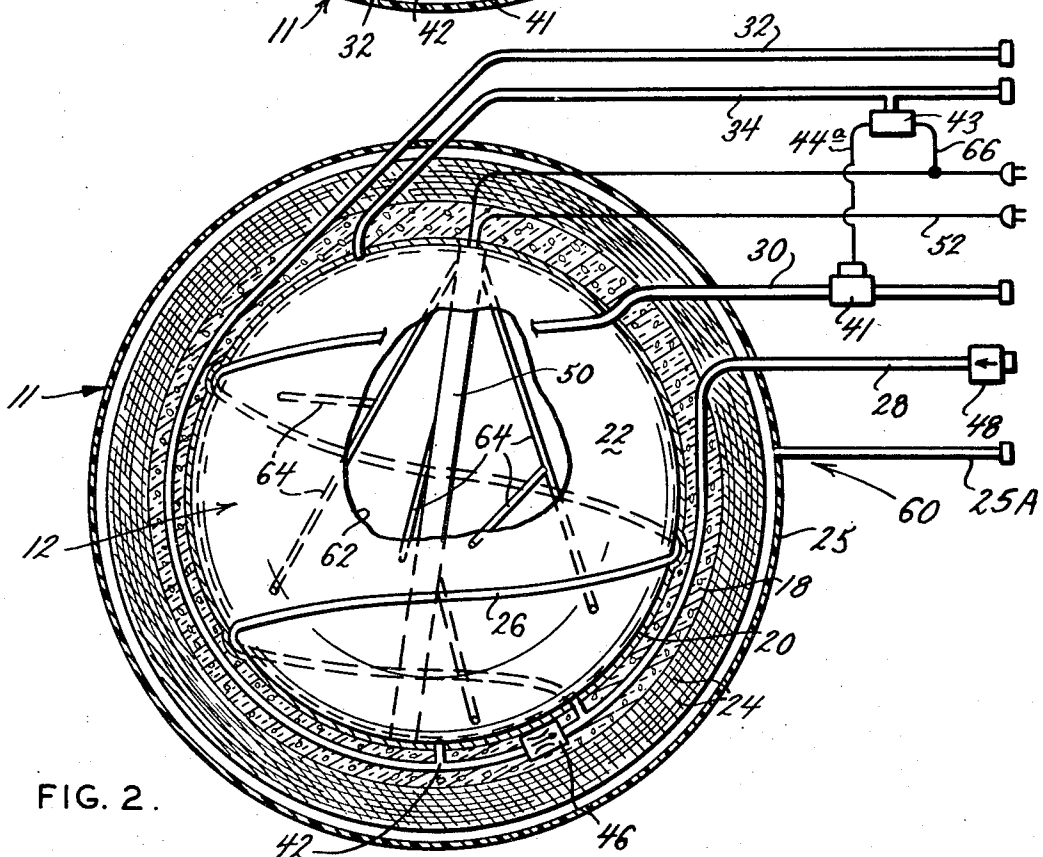


FIG. 2.

CRYOGENIC STORAGE AND EXPULSION MEANS

Cryogenic storage and delivery systems including those for use in various hostile environments such as in space, must be able to store and/or supply cryogen without regard to the attitude thereof or the acceleration forces acting thereon. The capability of a cryogenic storage system to reliably deliver a cryogen from a container and particularly from a rigid container, in any attitude thereof and no matter what acceleration is acting thereon, is rather simply achieved by storing the cryogen in its super-critical state, super-critical being the state of the cryogen where the pressure thereof is high enough to convert the normal two-phase (gas and liquid) mixture into an homogeneous single-phase substance normally referred to as a liquid at temperatures below the critical temperature and a gas at temperatures above. To maintain the stored cryogen at high pressure as cryogen is being removed from the rigid vessel or container, heat is injected into the cryogen either by means of a heater or by means of natural heat leak through the walls of the container. If the cryogen is removed from the container at proper flow rates to relieve the pressure increase due to the natural heat leak into the container, the stored cryogen can be maintained in its super-critical state at a constant pressure by the heat leak alone. The heat leak required to maintain a relatively constant pressure at any given flow rate varies with the density of the super-critical cryogen and hence also with the amount of cryogen remaining inside the container. The amount or density of the cryogen remaining inside the container, of course, varies as cryogen is withdrawn therefrom and normally various flow rates including the condition of no flow at all are required from a cryogenic storage and expulsion system, which flow rates vary with the needs of the connected cryogen using system and not necessarily with the density of the cryogen. Usually therefore both heating and cooling means must be included in such a cryogenic storage system, the heating means for use when the natural heat is insufficient to maintain the proper system pressure for the desired flow rate, and the cooling means for use when the natural heat leak is too great for the desired flow rate and the pressure inside the container tends to rise above the pressure required to maintain the cryogen in its super-critical state to a pressure which causes venting of the stored cryogen. In this latter case, it has been common practice to vent super-critical cryogen from the container through an isenthalpic expansion valve which lowers the temperature and pressure thereof, and then to pass the cooled two phase (gas and liquid) cryogen which results, through a heat exchanger inside the container to act as an additional heat sink for heat leak interception and to cool the remaining super-critical cryogen in order to maintain the pressure thereof at a given super-critical level.

The known systems which perform the above described storage process are usually constructed utilizing double wall or Dewar containers to reduce the natural heat leak. Also to reduce the natural heat leak into the containers the operative components of such systems are usually located inside the container or at least between the two walls thereof and sometimes the operative components such as valves, pumps, and heaters are actually immersed in the stored cryogen.

This subjects the operative components to extremely low temperatures and greatly decreases their reliability while increasing the cost of their installation. Having the operative components within the storage containers also increases the complexity of the containers and makes maintenance thereon difficult and in some cases impossible when cryogen is actually being stored.

The present cryogenic storage and expulsion system overcomes these and other disadvantages and shortcomings of known cryogenic storage systems by incorporating certain refinements and improvements thereto that can be made to such systems especially when they are designed for use primarily in outer space. The present system includes an insulated single wall vessel or container rather than a double walled vessel or Dewar to store the cryogen at low temperatures in either a super-critical or a two-phase state, low conductivity suspension for the vessel to reduce the natural heat leak into the vessel, and a heat exchanger external to the vessel to intercept heat which might otherwise leak thereinto. The present system usually stores cryogen in a two phase state when the system is on the ground or in the atmosphere because cryogen is easier to handle and less dangerous when in its two phase state. The cryogen may also be stored in the super-critical mode if a higher fluid energy level is required. Since coolant is relatively easy and economical to obtain on the ground, a secondary cooling fluid such as liquid nitrogen is pumped through the heat exchanger to keep the system cool when it is storing cryogen in either the two phase or single phase state on the ground to compensate for the generally less efficient single walled storage vessel or container.

When the present system is to operate in the vacuum and sometimes accelerationless environment of space, the secondary cooling fluid supply is disconnected and the pressure of the cryogen is allowed to rise until the cryogen reaches its super-critical state. Operating in the vacuum of space eliminates gaseous conduction heat leak and thereby reduces the cooling requirement at any given flow rate including the condition of no flow out of the vessel. The storage vessel is cooled to compensate for the inevitable radiant and conductive heat leak thereinto by isenthalpically expanding a small amount of the cryogen and by feeding the cooled gas and liquid mixture which results through the heat exchanger, which expanded cryogen can then be used in spacecraft systems or wasted as desired. The super-critical pressure of the cryogen itself is used to expel the cryogen from the storage vessel on demand so that no pumps or other means are required to draw cryogen out of the vessel for use in the isenthalpic cooling process described above or for use elsewhere in the spacecraft.

Heat injection means are provided either internally or externally to the storage vessel of the present system to add heat to the cryogen for high flow rate operation when the natural heat leak even without the interception of heat by the external heat exchanger is too low to maintain proper cryogen pressure. The heat injection means besides heating the cryogen also include means to prevent the phenomenon of stratification of the stored super-critical cryogen. Stratification of stored super-critical cryogen occurs when the natural convective forces acting on the super-critical cryogen are in-

sufficient to keep it circulating and homogeneous and therefore portions thereof that become heated, such as by means of the natural heat leak through the wall of the storage vessel, have a tendency to remain at the same locations at which they are heated and stratify. Stratification is undesirable because it greatly decreases the storage efficiency of any cryogenic storage system.

Although the present system may have a higher natural heat leak than some known cryogenic storage means when operating in an atmosphere, its efficiencies are equal to or higher than the efficiencies of the known systems when operating in its intended environment of space. In addition the present system, because most if not all of its operative components are located outside the storage vessel and because the storage vessel is of single wall construction, can be more easily and economically constructed and maintained and is also lighter and less bulky than the heretofore known cryogenic storage and expulsion systems.

It is therefore a principal object of the present invention to provide cryogenic storage and expulsion means particularly adapted for use in space.

Another object of the present invention is to reduce the complexity of cryogenic storage systems.

Another object is to provide a cryogenic storage and expulsion system which is relatively economical to construct and maintain.

Another object of the present invention is to increase the storage capacity to weight ratio of cryogenic storage systems.

Another object of the present invention is to provide means to prevent cryogen stratification in cryogenic storage systems.

Another object of the present invention is to provide a cryogenic storage system with a minimum of moving parts and which can operate unattended for long periods of time.

Another object is to reduce the natural heat leak to a cryogenic storage system by reducing the number of heat conductive connections to the storage vessel thereof.

Another object is to extend cryogenic fluid storage time by reducing the temperature of venting fluid and providing an additional heat sink for heat leak interception.

These and other objects and advantages of the present invention will become apparent after considering the following detailed specification which discloses several preferred embodiments thereof in conjunction with the accompanying drawing, wherein:

FIG. 1 is a partial cross-sectional view taken through the center of a cryogenic storage means diagrammatically illustrating the features of the present invention, said view also showing other system components and connections therefor; and,

FIG. 2 is a partial cross-sectional view similar to FIG. 1 but showing a modified form of the present cryogenic storage system.

Referring to the drawing more particularly by reference numbers, number 10 in FIG. 1 refers to a cryogenic storage and expulsion system constructed according to the present invention. The system 10 includes storage means 11 the inner portion of which is a single walled storage vessel 12 which can be any

desired size and shape and which is shown as being spherical since a spherical shape is usually most desirable for a cryogenic storage vessel. This is so because a sphere has a minimum surface area for heat leaks for a given enclosed volume. The storage vessel 12 is supported by tension members 14 which are part of a truss structure 16 only a portion of which is shown. Since the tension members 14 come in contact with the vessel 12 at their connections 17 thereto and therefore are potential sources of heat leak therein, they are preferably fabricated from very low thermal conductivity materials such as fiberglass. The truss 16 is constructed to maintain the members 14 in tension because by being used in tension they can be made relatively smaller in cross-sectional area, and still be structurally stable thereby further reducing the heat which can be conducted therethrough. In addition, since the members 14 are maintained in tension they can be relatively long rod-like members which still further reduces the heat which can be conducted therethrough.

Surrounding the storage vessel 12 is a layer of foam insulation 18. The foam layer 18 is primarily for preventing heat leaks into the vessel 12 due to gaseous conduction when the system 10 is operating in the atmosphere. A thin layer of resilient spacer material 20 such as a layer of dimpled aluminum material is provided between the vessel wall 22 and the layer of foam insulation 18. This is included to prevent damage to the insulation layer 18 caused by thermal stresses therein due to differences which may exist in the thermal expansion coefficients of the foam and the material used in the construction of the wall 22 of the vessel 12. This is important because any damage to the layer 18 of insulation will degrade its performance. Layers 24 of crinkled aluminized and silver metalized plastic material or the like are applied to the outer surface of the foam layer 18. The layers 24 form the outer portion of the subject device and are included to provide means which primarily block radiant heat leak into the storage vessel 12. The layers 24 can be applied in any convenient way such as by the use of pressure sensitive adhesive tape. In a typical experimental application 100 layers of the aluminized material were found to be sufficient but greater or fewer layers 24 may be required depending on the intended purpose for the system 10 and the insulative characteristics of the particular type of material used. Vapor barrier 25 in the form of a plastic membrane is used to prevent the absorption of moisture into the insulation scheme when the system is on the ground or in the atmosphere, by purging the enclosed area through a line 25A with a dry inert gas. When the system is to be operated in space the enclosed area is vented to the surrounding vacuum. Since various thicknesses of insulative and spacer materials may be used in the present system 10, the relative thicknesses of the insulative and spacer materials shown in the drawing is chosen for ease of understanding rather than to indicate any precise relative thickness relationship between the layers.

A heat exchanger coil 26 is wound around the storage vessel 12 between the vessel wall 22 and the foam insulation layer 18. When the system 10 is on the ground where low temperature coolant such as liquid nitrogen is easily and economically obtainable, such

coolant is pumped through an inlet line 28 to cool the vessel 12 and the heat exchanger coil 26. After the coolant has done its cooling job in the heat exchanger coil 26, it is vented through a vent line 30 and recirculated or wasted as desired. The coolant is provided to lower the temperature of the storage vessel 12 so that when the cryogen, which may be relatively more expensive than the coolant, is introduced into the interior of the vessel 12, it will not boil away or be excessively warmed because it then does not have to cool the vessel 12.

The cryogen is introduced into the storage vessel 12 through another inlet line 32 shown connected at the bottom thereof, which inlet line 32 is connected to an external source of the desired cryogen. The cryogen which passes through the inlet line 32 into the vessel 12 is usually at or only slightly above atmospheric pressure and is therefore in its two-phase (gas and liquid) state. A vent line 34 is connected to the interior of the vessel 12 at or near the top thereof, and during filling of the vessel 12, or when cryogen in the two phase state is being stored, the vent line 34 is connected to means (not shown) which open the line 34 to atmosphere so that no appreciable pressure build up can occur inside the vessel 12. After the storage vessel 12 has been filled to capacity, or filled with a desired amount of the cryogen, coolant can still be pumped through the heat exchanger coil 26 to maintain the cryogen in the vessel 12 in its two phase state. This is usually done when the cryogen storage system 10 is in a condition such as a "ground hold" condition as when a spacecraft is required to be maintained on the ground in a ready condition for considerable or indefinite periods of time. Once it has been determined that the spacecraft is ready for launch, the supply of coolant is disconnected from the inlet line 28 and the vent line 34 is closed. The natural heat leak into the storage vessel 12 thereafter increases the pressure of the stored cryogen, as for example in the case of oxygen, to about 1,000 psi at which pressure its state becomes super-critical. If the pressure of the cryogen inside the storage vessel 12 must be raised faster than can be accomplished by the natural heat leak alone, heat can be added thereof by means of a heater 36. In this case, the cryogen is pumped through the heater 36 by a pump 38, the heater and pump both being connected in a bypass line 39 connected between the vent line 34 and the inlet line 32. A check valve 40 is also placed in the bypass line 39 and oriented as shown in FIG. 1 to prevent cryogen from undesirably escaping out of the system 10 when the vessel 12 is being filled.

Once the desired pressure inside the vessel 12 has been reached so that the cryogen is in its super-critical state, venting of the cryogen to prevent a further increase in pressure can be accomplished by intermittent operation of a remotely operated shut-off valve 41 which is connected to the inlet line 32 at a T-connection 42 shown positioned adjacent to the entry of the inlet line 32 into the storage vessel 12. The shut-off valve 41 can be operated automatically by a pressure sensor 43 which is connected thereto through a connection 44, and the pressure sensor 43 can be located anywhere in the pressurized portion of the system 10 being shown attached to the inlet line 32. The valve 41 can be operated by other automatic or manual means as well. The pressure sensor 43 can also include an

operative connection 45 to the heater 36 for controlling the operation of the heater 36 as well. The cryogen which of course is in its super-critical state when passing through the valve 41, is passed through an isenthalpic throttling valve or orifice 46 which subjects the super-critical cryogen to an isenthalpic expansion process and reduces the pressure and temperature thereof. The cryogen then in the form of a gas or a gas-liquid mixture, is vented through the heat exchanger coil 26 and out the vent line 30. The venting of the cooled two phase cryogen through the heat exchanger coil 26 lowers the temperature of the surface of the vessel 12 and intercepts a substantial portion of the natural heat leak therein which in combination with the pressure drop which results from venting the storage with the storage vessel 12 reduces the pressure of the cryogen remaining in the vessel 12. A check valve 48 oriented as shown in FIG. 1 and positioned in the cooling fluid inlet line 28 prohibits the isenthalpically cooled cryogen from flowing out through the inlet line 28 and thereby assures that instead it flows out through the heat exchanger coil 26 as desired. The check valve 48 may be located within the insulation adjacent to the isenthalpic valve 46 in which case the connected line 28 can be constructed of relatively weak materials with low heat conductivities or the check valve 48 may be outside the insulation as shown in FIG. 2. In this latter case, the valve 48 may take the form of a conventional quick disconnect self-sealing connector on the end of line 28.

The relatively high pressure of the super-critical cryogen inside the storage vessel 12 is utilized to force the cryogen out the vent line 34 to supply connected spacecraft systems with cryogen as needed. When high rates of flow of the cryogen are required, the natural heat leak may not be sufficient to maintain the super-critical pressure of the cryogen within the vessel 12. At these times, the pump 38 connected to the vent line 34 is energized to circulate super-critical cryogen through the heater 36 which is also energized to inject heat therein. The heated super-critical cryogen is then returned to the storage vessel 12 through the inlet line 32 to which the outlet of the heater 36 is connected. The above described artificial heating process to maintain super-critical storage and expulsion pressures may be automatically controlled by means such as the pressure sensor 43 or by other means, if desired. It may also be desirable to operate the pump 38 without operating the heater 36 to circulate cryogen within the storage vessel 12 to avoid the aforementioned stratification problems. In this manner the pump 38 acts as destratification means.

As shown in FIG. 1 a conventional capacitive probe 50 may be positioned in the interior of the storage vessel 12. The capacitive probe 50 produces electrical outputs on lead 52 which outputs are indicative of the density and hence also the amount of super-critical cryogen remaining in the storage vessel 12.

FIG. 2 discloses a slightly modified form 60 of the cryogenic system 10 shown in FIG. 1. Whenever possible the parts of the modified system are numbered the same as the corresponding parts of the system of FIG. 1. As can be seen through the cut-away wall portion 62 of the vessel 12, the system 60 includes internal rather

than external heater means to inject heat into the stored supercritical cryogen. In the system 60, these heating means include heating elements 64 which extend from around the capacitive probe 50 throughout the interior of the storage vessel 12. The heating elements 64 in addition to providing heat to maintain the cryogen in its super-critical state during high flow rate periods are themselves relatively good heat conductors and therefore are able to relatively evenly distribute heat throughout the cryogen whether the heat is naturally or artificially injected therein to assure that the cryogen within the container 12 is everywhere at the same temperature and density thereby preventing stratification. As shown no pump is then required either in conjunction with heating or destratification means in this embodiment.

In a system such as the modified cryogenic storage and expulsion system 60 shown in FIG. 2 the cooling system can also be modified to make construction and maintenance even easier by connecting the remote operated valve 41 in the vent line 30 of the heat exchanger coil 26 at a location outside the layers of insulation 18 and 24 or by eliminating the valve 41 altogether. In both such embodiments, the cryogen storage system including the storage vessel 12 and the inlet line 32 can be held at a pressure slightly above the pressure of the coolant in the heat exchanger coil 26 so coolant will not flow backwards through the isenthalpic valve 46 and into the storage system to undesirably mix with the stored cryogen when the system is in "ground hold" condition. Holding the cryogen in the system 60 at elevated pressures or even at super-critical pressures on the ground is sometimes desirable since it is sometimes desirable to have super-critical cryogen available to the connected spacecraft systems while the cryogenic storage system 60 is in its "ground hold" configuration. When in the "ground hold" configuration, the system 60 will, of course, allow cryogen to pass through the isenthalpic valve 46 to mix with the coolant and flow through the heat exchanger coil 26. Usually the amount of cryogen lost in this manner is relatively negligible even if the cryogen is being held at super-critical pressures because the isenthalpic expansion valve 46 is usually constructed to allow relatively little cryogen flow therethrough even when high pressure differentials exist thereacross.

Once the system 60 is storing the cryogen in its super-critical state with the supply of secondary coolant cutoff, it operates like system 10 of FIG. 1 except that when the valve 41 is closed the heat exchanger coil 26 fills with super-critical cryogen which is lost when the valve 41 again turns on. The total volume of the space enclosed by the heat exchanger coil 26 is usually so small with respect to the enclosed volume of the storage vessel 12, that the loss of the super-critical cryogen therein is barely noticable. As shown in FIG. 2, the remote operated valve 41 can be controlled by the pressure sensor 43 operatively coupled thereto by connection 44a. As in the system 10, the pressure sensor 43 may be connected anywhere in the pressurized portion of the system 60 and is shown connected to sense the pressure in the vent line 34. The pressure sensor 43 may also control the operation of the heater 64 through an electrical connection 66 therebetween or otherwise if desired.

The isenthalpic throttling valve 46 in a system such as the systems 10 and 60 can be designed to be passively variable so that the amount of super-critical cryogen which is expanded and cooled for use in the heat exchanger coil 26 varies with the density and/or the temperature of the super-critical cryogen at the inlet side thereof. For this system such a valve can to some extent compensate for the differences in the specific heat of the cryogen at different densities to automatically vary the cooling of the system as the density of the stored cryogen changes, thereby maintaining the pressure of the cryogen therein relatively constant automatically and without the use of any moving parts and vary little cycling of the valve 41.

As can be seen in the drawing, the functional components of the present invention that have the greatest potential for failure such as pumps and valves are located external to the insulation and this is an important factor from the standpoint of ease of maintenance and otherwise. Also by locating as many of the functional components as possible external to the vessel 12, electrical wiring for control and instrumentation which would otherwise pass through the insulation and generate further heat leaks into the system is eliminated. The present systems also, and importantly, utilizes single wall storage vessels rather than more complex and costly double wall or Dewar types and for this and other reasons the subject system is less expensive to make and maintain than previously known cryogenic storage and expulsion systems. However, more complex storage vessels could be used with the present device although as a general rule they are not needed.

Although the present system is primarily for use in storing cryogens such as oxygen, hydrogen, nitrogen or helium, various other fluids that must be stored at relatively low temperatures can also be stored therein.

Thus there has been shown and described novel cryogenic storage and expulsion means which are able to be maintained in a "ground hold" condition indefinitely, which reduces the cost of such systems while also reducing the weight and bulk thereof, and which makes such systems relatively easy to service and repair. The present means also fulfill all of the objects and advantages sought therefor. Many changes, alterations, modifications, and other uses and applications of the subject means will, however, become apparent to those skilled in the art after considering this specification which discloses several preferred embodiments thereof. All such changes, alterations, modifications and other uses and applications of the subject means which do not depart from the spirit and scope of the invention are deemed to be covered by the invention which is limited only by the claims which follow.

What is claimed is:

1. Cryogenic storage and delivery means comprising a cryogen storage vessel having a single storage chamber therein, means for establishing and maintaining cryogen in said vessel in a pressurized condition, heat exchanger means disposed in heat transfer relation to the exterior of said storage vessel, means for controllably communicating the interior of said vessel with said heat exchanger means so cryogen can flow out from the vessel into and through said heat exchanger means, means for isenthalpically reducing the pressure

of the cryogen flowing out from the interior of said vessel into said heat exchanger means, means for alternatively circulating a coolant substance through the heat exchanger means, means for controllably injecting heat into said stored cryogen, and other means for delivering pressurized cryogen out of said vessel.

2. The means defined in claim 1 including means for communicating said heat exchanger means to an external source of coolant.

3. The means defined in claim 1 including valve means responsive to the pressure of said stored cryogen, said valve means controlling the flow of said cryogen to the heat exchanger means to vary the flow thereof in relation to changes in pressure of the stored cryogen.

4. The means defined in claim 1 including means responsive to the pressure of the stored cryogen, said means being connected to said heat injecting means to control the operation thereof in a manner to maintain the stored cryogen in a super-critical state, said heat injecting means including pump means which when operating cause some agitation of the stored cryogen preventing stratification thereof.

5. The means defined in claim 1 wherein said means for controllably injecting heat into said cryogen include heat conductive means positioned inside said vessel immersed in said stored cryogen, said conductive means operating to evenly distribute heat throughout said stored cryogen thereby preventing stratification of the cryogen.

6. Means for storing cryogen in a liquid-gas or a super-critical state comprising a storage vessel having a single storage chamber therein, means for feeding cryogen into said storage chamber, means responsive to a condition of the stored cryogen to controllably inject heat into said stored cryogen to raise and maintain sufficient pressure in said vessel chamber to cause at least some of the cryogen therein to go from a gas-liquid state to a super-critical state, means insulating said vessel, said insulation means including tensioned truss members having spaced locations thereon where they are in contact with the vessel to permit some heat leakage thereinto, heat exchanger means positioned adjacent to the exterior of said storage vessel to intercept heat leaking into said vessel, primary means for establishing a flow of coolant from an external source through said heat exchanger means, other means for alternatively venting cryogen contained in said vessel through said heat exchanger means, said other means including means for isenthalpically expanding said venting cryogen.

7. The means defined in claim 6 wherein said means for injecting heat into said stored cryogen include conduit means communicating with the interior of said storage vessel, pumping means connected to said conduit means for circulating cryogen through said conduit means and said storage vessel, and heater means connected to said conduit means to inject heat into said cryogen circulated through said conduit means by said pumping means.

8. The means defined in claim 6 including pressure responsive means located outside said storage vessel, said pressure responsive means being in communication with said stored cryogen and responsive to the pressure thereof, said pressure sensitive means being

connected to energize said heat injecting means to inject heat into said cryogen when the pressure of the cryogen is below a predetermined pressure.

9. The means defined in claim 6 including pressure responsive means located outside of said storage vessel, said pressure responsive means being in communication with the stored cryogen and responsive to the pressure thereof, said pressure responsive means being operatively connected to said cryogen venting means to cause venting of isenthalpically expanded cryogen through said heat exchanger means to take place when the pressure of said stored cryogen is above a predetermined pressure.

10. The means defined in claim 6 including heat insulating support means for said storage vessel, said support means including a truss formed of connected support members constructed of materials having low heat conductivity characteristics and connected to the storage vessel in such a fashion as to assure said support members are maintained in tension, said truss engaging the vessel at spaced locations thereon.

11. The means defined in claim 6 wherein said heat exchanger means include a cooling coil wrapped around said storage vessel and connected to conduct said venting cryogen having passed through said isenthalpic expanding means about said storage vessel, said cooling coil also being connected to said secondary means to conduct said coolant about said storage vessel, a junction between said primary and secondary means and said cooling coil, and a check valve adjacent said junction in said secondary means oriented to prevent vented cryogen from flowing through said secondary means.

12. The means defined in claim 6 wherein said heat injecting means include means to distribute heat relatively uniformly throughout the stored cryogen to prevent stratification thereof.

13. The means defined in claim 6 wherein said insulation means include a first layer of insulation material substantially surrounding said storage vessel to reduce conduction heat leak thereinto, and at least one secondary layer of insulation material substantially surrounding said storage vessel to reduce radiant heat leak thereinto.

14. The means defined in claim 13 wherein said first layer of insulation material is foam insulation material and wherein said insulation means include a layer of resilient spacer material positioned between said storage vessel and said foam layer.

15. Super-critical fluid storage and delivery means comprising a fluid storage vessel having a single storage chamber therein, a heat exchanger adjacent the exterior of said vessel, a throttling valve outside said vessel, said valve having an inlet communicating with the interior of said vessel and an outlet communicating with said heat exchanger, heater means and pressure responsive means in communication with said stored fluid, said pressure responsive means being operatively connected to said heater means to energize said heater means in response to predetermined pressure conditions of the fluid whereby said heating means deliver heat to the stored fluid to increase the pressure thereof, means associated with said heater means operable in conjunction therewith to prevent stratification of the contents of the storage vessel, and fluid conduit means for delivery of said stored fluid from said vessel.

16. Means for storing cryogen in a liquid-gas or a super-critical state comprising a storage vessel, means for feeding cryogen to said storage vessel, means to controllably inject heat into said stored cryogen to raise and maintain sufficient pressure in said vessel to cause the cryogen to go from a gas-liquid state to a super-critical state, means insulating said vessel, said insulation means permitting some heat leak therethrough, heat exchanger means positioned adjacent to the exterior of said storage vessel to intercept heat leaking into said vessel, primary means for establishing a flow of coolant through said heat exchanger means including means for venting cryogen contained in said vessel through said heat exchanger means and means for

isenthalpically expanding said venting cryogen, secondary means for establishing a flow of coolant from an external source through said heat exchanger means at predetermined times, and cryogen density sensitive means located within said storage vessel to measure the density of the cryogen therein when the cryogen is in a super-critical state and hence the amount of the cryogen stored within said vessel, said density sensitive means including means to generate information signals as to the amount of cryogen remaining in said storage vessel.

17. The means defined in claim 16 wherein said density sensitive means include a capacitive probe.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,699,696 Dated October 24, 1972

Inventor(s) Ronald L. Rhoton

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 6, line 15, cancel "with"; line 16, cancel "the pressure drop which results from venting the"; line 17, cancel "storage".

Signed and sealed this 22nd day of May 1973.

(SEAL)
Attest;

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents