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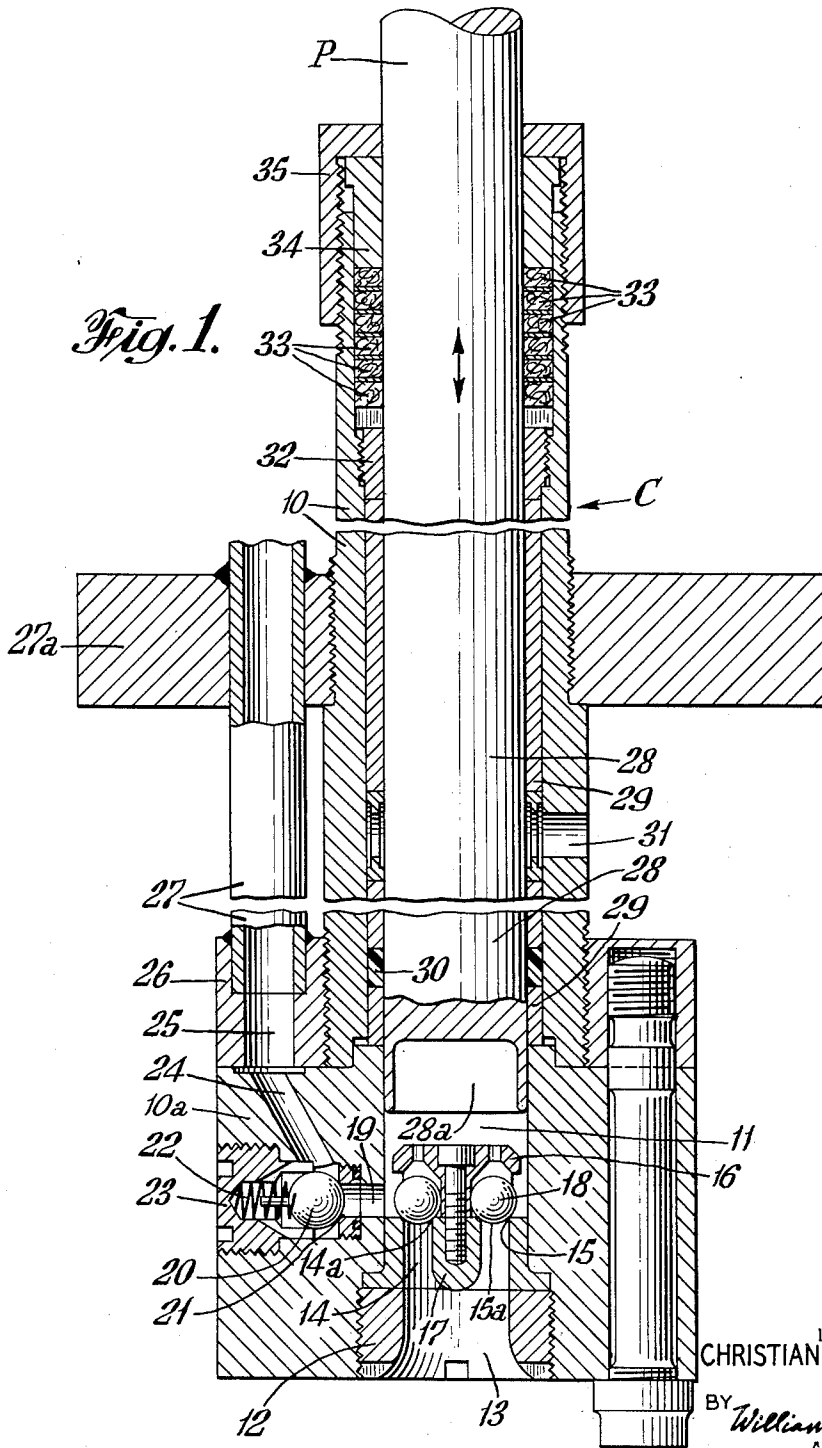
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APPARATUS FOR STORING AND PUMPING A VOLATILE LIQUID

Filed Oct. 25, 1957

2 Sheets-Sheet 1



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Fig. 2.

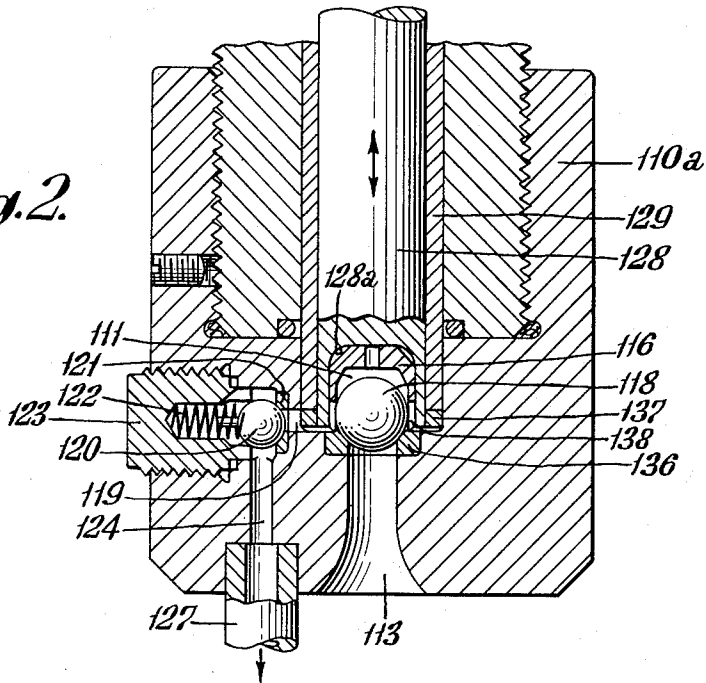
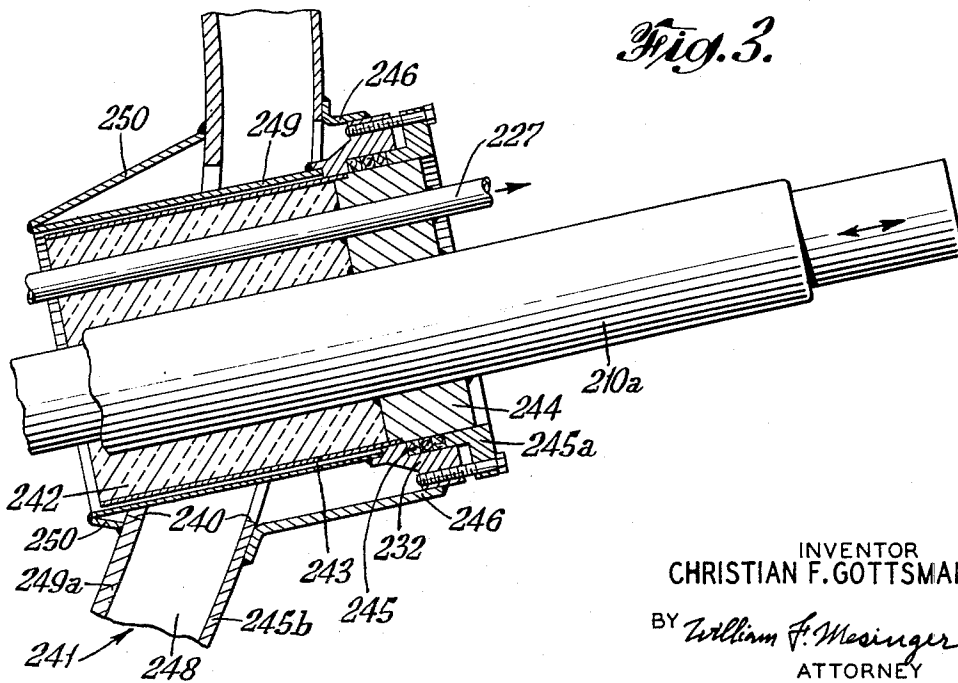


Fig. 3.



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APPARATUS FOR STORING AND PUMPING A VOLATILE LIQUID

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This invention relates to apparatus for storing and pumping a volatile liquid having a boiling point temperature at atmospheric pressure materially below 273° K., and more particularly to a reciprocating pump for pumping a liquefied gas having a normal boiling point below 233° K., such as liquid oxygen, nitrogen, and the like, to an ultrahigh pressure, for example, 10,000 p.s.i.

Pumps heretofore proposed for pumping liquefied gases to high pressures have involved difficulties due to the physical properties of the highly volatile liquids. For example, liquefied gases have greater compressibility than water, and thus present greater heat of compression problems. However, these difficulties have been largely overcome when the desired discharge pressure was below about 3,000 p.s.i. On the other hand, the previously known pumps are either inefficient or unworkable in the ultrahigh pressure range above about 5,000 p.s.i. This is because special problems, in addition to strength considerations, arise which tend to decrease the efficiency of the heretofore known pumps in this ultrahigh pressure discharge range, and these difficulties could eventually make the pumps inoperative. These unique problems are due to the increased pressure drop across the leakage path between the pump plunger and surrounding cylinder, greater plunger forces and therefore higher plunger friction, and the larger amount of heat added to the liquefied gas during compression. The latter fact leads to vapor flashoff from the liquid trapped in the clearance space; that is, the portion of the pumping chamber not taken up or filled by the plunger at the end of the discharge stroke, after the pressure in the pumping chamber has been released. Vapor flashoff in this unfilled portion of the pumping chamber limits the amount of liquid that can enter the pumping chamber during the suction stroke, and may cause the pump to become vapor bound and lose prime. The heretofore proposed pumps have relatively large clearance spaces, which were tolerable with discharge pressure below about 3,000 p.s.i., but cannot be tolerated when a pump must operate in the ultrahigh pressure range.

Another limitation of the heretofore known immersion pumps is the requirement of a relatively high pressure differential between the pumping chamber and the surrounding liquefied gas, to open the suction valve. This characteristic becomes critical in ultra-high pressure operation, since the increased vapor flashoff results in a higher pressure in the pumping chamber at the end of the discharge stroke. Thus, to maintain the same pressure differential across the suction valve, it is necessary to supply the liquefied gas in the surrounding container at a relatively higher pressure. This requirement may increase the operating costs of the system.

An additional problem not sufficiently overcome by the previously proposed systems for pumping volatile liquids to high pressures is the substantial transmission of heat from the atmosphere through the pump mounting assembly into the container. This heat leak is partly due to conduction and also results from splashing of the liquefied gas against the pump mounting assembly, with resultant wetting of the warm parts of this assembly, thereby increasing the liquid evaporation rate. Because of this wetting, the heat leak problem is particularly acute when the immersion pump-liquid container assembly is

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subject to considerable vibration and movement, or when the pump is mounted substantially horizontally in the container. In the latter case, the pump mounting assembly is either directly immersed in the liquefied gas, or in relatively close proximity thereto.

Still another disadvantage of the presently used immersion pumps is the slow plunger speed necessary to prevent excessive generation of frictional heat and to avoid the previously discussed excessive pressure drop across the suction valve. A relatively low plunger speed requires a larger diameter pump cylinder or body to achieve a given pumping rate, and this in turn necessitates a massive pump body resulting in a high rate of heat transmission into the liquid both inside and outside the pump and requiring a large opening in the container wall for pump installation. The percentage of the liquid which leaks between the plunger and cylinder wall also increases at slow plunger speeds. Finally, the forces imposed on the plunger and driving mechanism for a given pumping rate are higher at slower speeds which adds to the expense and massiveness of the entire assembly.

One object of the present invention is to provide a highly efficient immersion pump for pressurizing liquefied gas to an ultra-high pressure;

Another object of the present invention is to provide a reciprocating-type pump having a minimum clearance space;

A still further object is to provide a reciprocating-type immersion pump which requires a relatively low pressure differential between the pumping chamber and the surrounding liquefied gas, to open the suction valve;

An additional object is to provide an immersion pump-liquid container assembly whereby heat leak through the pump mounting assembly into the container is minimized; and

Another object is to provide a compact immersion pump which operates at a relatively high plunger speed but is characterized by low frictional heat and low suction valve pressure drop thereby achieving low cost, high efficiency and operation dependability.

These and other objects and advantages of this assembly will be apparent from the following description and the accompanying drawings in which:

FIGURE 1 is a view of a longitudinal cross-section through an immersion pump embodying features of the present invention;

FIGURE 2 is a view of a longitudinal cross-section through the valve end of an immersion pump embodying another form of the present invention; and

FIGURE 3 is a view of a longitudinal cross-section through an assembly for mounting an immersion pump through the walls of a liquefied gas container, according to the present invention.

The reciprocating pump of one embodiment of this invention comprises an elongated pump body having a pumping chamber at one end and an opening at the other end. An inlet or suction valve protrudes into the pumping chamber and an inlet valve-controlled port is situated near the end of the pumping chamber opposite the open end of the pump body. A discharge valve is also provided and a discharge valve-controlled outlet passage communicates with the pumping chamber for discharge of ultra-high pressure liquid therethrough. A reciprocating plunger extends through the pump body opening, the plunger having an inner end portion with a recessed section or cavity which covers at least most of the inlet valve at the end of discharge stroke. Thus, the clearance space in the pump of the present invention is appreciably reduced by having the plunger fill up a major part of the clearance space between the suction valve and the pumping chamber inner wall at

the end of the pump stroke, after the plunger has pumped the liquefied gas to an ultra-high pressure and forced it through the discharge valve-controlled outlet passage. In the preferred embodiment of this invention, multiple suction valves are used since they permit a smaller combined volume than a single valve and thus require less clearance space while also providing a desired total opening area. For example, using ball-type valves in a pump having a 4-inch stroke and a total displacement of slightly under 2.5 cu. in., the clearance volume obtained with a four inlet valve arrangement was found to be about 4 percent of the pump displacement whereas the corresponding figure using a single inlet valve arrangement is about 6 percent. Ball type inlet and discharge valves are preferred in the immersion pump of the present invention because they provide the most satisfactory and trouble-free pressure seal at ultra-high pressures. Thus, it can be seen that the present invention provides a reciprocating pump having a substantially smaller clearance volume than the heretofore proposed pumps; that is, less than about 8 percent. This is accomplished by separately and in combination providing a plunger with an inner end portion having one or more cavities which cover at least most of a multiplicity of ball-type inlet valve assemblies at the end of the discharge stroke, thus filling up most of a relatively smaller clearance space. One advantage of minimizing this space may be illustrated by the fact that for an immersion pump operating at 10,000 p.s.i. discharge pressure and 15° F. subcooling, it is estimated that there will be a 3 percent loss in volumetric efficiency for each 1 percent increase in clearance volume.

Another advantage of using multiple ball-type inlet or suction valves is that a lower pressure drop is required to lift small multiple balls from their seats during the suction stroke than is required to lift a large single ball. Pressure drop across the suction valve is critical in low temperature liquefied gas pumps because the liquid has a strong tendency to flash, thereby reducing the capacity of the pump and perhaps causing loss of prime. An inlet valve port with a large cross sectional area is advantageous in minimizing this pressure drop. With a single ported valve, a large port size requires a large heavy-weight ball valve; whereas, with multiple ports, the same inlet port area may be obtained by using several valves, all of which are of uniform minimum weight. Furthermore, light-weight multiple balls are subjected to less impact during operation, and this results in a longer seat life. The required pressure differential may be further reduced in the pump of the present invention by using hollow ball-type inlet valves.

A still further novel feature of the present invention is a method of sealing the annular space between the pump body and the concentrically positioned entrance tube forming the walls of the opening through which the pump is inserted, so as to minimize heat leak and liquid evaporation. This is accomplished by providing an annular section of low heat conductive material around the pump body in the container wall opening. The low conductive insulating material is preferably contained in a concentric envelope within the aforementioned entrance tube. It can thus be seen that the free space in the entrance tube is substantially filled with the low conductive material, and any remaining passages through the annulus will be long and of very small cross section. Such passages are readily vapor-bound by unavoidable heat leak so that the liquefied gas cannot normally penetrate the annulus to the warm zone at the outer end. This allows the pump to be installed in the container below the liquid level and through a relatively short entrance tube. The aforementioned insulation section also serves to prevent convection of vapor within the annular space between the cold container and the warm outer end. A non-circulating vapor cushion is

created in the small remaining spaces within the annulus, which substantially reduces the passage of heat by this mode of transfer.

Also, an annular stuffing box is preferably provided which surrounds the pump body and seals the annular space between the pump body and the container wall opening from the atmosphere.

Referring now to the drawings, and specifically to FIG. 1, the pump comprises a cylinder or pump body indicated generally at C having an upper body portion 10 which may be thread-connected to the lower body portion 10a. The head 12 has a central opening 13 which communicates with branch passageways 14 in valve seat member 14a. The inner ends of passageways 14 provide inlet valve seats 15 and ports 15a. Inlet valve cage 16 is positioned by projection 17 which, for example, may be thread-connected to the inner end of seat member 14a. Ball inlet valves 18 (either solid or hollow) are situated within the cage 16, rest against valve seats 15 in the closed position, and are stopped by the cage 16 in the open position. The discharge passage 19 is controlled by discharge ball valve 20 which is urged to its seat 21 by a spring 22 which is retained by a cap 23. From the side of the discharge valve 20 a discharge conduit 24 passes the pumped liquefied gas to a passage 25 in lower flange 26 which communicates with conduit 27. The latter passes through cover plate 27a, and the pumped liquefied gas may be conducted therethrough for further processing as desired. Ball valves 18 and 20 are preferably metallic because of hardness and impact requirements. Suitable metals include stainless steel, nickel steel and hard surface aluminum.

The pump is provided with a reciprocating pumping element indicated generally at P, the inner working or pumping portion of which is a plunger 28 which enters the end of the working or pumping chamber 11 which is opposite the head 12. The inner end of the plunger 28 has recessed part or cavity 28a machined therein, which covers the cage 16 and inlet valve 18 at the end of the discharge stroke. The inner end surface of plunger 28 at this point of the pumping cycle is in close proximity with the inner surface of the head 12, thereby minimizing the clearance volume within the pumping chamber. It is to be noted that in this embodiment of the present invention, the clearance space or volume consists of essentially only that part of the space within the cavity 28a which is not filled up by the inlet valves 18 and cage 16.

Plunger 28 preferably fits the bore of the working chamber fairly closely to provide an easy sliding fit. There should, however, be a small clearance at working temperatures to permit a slight liquefied gas flow along the plunger. A flow restricting liner or guide sleeve 29 is preferably disposed between the upper body portion 10 and the plunger 28, the sleeve 29 having an internal cylindrical surface of a diameter similar to that of the pumping chamber 11. It was found that a diametrical clearance between the plunger 28 and the guide sleeve 29 of 0.0020 to 0.0035 inch at the low operating temperature permits free movement of the plunger, and at the same time gives reasonably low leakage rates. Although self-lubricating material, for example, a bonded graphite or carbon is suitable for the sleeves 29 of pumps operating with discharge pressures in the range of about 3,000 p.s.i., such material has been found to be unsuitable for service in ultra-high pressure pumps because of the increased strength and ductility requirements. As a consequence, lubricant-containing metals are preferred as the sleeve material for the pump of the present invention. Suitable materials include high graphite content sintered bronze, porous bronze impregnated with plastics such as polymerized tetrafluoroethylene, or chlorotrifluoroethylene, and porous bronze impregnated with a low pour point oil of a character compatible with the liquid pumped. These materials provide a low friction factor between the plunger

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er 28 and the sleeve 29 of less than about 0.35. A low thermal conductivity plastic spacer 30 is positioned in the sleeve 29 to restrict the flow of heat generated by friction due to plunger movement. The effect of the plastic spacer 30 is to break up the otherwise smooth temperature gradient between the warm end of the pump and the pumping chamber 11, thereby reducing the temperature of the walls in the pumping chamber. The spacer 30 is preferably located just above the inner end of the plunger 28 when it has reached the end of the suction stroke. Suitable materials for the plastic spacer 30 include polytetrafluoroethylene, glass cloth reinforced melamine resin, and cloth or fiber reinforced phenol formaldehyde resin for processing inert gases such as nitrogen. Polytetrafluoroethylene is also suitable for oxygen service. Also, in order to minimize heat conduction from the cold or operating end of the pump, the upper body portion 10 is made as long and thin as is consistent with adequate strength. Preferably, the material employed also has a low thermal conductivity to minimize longitudinal heat leak.

For venting the liquefied gas flowing along the plunger 28 from the pumping chamber 11, a passage means communicating with the liquid container (not illustrated) is provided preferably in the form of one or more vent passages or holes 31 in the lower part of the upper body portion 10. These holes 31 are preferably located as far towards the warm end of the pump as practical in order to provide the longest possible leakage path. This is because a long leakage path minimizes the amount of liquid leaking back into the liquid container. The vent holes 31 are closed by the plunger, but since there must be some clearance for easy operation, a small amount of the liquid will escape from the pumping chamber 11 through the vents 31 back to the container in which the pump body is immersed. Thus, the pump "blow-by" is not lost to the atmosphere but recycled for repumping.

The warm end of the sleeve 29 is retained by a gland 32 which forms a bottom for the stuffing box section of the upper body portion. This section is filled with packing rings 33 which are retained by a gland follower 34 and a packing nut 35. The warm end of the plunger 28 is secured to a reciprocating mechanism by means not shown. A suitable type of warm end packing may be composed of asbestos and graphite composition rings which provide a gas seal. When the liquefied gas to be pumped is liquid oxygen, a suitable type of packing at 33 may be similar to that described in United States Patent No. 2,292,543 to J. F. Patterson.

FIGURE 2 illustrates another embodiment of the present invention in which similar reference numerals have been given to those components which are similar to FIGURE 1. Here, a single inlet ball valve 118 is used instead of multiple valves, and it seats on an insert 136 which is retained in a recessed portion of the inner part of the lower body portion 110a, facing the pumping chamber 111. The inlet valve cage 116 is supported against the inner surface of the lower body portion 110a, adjacent to and above the seat insert 136. In this embodiment, the sleeve 129 extends into the lower body portion 110a, and is supported at its cold end by the top edge 137 of the inlet valve cage base. FIGURE 2 also illustrates the plunger 128 at the end of the discharge stroke, when the inlet valve 118 and cage 116 are enclosed in the plunger cavity 128a, thereby minimizing the clearance space. The inner end of plunger 128 fits in groove or slot 138 of the cage base at this point of the pumping cycle. The discharge passage 119 is controlled by discharge ball valve 120 which is urged to its seat insert 121 by a spring 122 which is retained by a cap 123. From the lower side of the discharge valve 120, a discharge passageway 124 conducts the pumped liquefied gas to a conduit 127 for further processing as desired.

FIGURE 3 illustrates an immersion pump-liquefied gas container assembly in accordance with the present inven-

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tion whereby heat leak through the assembly is minimized. Although this assembly method is suitable for vertically mounted immersion pumps, it is particularly advantageous for assemblies in which the pump is mounted in a substantially horizontal position, or between the vertical and horizontal positions. As previously discussed, the heat leak problem is more critical when the pump is mounted in a non-vertical position since the pump mounting assembly is in relatively close proximity to the liquefied gas at all liquid levels. Such mounting may, for example, be necessary when there is an overall height limitation on the pump-container assembly. Another reason for employing a non-vertical pump position is to facilitate installation in the side of a relatively tall liquid container so that the inner end of the pump will extend to the bottom of the container. In such instances, a non-vertical position eliminates the need for a separate sump offset from the bottom of the container.

Referring now specifically to FIGURE 3, the upper body portion 210a of the pump body projects through an opening 240 in the double walled liquefied gas container 241 preferably at a small angle above the horizontal position, for example, 10 degrees. The part of the upper body portion 210a immediately adjacent to the opening 240 is surrounded by an annular section 242 of low conductivity material, for example, plastic foam molded to the proper dimensions. Alternatively, powder or fiber material may be employed such as diatomaceous earth, silica aerogel, or glass wool. For all the insulants and especially for the bulk materials, it is preferable to employ an envelope of the proper size and shape to sheath and contain the insulant. Suitable materials for the envelope include metal and plastic foils which are not severely embrittled at low temperatures. Thin metal foil 243 is preferred in the present embodiment of the invention. The warm end of the plastic foam section 242 is secured to an annular bracket 244 which is concentrically positioned around, and bonded to the upper body portion 210a. Pumped liquefied gas discharge conduit 227 passes through the plastic foam section 242 and annular bracket 244 to the atmosphere. Gas leakage from the pressurized container to the atmosphere is prevented by providing a flange 232, and a stuffing box section 245 followed by a packing nut 245a. A suitable type of packing for the stuffing box section 245 may be composed of asbestos and graphite composition rings which provide a gas seal from the atmosphere. The flange 232 is leak-tightly connected to the outer wall 245b of double-walled container 241 by outer cylindrical or conical member 246 which seals off the insulation space 248 from the atmosphere. A thin metal entrance tube 249 is concentrically positioned around the upper body portion 210a and plastic foam section 242 to separate the latter from the insulation space 248 between the walls of the container 241. The inner end of the entrance 249 is leak-tightly connected to the inner wall 249a of the container 241 by inner conical member 250 which seals off the insulation space 248 from the liquefied gas within the container. The outer end of the entrance tube 249 is bonded to the inner side of flange 232.

In the above assembly method, outer member 246 may serve to support the pump and transmit the plunger thrust into outer wall 245b. Alternatively, the structural framework which supports the double-walled container and the pump drive mechanism may also support the pump by means of a rigid member (not shown) secured to the outer portion of body 210a. The latter arrangement has the advantage that the pump thrust is borne entirely by the structural framework, and the entrance enclosing members 246, 249, and 250 are relieved of stress and strain due to pump thrust.

Metal entrance tube 249 and the pump itself provide sufficient heat leak to insure the formation of a vapor cushion within the plastic foam section 242, the cushion serving to trap any remaining small passages through

the plastic foam and thus minimize heat leak into the container and cold pump elements from the atmosphere. The insulation space 248 and the connecting volume surrounding metal entrance tube 249 and bounded by entrance enclosing members 246, 249, and 250 may, for example, be filled with powder and maintained under a vacuum, in a manner similar to that described in United States Patent No. 2,396,459 to L. I. Dana. Alternatively, the metal surfaces bounding the aforementioned vacuum space may be coated with a highly polished reflective material.

It is contemplated that various modifications of the pumping apparatus may be made without departing from the spirit and scope of the invention herein described.

What is claimed is:

1. A reciprocating pump for liquefied gases having a boiling point below 273° K. and having a clearance space, said pump comprising an elongated pump body having a pumping chamber therein adjacent one end and an opening at the other end; an inlet valve having a cage protruding into said pumping chamber and an inlet valve-controlled port near the end of said pumping chamber opposite said opening; a discharge valve and a discharge valve-controlled outlet passage from the pumping chamber; a reciprocating plunger extending through said opening in the pump body and having an inner pumping end portion with a cavity therein operable in said pumping chamber, the inner pumping end cavity being constructed and arranged for enclosing at least most of said inlet valve cage at the end of the discharge stroke and substantially filling the clearance space about said inlet valve cage; warm end packing means for the portion of said reciprocating plunger passing through said opening, said packing means being spaced at a substantial distance from said pumping chamber; and a flow restricting sleeve in said pump body closely fitting the plunger.

2. A reciprocating pump for liquefied gases according to claim 1 in which said flow restricting sleeve comprises portions made of a lubricant-containing metal, and at least one low thermal conductivity plastic spacer interposed between said portions so as to minimize the flow of frictional heat along the sleeve.

3. A reciprocating pump for liquefied gases according to claim 1 in which said flow restricting sleeve comprises portions made of a lubricant-containing metal which affords a friction factor between said plunger and the sleeve of less than about 0.35, said plunger and sleeve being sized so as to provide a diametrical clearance of about 0.0020 to 0.0035 inch at the low operating temperature.

4. A reciprocating pump for liquefied gases having a boiling point below 273° K. and having a clearance space, said pump comprising an elongated pump body having a pumping chamber therein adjacent one end and an opening at the other end; multiple inlet ball valves protruding into said pumping chamber and inlet valve-controlled circular ports near the end of said pumping chamber opposite said opening; a discharge valve and a discharge valve-controlled outlet passage from the pumping chamber; a reciprocating plunger extending through said opening in the pump body and having an inner pumping end portion with at least one cavity therein operable in said pumping chamber, the inner pumping end cavity being constructed and arranged for enclosing at least most of said multiple inlet ball valves at the end of the discharge stroke and substantially filling the clearance space about the inlet ball valves; warm end packing means for the portion of said reciprocating plunger passing through said opening, said packing means being spaced at a substantial distance from said pumping chamber; and a flow restricting sleeve in said pump body closely fitting the plunger.

5. A reciprocating pump for liquefied gases according to claim 4 in which said discharge valve is the ball type.

6. A reciprocating pump for liquefied gases according to claim 4 in which said inlet valve is the hollow ball type.

7. A reciprocating pump apparatus for liquefied gases according to claim 1 which includes a liquefied gas container with an opening in the container wall through which said pump body is inserted for immersion in said liquefied gas; an annular space between the pump body and the container wall opening; means for sealing said annular space from the atmosphere; means for vapor binding said annular space comprising an annular envelope enclosing heat insulating means and substantially filling said annular space and positioned between said sealing means and the liquefied gas.

8. A reciprocating pump apparatus for liquefied gases according to claim 7 in which said heat insulating means is molded plastic foam and is contained in said annular envelope which is formed of a metal foil.

9. A reciprocating pump apparatus for liquefied gases according to claim 7 in which an annular stuffing box surrounds the pump body and constitutes said means which seals said annular space between the pump body and the container wall opening from the atmosphere.

10. Apparatus for storing and pumping liquefied gases having a boiling point below 273° K. comprising a liquefied gas container with an opening in the container wall; a reciprocating pump including an elongated pump body having a pumping chamber therein adjacent one end; an inlet valve and a discharge valve also adjacent said one end and communicating with said pumping chamber, said elongated pump body passing through the container wall and said inlet valve being immersed in said liquefied gas; an annular space between the pump body and the container wall opening; and means for vapor binding said annular space comprising an annular envelope and a low heat conductive mass contained therein and therewith substantially filling said annular space.

11. Apparatus for storing and pumping liquefied gases according to claim 10 in which said low conductive mass is molded plastic foam.

12. Apparatus for storing and pumping liquefied gases according to claim 10 in which an annular stuffing box surrounds the pump body and constitutes said means which seals said annular space from the atmosphere.

13. A reciprocating pump for liquefied gases according to claim 1 wherein said cavity of said reciprocating plunger is less than about 8% larger than the volume occupied by said inlet valve cage.

14. A reciprocating pump for liquefied gases according to claim 1 wherein said cavity of said reciprocating plunger is about 4% larger than the volume occupied by said inlet valve cage.

15. A reciprocating pump for liquefied gases according to claim 4 wherein said cavity of said reciprocating plunger is less than about 8% larger than the volume occupied by said inlet valve cage.

16. A reciprocating pump for liquefied gases according to claim 4 wherein said cavity of said reciprocating plunger is about 4% larger than the volume occupied by said inlet valve cage.

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