

May 17, 1966

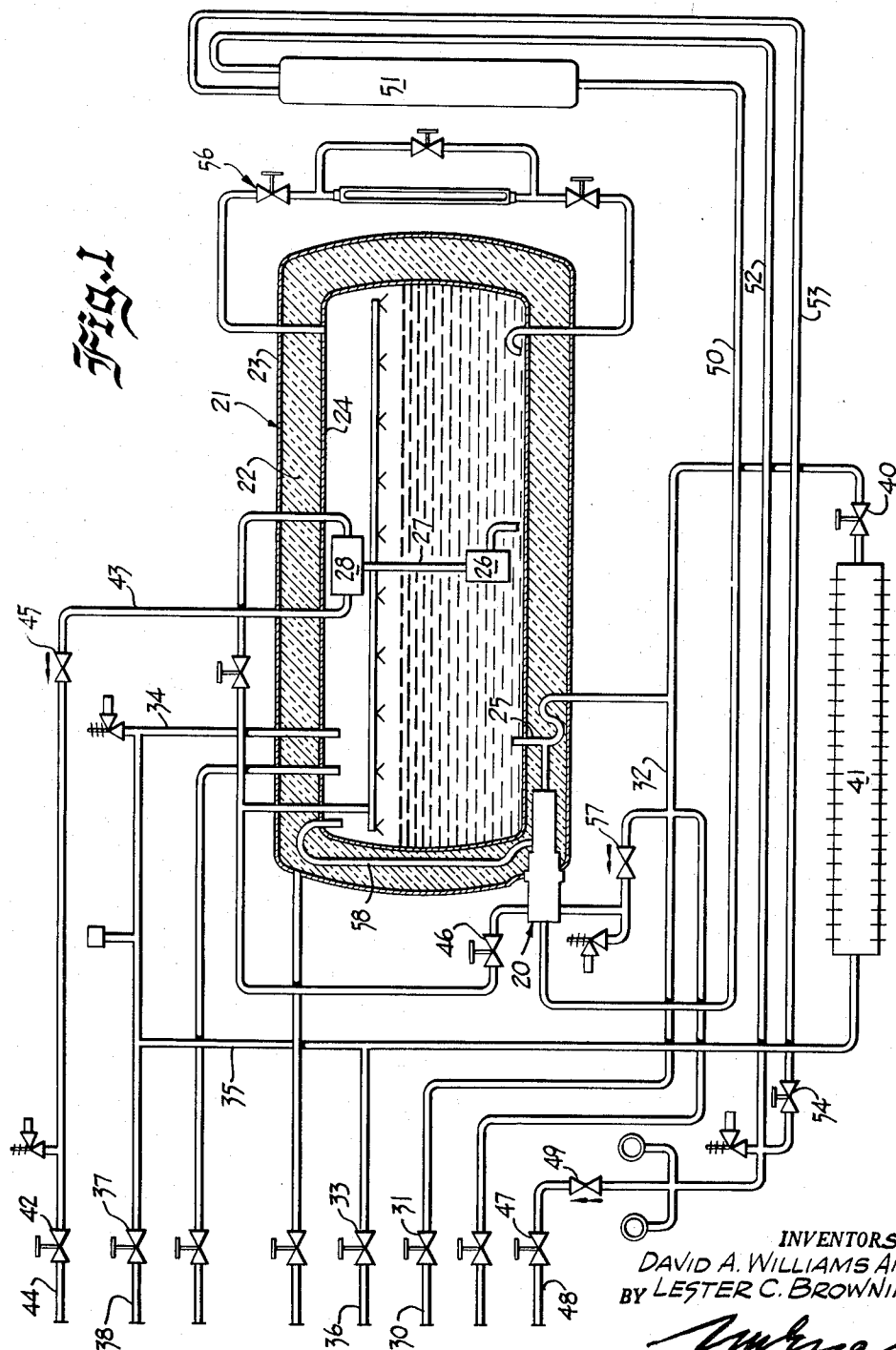
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3,251,602

APPARATUS FOR HANDLING LIQUEFIED GASES

Original Filed June 29, 1959

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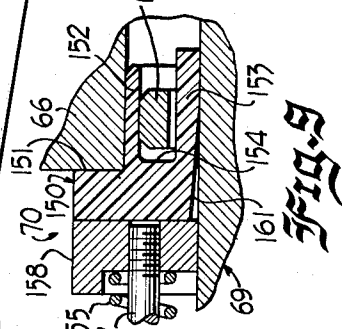
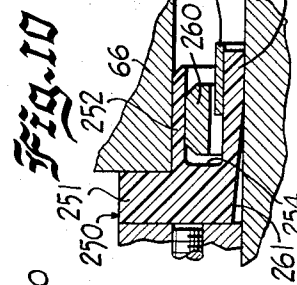
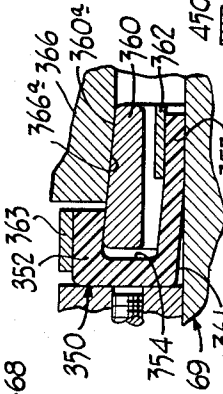
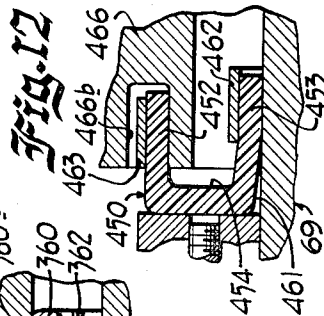
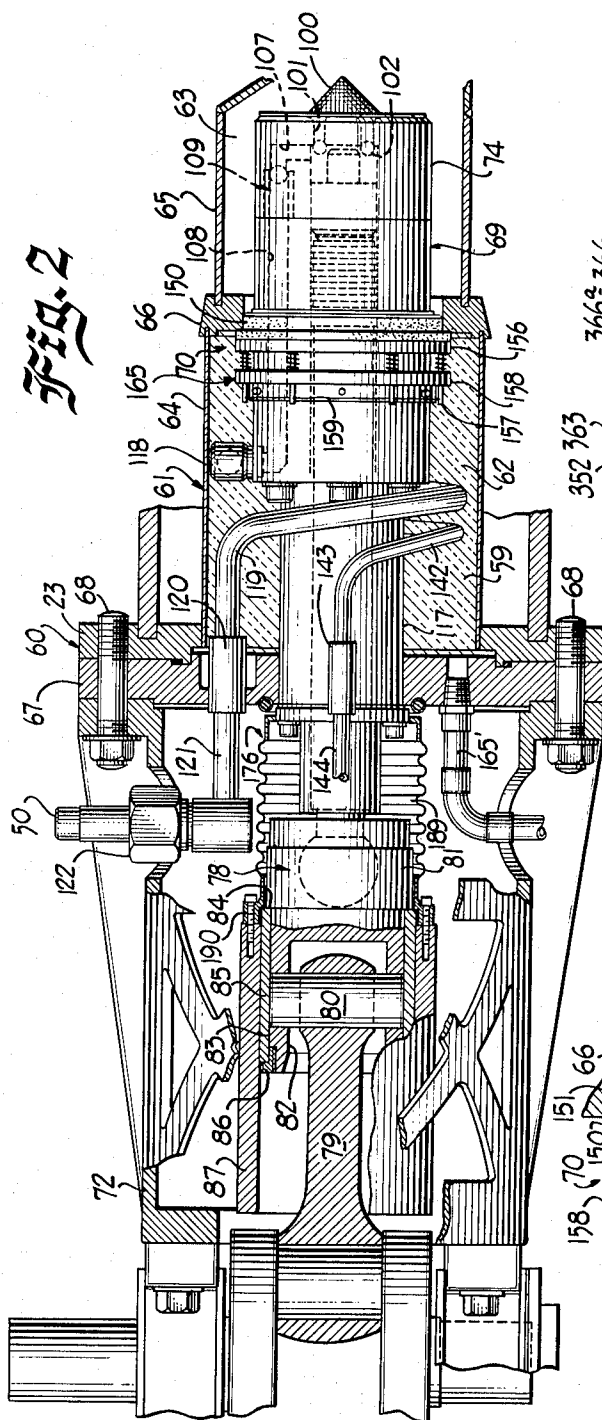
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Fig. 3

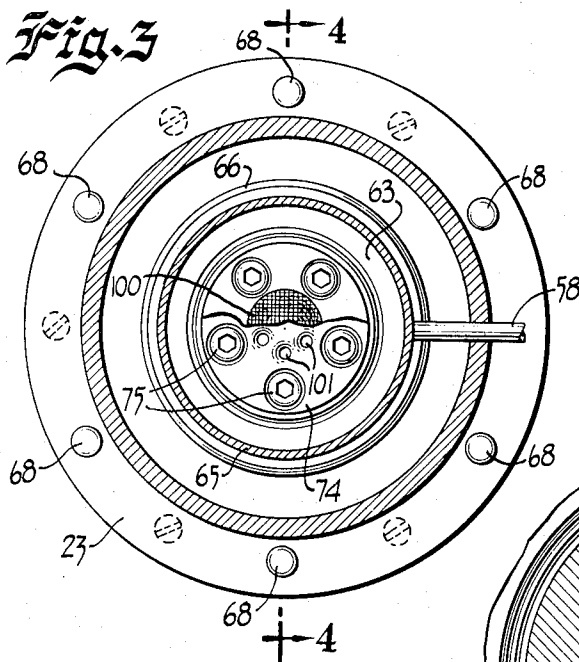


Fig. 4

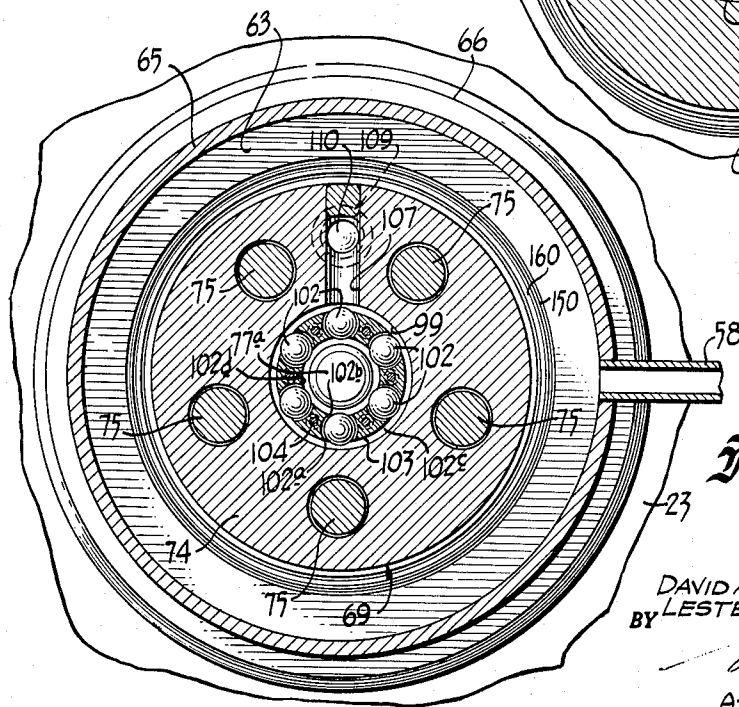
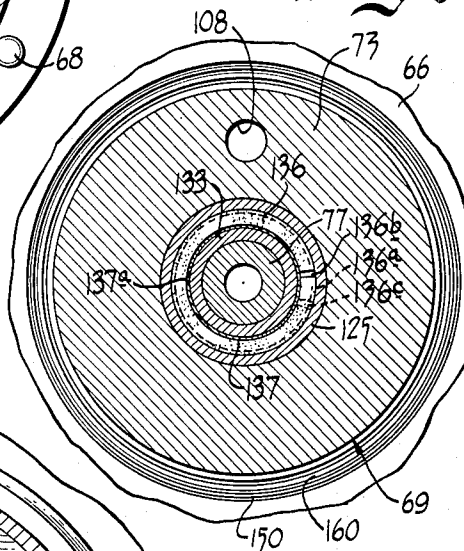


Fig. 5

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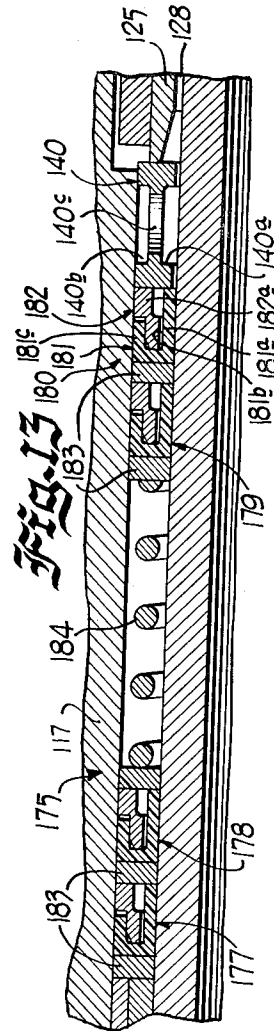
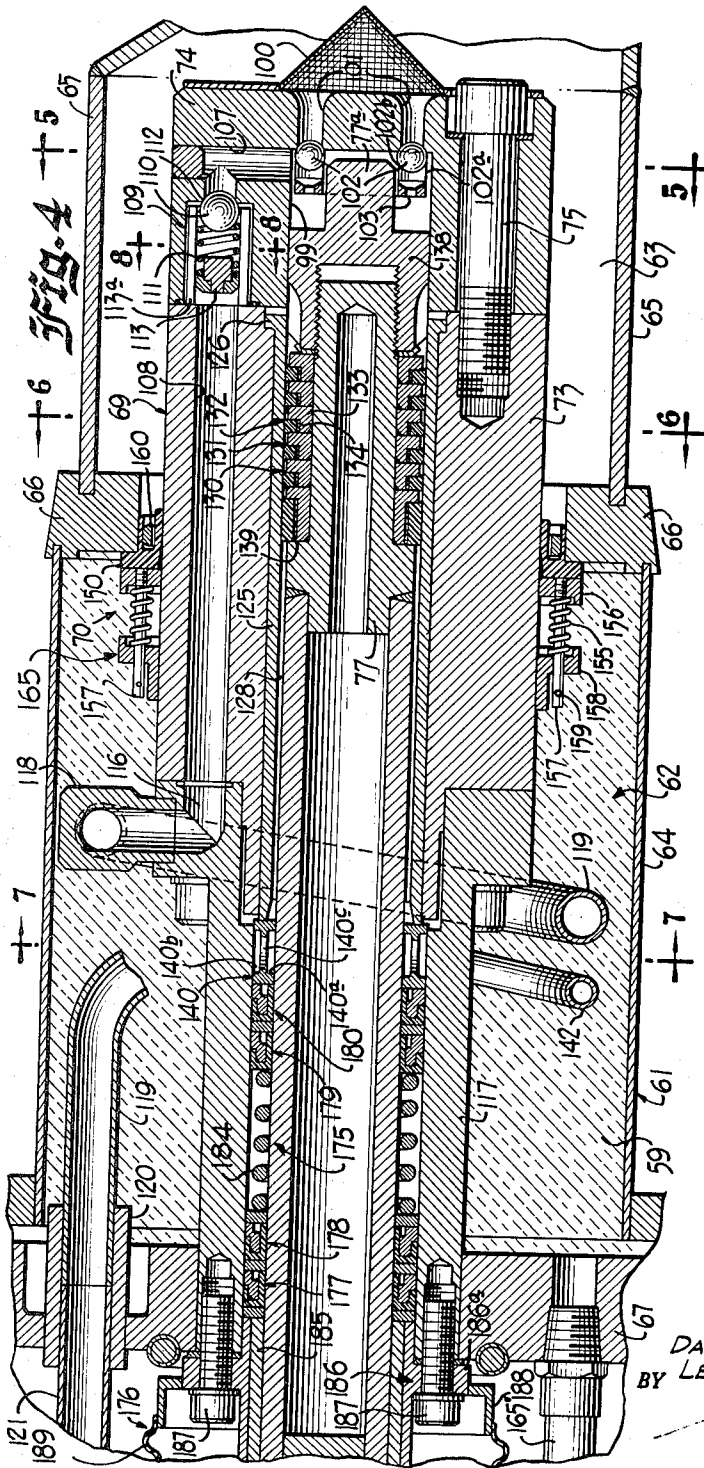
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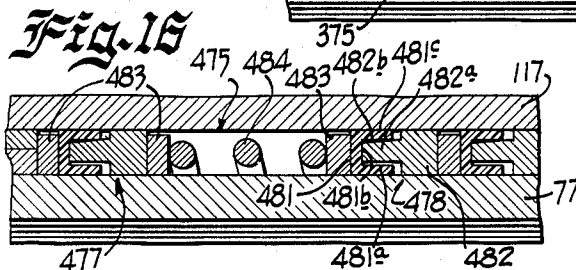
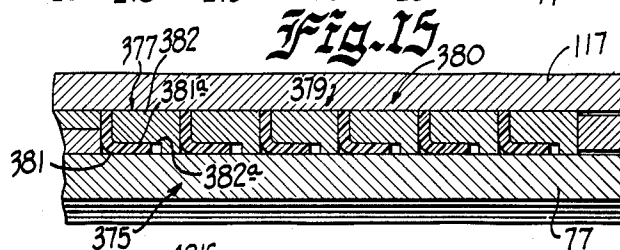
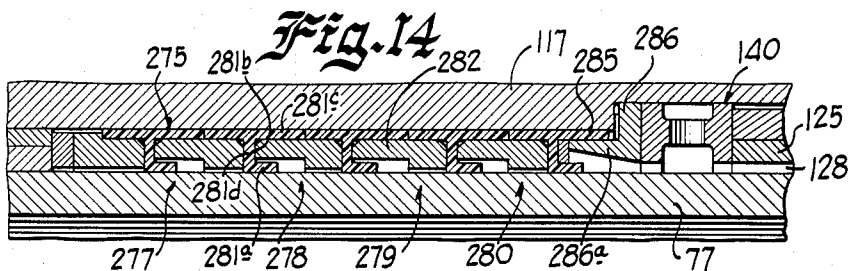
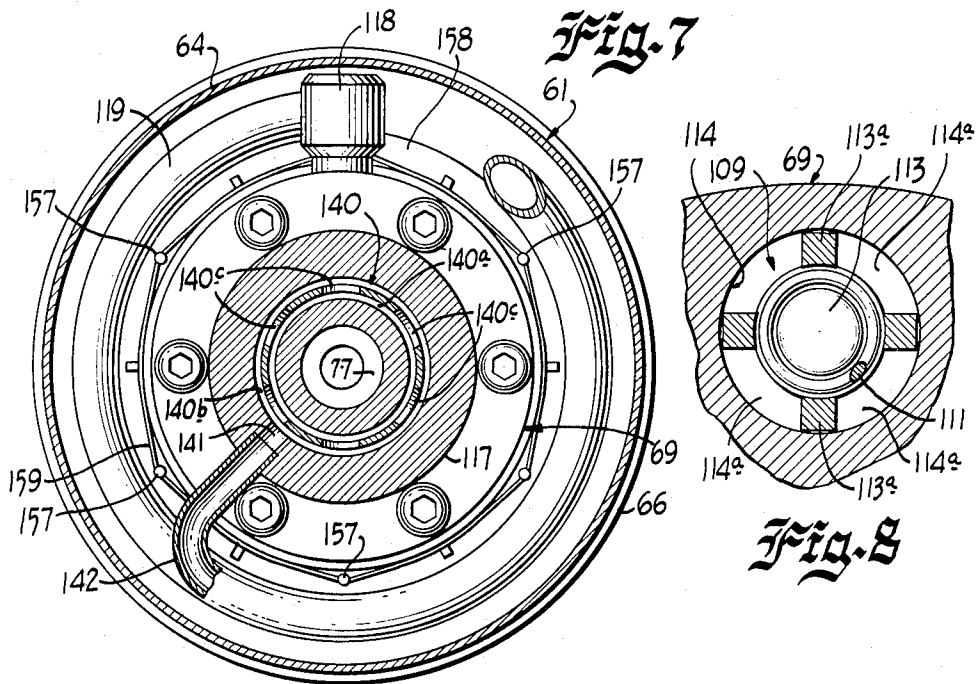
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5 Sheets-Sheet 5



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3,251,602

APPARATUS FOR HANDLING LIQUEFIED GASES
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Original application June 29, 1959, Ser. No. 823,400, now
Patent No. 3,109,293, dated Nov. 5, 1963. Divided
and this application May 1, 1963, Ser. No. 283,130
4 Claims. (Cl. 277-62)

This is a division of the patent application of David A. Williams and Lester C. Browning, Serial No. 823,400, filed June 29, 1959, now Patent No. 3,109,293.

The present invention relates generally to new and improved apparatus for pumping highly volatile liquefied gases which have boiling points at ambient pressure below -200 degrees Fahrenheit and the invention is more particularly concerned with improvements in pumps of the type employing a reciprocating plunger or piston for delivering against a high pressure a liquefied gas such as liquid oxygen, nitrogen, argon, and the like.

The unique properties of liquefied gases, particularly their highly volatile characteristics and their very low temperatures, introduce a number of problems in the construction of a pump for handling these gases. Many of these problems concern the necessity for isolating the liquefied gas from the so-called warm end of the pump in order to prevent the transfer of heat which will convert the liquid to its gaseous state. These problems are difficult to solve in stationary installations where the pump is employed at a factory or other fixed location but they become even more complex in mobile installations where the liquefied gas must be transported from place to place for delivery to customers without the use of compressors. In both of these types of installations the pump must not only solve the special problems peculiar to the handling of liquefied gases but, in addition, it should provide or embody those desirable characteristics which are normally required of pumps. Thus, the pump should be easy to install and remove for maintenance or replacement, it should be simply constructed so that it can be manufactured at minimum costs, it should be substantially trouble-free in operation over as long a period as possible, it should be self-priming so that it need not be filled or primed each time that it is operated, and it should provide efficient pumping action especially at very low or cryogenic temperatures.

One of the primary objects of the present invention is, therefore, to provide a pump of the character indicated above which is very easy to install and to remove for maintenance or replacement of parts, which is self-priming, and which is not subject to vapor binding as a result of gases created during the pumping operation.

The invention has for another object the provision of a new and improved pump of the type indicated above for pumping liquefied gas from a liquid filled chamber which is isolated from the pump mounting by a relatively long gas chamber, thus reducing the transfer of heat from the relatively warm pump mounting to the liquid sump and, hence, avoiding volatilization of the liquid.

It is another object of the present invention, in accordance with the preceding object, to provide a novel dam ring assembly for isolating the liquid sump from the gas chamber.

A further object of the present invention, in accordance with the preceding object, is to provide means including a fluid bleed line for equalizing the pressure existing on opposite sides of the dam ring, thereby minimizing the possibility of this ring becoming unseated to break the seal between the gas chamber and the liquid sump.

The invention has for another object the provision of a pump of the character indicated above wherein the gas

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chamber is provided with means for minimizing the transfer of heat therethrough either by way of convection, conduction or radiation.

It is a further object of the invention, in accordance with the preceding object, to provide a check valve in the fluid bleed line to the gas chamber for effectively shutting off fluid flow in the event that liquefied gas is inadvertently introduced into the gas chamber during pump operation.

A further object of the invention is to provide in a liquefied gas pump of the reciprocating piston type a new and improved arrangement for holding in position the wear sleeve encircling the piston.

Another object of the invention, in accordance with the preceding object, is to provide a wear sleeve so dimensioned that at ambient temperatures it fits readily within the piston cylinder and, hence, can be assembled very easily; while at cryogenic temperatures, the sleeve is held firmly in position by differential contraction between the sleeve and the adjacent pump body or cylinder.

The invention has for a further object the provision of a new and improved sealing ring assembly between the piston and the wear sleeve which is effective to provide a more efficient sealing action than rings of prior design and also to provide a pump having a longer useful operating life.

A further object of the invention is to provide a new method of pump operation which is effective periodically to reseal the sealing rings referred to above so that the useful life of the rings is effectively increased.

Another object of the present invention is to provide for the warm end of the pump a new and improved low pressure seal which is of simple construction but is, nevertheless, effective to prevent the escape of cool gas through the warm end and, at the same time, to isolate the packings at the warm end of the pump from the cool liquefied gases, thereby preventing these liquefied gases from adversely affecting the packings.

A further object of the present invention is to provide a new and improved inlet and outlet valve construction for controlling the flow of fluid from the liquid sump to the pump outlet in response to reciprocation of the pump piston.

Another object of the invention, in accordance with the preceding object, is to provide inlet and outlet valves of the ball type constructed and arranged to provide uniform flow of fluid around both sides of the valve balls in order to avoid spinning of the balls and, hence, to reduce wear on these members.

A further object of the invention is to provide a new and improved arrangement for isolating the cold liquid sump from the warm end of the pump when the pump is shut down.

It is also an object of the invention to provide a new and improved arrangement for venting the pump to permit the escape of gases and, hence, to avoid vapor binding at low suction heads.

The invention has for a further object the provision of a pump of the character indicated above wherein a gas pocket is formed between the piston and the wear sleeve in back of the sealing rings and wherein provision is made for venting this pocket during normal pump operation and for closing the vent line when the pump is shut down, whereby any liquid trapped in the gas pocket will be volatilized to generate a gas pressure for forcing the liquid towards the cold end of the pump in order to effectively lengthen the heat path from the warm pump mounting flange to the sump.

The foregoing and other objects are realized, in accordance with the present invention, by the provision of a new and improved pump employing a reciprocating piston mounted for sliding movement within a pump body

or cylinder head. The pump body includes the usual mounting flange detachably secured to suitable fixed structure defining a housing which cooperates with the pump body to form a gas chamber adjacent the mounting flange and a liquid sump or reservoir remote from this flange. This gas chamber is relatively long and effectively isolates the liquid sump from the mounting flange. To reduce the transfer of heat through the isolating gas chamber either by way of radiation, convection or conduction, this chamber is filled or packed with a wadded, crumpled, highly reflecting, metal foil. A sealing means in the form of a dam ring is interposed between the pump body and the fixed structure to isolate the gas chamber from the liquid reservoir. To equalize the pressures on opposite sides of the dam ring, the liquid reservoir is connected to the gas chamber through means including a small bleed line leading to the gas chamber through the mounting flange. This bleed line includes a check valve which is operated automatically in response to an increase in pressure in the gas chamber caused, for example, by inadvertent flow of liquefied gas into this chamber and the subsequent volatilization of this liquefied gas. The check valve prevents further flow of fluid to the chamber until the high pressure subsides.

Liquefied gas from the reservoir is drawn into the pump body through a novel inlet valve construction employing a plurality of ball type valves constructed and arranged to effect uniform flow of the liquefied gas around both sides of each valve ball thus avoiding spinning of the valve balls and, hence, reducing wear. Fluid is, of course, drawn into an inlet chamber in the pump body during the suction stroke of the reciprocating piston and these valves are automatically closed by the pressure in the inlet chamber when the piston is advanced for its pressure stroke. During the pressure stroke of the piston, the fluid is forced out of the pump body through an outlet passage extends through the body and is connected to a conduit leading to the mounting flange for the pump. A spring biased outlet valve of the ball type is disposed in the outlet passage to control the flow of fluid from the inlet chamber to the outlet conduit and this valve is also subjected to uniform fluid flow on all sides for the purposes indicated above. The outlet valve, of course, is opened against the action of its biasing spring by the pressure of the liquid in the inlet chamber of the pump body during the pressure stroke of the pump piston.

In order to reduce wear and, hence, to increase the life of the pump, the piston reciprocates within a hardened wear sleeve inserted within the pump body. This sleeve, at ambient temperatures, is dimensioned to fit readily within the pump body but the body and the sleeve are constructed of different materials which are so selected that they contract differentially when the temperature is reduced to the cryogenic range with the result that the pump body holds the wear sleeve firmly in position despite vibration of the pump. A plurality of sealing ring assemblies interposed between the piston and the wear sleeve effectively separate the inlet chamber of the pump from a gas pocket formed behind the rings. Each of the sealing ring assemblies includes an outer seal ring and a resilient expander normally urging the seal ring into engagement with the sleeve. The outer ring is formed of a material which at cryogenic temperatures is extremely hard and resistant to wear but which at ambient temperatures exhibits plastic flow. The seal rings thus seat against the wear sleeve at ambient temperatures existing prior to installation of the pump and, when the operating temperature is reduced to the cryogenic range, these rings harden to form an effective, wear-resistant seal against the inner wall of the wear sleeve. It has been found that use of a material of this type provides a very long operating life for the piston rings. Moreover, these rings can be resealed to compensate for wear by heating them to ambient temperature so that they flow into firm engagement with the wear sleeve. This feature gives rise to a new

and improved method of operating the pump to extend its useful life. Thus, the pump is operated at cryogenic temperatures for a predetermined period of time which has been found to be insufficient to cause excessive wear on the rings, for example, a period of 1500 hours, and the temperature is then raised to that of the ambient in order to reseal the rings. The pump can then be operated for another 1500-hour period at cryogenic temperatures before resealing the rings. The above procedure can be repeated to give the pump a useful operating life in excess of 10,000 hours before replacement of the rings is required.

The gas pocket formed behind the sealing rings is isolated from the warm end of the pump by means of a new and improved low pressure seal assembly. This low pressure seal includes a plurality of ring assemblies each including a pair of ring members susceptible to differential contraction when the temperature is reduced so that one of the ring members effectively seals against the reciprocating piston while the second ring member seats against the wall of the adjacent cylinder. A connection is made from the gas pocket to the liquid sump through a valved line which during normal pump operation is opened to vent the pocket in order to permit the escape of any gas developed, thus avoiding the possibility of vapor binding of the pump. This line is blocked or closed when the pump is shut down, whereupon any liquefied gas entrapped within the gas pocket will be vaporized by the heat from the warm end of the pump in order to create a gas pressure for forcing the liquid back towards the cold end of the pump adjacent the liquid sump. This feature effectively lengthens the heat path from the warm pump mounting flange to the sump thus reducing volatilization of the liquefied gas during the shut down period.

The invention, both as to its organization and manner of operation, together with further objects and advantages thereof, will best be understood by reference to the following detailed description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a schematic view showing a mobile system for supplying customers;

FIG. 2 is an elevational view partly broken away and shows the high pressure pump of the present invention employed in the system illustrated in FIG. 1;

FIG. 3 is an end view of the pump looking from the right side as viewed in FIG. 2;

FIG. 4 is an enlarged, sectional view taken along a line substantially corresponding to the line 4—4 in FIG. 3;

FIG. 5 is an enlarged, sectional view taken along a line substantially corresponding to the line 5—5 in FIG. 4 and showing particularly the construction of the inlet valves for admitting fluid from the liquid sump to the inlet chamber of the pump;

FIG. 6 is an enlarged, sectional view taken along a line substantially corresponding to the line 6—6 in FIG. 4 and showing particularly one of the sealing rings employed between the pump piston and the wear sleeve;

FIG. 7 is an enlarged, sectional view taken along a line substantially corresponding to the line 7—7 in FIG. 4 and shows particularly the outlet line from the cylinder head and the vent line leading from the gas pocket;

FIG. 8 is an enlarged, sectional view taken along a line substantially corresponding to line 8—8 in FIG. 4 and shows particularly the construction of the discharge or outlet valve;

FIG. 9 is an enlarged, sectional view of the dam ring employed on the pump shown in FIG. 2;

FIG. 10 is an enlarged, sectional view showing an alternative construction of the dam ring;

FIG. 11 is an enlarged, sectional view showing still another modification of the dam ring;

FIG. 12 is an enlarged, sectional view showing a further modification of the dam ring;

FIG. 13 is an enlarged, sectional view showing the

low pressure seal employed on the pump shown in FIG. 2;

FIG. 14 is an enlarged, sectional view showing a modification of the low pressure seal;

FIG. 15 is an enlarged, sectional view showing another modification of the low pressure seal; and

FIG. 16 is an enlarged, sectional view showing a still further modification of the low pressure seal.

Referring now to the drawings and first to FIG. 1 thereof, the high pressure pump of the present invention is there identified generally by the reference numeral 20 and is shown as used in a mobile system for delivering fluid from a liquid tank or reservoir 21. The installation shown in FIG. 1 is of the type which is installed upon a truck or the like so that it can be moved from station to station to satisfy the demands of different customers. The system includes a plurality of valves and fluid lines as illustrated which may be rendered selectively operable to deliver fluid from the tank 21 either in the form of a liquefied gas or in vaporized form.

The high pressure pump 20 is used only when it is desired to vaporize the liquefied gas in order to deliver gas to the customer. As is shown in FIG. 1, the pump is mounted in a horizontal position and extends into an insulating chamber 22 such as a vacuum space formed in the tank 21 between an outer shell 23 and an inner tank 24. The chamber 22 isolates the inwardly extending parts of the pump 20 including its liquefied gas sump or reservoir from the ambient. The inner tank 24 contains a supply of liquefied gas which, as indicated above, may be liquid oxygen, nitrogen or argon. The liquefied gas from this tank passes through a line 25 to a liquid sump formed at the inlet of the high pressure pump 20. Liquefied gas may also be drawn from the tank 24 for delivery to the customer by means of a medium pressure pump 26 submerged within the liquid. The outlet of the pump 26 is passed through a fluid line 27 to a conventional meter 28 which registers the amount of liquid passing therethrough so that the operator can determine the proper charge to be assessed against the customer after the delivery has been made.

In operation, the tank 24 is filled with liquefied gas before the truck leaves a central distributing station to make its rounds to the various customers to be supplied. To fill the tank, liquefied gas is supplied through an inlet line 30, through a manually operated valve 31 and through a fluid supply line 32 to the tank 24. At this time, the remaining valves shown in the system are closed except for a vent valve 33 which is opened to permit the escape of gas created by vaporization of the liquid in the tank during the filling. The latter gas, of course, escapes through a fluid line 34, through a second line 35 and through the open vent valve 33. This gas may be collected by a suitable collector or holder connected to the line 36 so that it can be used again either in its gaseous state or after reduction to its liquid state.

When the truck has been filled and is ready to make its delivery, provision may be made for leaving the truck in a condition which is referred to as the "standing vented condition." This is accomplished by closing the manually operated valve 31 while leaving the valve 33 open. The remaining valves in the system are, at this time, closed and, hence, the gas created in the tank 24 is collected in the manner previously described by the holder connected to the line 36. The standing vented condition is, of course, set up during the time that the truck is standing at the central distributing station with its supply tank 21 filled.

Whenever the truck is being driven, the manually operated valve 33 is closed and, at this time, a manually operated valve 37 may be opened at spaced apart intervals whenever the pressure exceeds a predetermined amount, for example, fifty pounds per square inch. The opening of the valve 37 relieves the excess pressure by permitting the gas in the line 34 to escape slowly to atmosphere through an exhaust line 38.

When the truck has reached a customer's plant or station and is ready for a delivery to be made, it is desirable to circulate liquefied gas through the system in order to prime the meter 28 until it is cooled to its proper operating temperature. In this connection, it should be observed that the meter is adjusted to function at temperatures in the cryogenic range and, hence, it is necessary to reduce the temperature of this meter before the actual measurement of liquid flow begins. To circulate the fluid for this purpose, the medium pressure pump 26 is placed into operation. A manually operated valve 40 is opened slightly to admit fluid from the tank 24 to a pressure building coil 41 which functions to heat the liquefied gas in order to vaporize it. The gas thus created appears at the outlet of the pressure building coil 41 and is delivered through the fluid lines 35 and 34 to create a gas pressure above the liquid in the tank 24 in order to prevent the volatilization of the liquefied gas in the pump inlet line. It should be understood that at this time the high pressure pump 20 is not running. The circulation of liquefied gas through the meter 28 reduces the temperature and when the proper operating temperature has been reached, the system is ready to begin delivery.

If it is desired to deliver liquefied gas to the customer, the medium pressure pump 26 is maintained in operation and the high pressure pump 20 remains shut down. A manually operated valve 42 is opened to connect the outlet line 43 from the meter 28 to a liquid outlet line 44, through a check valve 45. The outlet line 44 is connected to a suitable liquefied gas receiver such as a converter located on the premises of the customer and, hence, when the valve 42 is opened, liquefied gas flows from the meter to the customer's receiver. At this time, the valve 40 is again opened slightly to throttle liquid from the tank 24 into the pressure building coil 41 for the purpose of maintaining the tank pressure at the desired level.

In the event that it is desired to deliver a gas to the customer, the valve 42, of course, is closed and the medium pressure pump is shut down. The high pressure pump 20 is placed in operation and, at the same time, a pair of manually operated valves 46 and 47 are opened. As will be described more fully hereinafter, the valve 46 opens a vent line to the tank 21 in order to permit the escape of gases generated within the pump 20 during the pumping operation. The gas receiving equipment of the customer is connected to an outlet line 48 which receives gas flowing through the valve 47 from a check valve 49. The high pressure pump 20 delivers liquefied gas from its outlet through a delivery line 50 to a vaporizer 51 which converts the liquefied gas to its gaseous state and delivers the conversion product through an outlet line 52 and through the check valve 49 to the customer's gas receiving equipment. At this time, the valve 40 remains slightly open to throttle the liquefied gas entering the pressure building coil 41 so that a gas pressure is created above the liquid in the tank 24 in the manner previously described. Vaporized, but not super-heated gas, from the cool portion of the vaporizer 51 is delivered from a gas line 53 through a valve 54 which may be throttled to control the amount of cool gas passing to the line 52. The valve 54 may be adjusted to control the temperature of the gas passing to the outlet line 48 in a manner which will be obvious. The various delivery lines may be provided with suitable safety valves as indicated in the drawings but these have not been described in detail. Conventional liquid level indicating equipment and associated valves indicated generally by the reference numeral 56 may be employed to indicate the level of the liquid in the tank 24. A connection is also made from the line 32 through a check valve 57 to the high pressure pump 20 for a purpose which will be described more fully hereinafter. The liquid sump for the pump is also connected through a gas vent line 58 to the upper end of the tank 24 for a

purpose which will become evident as the description proceeds.

Under some circumstances, it may also be desirable to deliver liquefied gas by pressure alone without the use of either of the pumps 20 or 26. To effect such a pressure transfer, all of the valves in the system are closed except for the valves 31 and 40 which are opened. Liquefied gas is thus delivered to the pressure building coil 41 in large quantities with the result that a relatively large amount of gas is evolved and transmitted through lines 34 and 35 to the upper end of the tank 24. The resulting gas pressure is sufficient to force liquid in the tank through the line 25, through the line 32 and through the open valve 31 to the outlet line 30 where it may be collected.

Since both of the pumps 20 and 26 and the liquid meter 28 are cooled at all times, the usual losses encountered in cooling down these devices are avoided. Thus, all of these units operate at very low loss, a feature which contributes to the efficiency of the system illustrated in FIG. 1.

Considering next the high pressure pump 20 and referring first to FIG. 2 of the drawings, the pump of the present invention is there illustrated as comprising a pump body or casing 60 detachably secured to the outer shell 23 of the tank 21. The shell 23 includes a housing 61 cooperating with the pump body to define a gas chamber 62 and a liquid sump or reservoir 63. To this end, the housing 61 includes a cylindrical sleeve 64 and a somewhat cup-shaped cover 65 joined together by an annular support ring 66. The cup-shaped cover opens to fluid line 25 in order to permit the flow of fluid from the tank 24 to the liquid sump 63.

To attach the pump body to the shell 23, this body is provided with a radially and outwardly extending mounting flange 67 secured to the shell 23 by means of a plurality of mounting screws 68. The pump body includes a cylinder portion 69 extending within the housing 61 and through the chambers 62 and 63 so that the pumping or cold end of the pump is immersed within the body of the liquefied gas. The pumping elements are, therefore, maintained at the proper operating temperature and the pump can be started without priming. The cylinder portion 69 is spaced from the sleeve 64 and from the cover 65 to define the chambers 62 and 63 referred to above. A novel dam ring assembly 70, which will be described more fully hereinafter, cooperates with the annular ring support 66 and with the cylinder portion or annular member 69 to isolate the gas chamber 62 from the liquid sump or reservoir 63. The gas chamber is relatively long and serves to inhibit the transfer of heat from the mounting flange to the liquid in the sump 63 and also to isolate the packings at the warm end of the pump from the cold liquefied gases. It should be observed that heat can be transferred from the warm end of the pump to the cold end not only by the metal contact but also by conduction, convection and radiation through the gas in the chamber 62. To avoid the transfer of heat through the chamber 62 and to isolate the mounting flange from the cold portion of the pump, the chamber 62 is preferably packed with a wadded, crumpled, highly reflecting, metal foil such as aluminum as is indicated by the reference numeral 59. Due to the reflectivity of the foil, radiation through the chamber 62 is reduced. Since the volume of the chamber is substantially filled with foil, there is little gas circulation and, hence, very little heat is transferred by convection. Since the foil is wadded and crumpled, it provides a large number of very long heat paths thus reducing the heat transfer due to conduction.

The pump body 60 also includes a cage or super structure 72 suitably secured to the mounting flange 67 and extending outwardly from the shell 23 to be exposed to the ambient. For ease of manufacture, the cylinder portion 69 is preferably formed by a plurality of separate

pieces including a central sleeve 73 and a head 74 suitably secured to the sleeve by means of a plurality of spaced apart cap screws 75. A reciprocating piston or annular member 77 mounted for sliding movement longitudinally of the cylinder 69 effects the pumping action by drawing fluid from the sump 63 into the cylinder 69 during its suction stroke and by delivering pressurized fluid from the cylinder during its pressure stroke. Simple, automatically operated valves constructed as described below control the flow of fluid into and out of the cylinder 69.

To reciprocate the piston, the latter is connected through a ball and socket assembly 78 to a connecting rod 79 which is reciprocally driven by any suitable mechanism of conventional construction. The connecting rod 79 is connected by means of a wrist pin 80 to a cross head 81. The cross head includes an axially extending recess 82 for accommodating the head of the connecting rod 79 together with a pair of diametrically opposed openings for respectively receiving the ends of the wrist pin 80 which also extends through the recess 82 and through a transverse opening in the head of the connecting rod. The cross head is also provided with an annular, peripheral recess 83 cooperating with the main body of the cross head to form a shoulder 84 against which is seated a bushing 85. The latter bushing is retained in position by means of a lock nut 86 threaded onto the cross head 81. When the connecting rod 79 is reciprocated, the bushing slides within a cylindrical sleeve 87 suitably supported from the super structure 72. The reciprocating movement of the connecting rod 79 is transmitted through the ball and socket assembly 78 to the piston rod 77 with the result that the latter rod is moved back and forth within the cylinder head 69.

During the suction stroke of the piston rod 77, liquid is drawn from the sump 63 through the head 74 of the cylinder and into an inlet chamber 99. This fluid passes through a filter screen 100 which removes any foreign particles or debris. The fluid from the filtering screen is delivered to a plurality of spaced apart openings 101 extending parallel to each other through the head 74. Fluid flow through each of these openings 101 is controlled by means of an inlet valve ball 102. All of the valve balls 102 are mounted upon an annular supporting cage 103 secured to the head 74 by means of a plurality of spaced apart socket headed cap screws 104.

As is best shown in FIG. 5, each of the valve balls 102 is guided for movement upon the cage 103 by means of a pair of parallel slots 102a and 102b respectively formed in the two sides 102c and 102d of the cage. The ball has a diameter which is greater than the width of the slots and is also greater than the spacing between the sides 102c and 102d, whereby the movement of the ball is restricted to a path extending axially of its associated opening 101. The cage 103 is dimensioned to accommodate an axially extending projection 77a formed on the piston rod 77 when the latter rod is advanced or extended at the completion of its pressure stroke. The reduced pressure created in the inlet chamber 99 during the suction stroke of the piston rod allows the valve balls 102 to be unseated by pressure external to the pump so that fluid from the sump 63 passes through the openings 101 and into the inlet chamber 99. The fluid flow past each valve ball is uniform on both sides of the ball since the fluid passes along the ball through the slots 102a and 102b. Thus, the valve balls do not spin or turn when the fluid is drawn into the inlet chamber and, as a consequence, these balls are not subjected to excessive wear. Moreover, fluid passing through the valves is not forced to undergo an abrupt or sharp turn, a feature which avoids turbulence and prevents cavitation of the pump on the suction stroke.

When the piston moves to the right as viewed in FIG. 2, that is, during its advance or pressure stroke, the pressure created within the chamber 99 seats the valve balls 102 to close the openings 101 and, hence, to prevent the

escape of fluid from the inlet chamber to the liquid sump 63. Fluid under pressure then flows from the inlet chamber through an outlet passage formed in the cylinder 69. This outlet passage includes a radially extending opening 107 communicating with an elongated passage 108 extending longitudinally of the cylinder 69. A spring biased discharge valve 109 is inserted within the elongated passage 108 to control the flow of outlet liquid. This discharge valve includes a valve ball 110 biased by means of a coil spring 111 towards an annular valve seat defined by a shoulder 112 in the passage 108. The spring 111 acts against a plug 113 which, as is best shown in FIG. 8, includes a central body portion 113a and a plurality of outwardly extending fins or ribs 113b. These fins are received within the chamber 114 for the outlet valve and define a plurality of guide slots 114a. The coil spring 111 biases the ball 110 towards one end of the chamber 114. The slots 114a also accommodate the ball 110 to guide the latter as it is moved towards and away from the valve seat shoulder 112. When the ball 110 is unseated, fluid flows uniformly around all sides of the valve ball and through the four slots 114a so that this ball is not spun or turned by the moving liquid. It will be observed that the liquid flowing past the valve is not forced to make a turn in direction as it passes there-through and, hence, the beneficial results described previously are realized.

In view of the foregoing description, it will be observed that during the pressure stroke of the piston rod 77 the pressure of the fluid in the chamber 99 becomes sufficient to overcome the action of the biasing spring 111, thus unseating the valve ball 110 and delivering fluid to the outlet passage 108. The fluid in the passage 108 passes through the central sleeve 73 and is delivered to an L-shaped passage 116 formed in an end sleeve or annulus member 117 forming part of the cylinder 69. The L-shaped passage 116 opens to a fitting or coupling 118 which is connected to a tube 119 extending through the gas chamber 62. The tube 119 is, in turn, connected through a sleeve coupling 120 mounted upon the flange 67, to a tube 121 and a fitting 122 in order to deliver fluid to the outlet line 50 shown in FIG. 1. The relatively cold liquid flowing through the tube 119 does not cool the packings around the flange 67 due to the insulation provided by the gas chamber 62 and by the packing 59 previously described.

In accordance with an important feature of the present invention, the central sleeve 73 of the cylinder 69 is lined by a cylindrical wear sleeve or liner 125 which is formed of a suitable hardened metal such as chrome iron in order to resist wear caused by reciprocation of the position rod. The length of the sleeve 125 may be varied as required but it is preferably somewhat longer than the stroke of the piston. The wear sleeve 125 is provided with an annular flange 126 at one end thereof seated within a suitable recess defined adjacent one end of the central sleeve 73. The wear sleeve is dimensioned so that at ambient temperatures its outer diameter is slightly smaller than the inner diameter of the central sleeve 73 and, as a result, during assembly of the pump, it can be inserted very easily into the interior of the sleeve 73 whereupon the head 74 can be attached to complete the assembly. The cylinder 69 and, more particularly, the central sleeve 73 is formed of a suitable metal, such as bronze, which has a much higher coefficient of construction than the material of the wear sleeve 125 and, as a result, the differential contraction between the sleeve 73 and the wear sleeve 125 causes the wear sleeve to be tightly retained within the cylinder when the pump reaches cryogenic temperature. The tight fit between the wear sleeve and the pump body is not distributed by vibration of the pump and, hence, the wear sleeve does not turn or vibrate when the piston rod is reciprocated. Since the pump body is made of bronze it possesses sufficient elasticity to avoid rupture of the sleeve when the parts contract.

The piston rod 77 may be spaced somewhat from the inner surface of the wear sleeve 125 and, hence, these parts need not be machined within strict tolerances, thus providing a construction which can be manufactured very easily and inexpensively. By avoiding the necessity for a tight fit between the piston and the wear sleeve, the heat generated by friction is reduced and excessive volatilization of the liquefied gas is prevented. The spacing between the wear sleeve 125 and the piston rod forms a gas pocket which is indicated in FIG. 4 by the reference numeral 128. This gas pocket is sealed from the inlet chamber 99 by means of a plurality of sealing assemblies 130, 131, 132, etc. The number of such assemblies employed may vary but a sufficient number is used to provide the desired sealing action. These sealing assemblies are substantially identical in construction and, hence, only one will be described in detail, namely, the assembly 132 shown in FIG. 6. This assembly includes an annular filler member 133 having an external recess 134 therein for receiving a sealing ring 136 and an expander ring 137. The filler member is seated against the piston rod 77 and is retained in alignment with the other sealing assemblies by means of a lock nut 138 forming part of the piston rod 77. The lock nut 138 is threaded onto the end of the rod and compresses the line of sealing ring assemblies against a shoulder 139 formed on the piston rod. The expander ring 137 is a split, resilient ring which acts to bias the sealing ring 136 into engagement with the inner wall of the wear sleeve 125. This expander ring is preferably formed of a material such as beryllium copper having a width dimension approximately equal to the width of the sealing ring 136 for the purpose which will be evident as the description proceeds. The sealing ring is formed of a plastic material which at cryogenic temperatures becomes very hard and resistant to wear but which, at temperatures near the ambient temperatures of the pump, exhibits plastic flow to form a good seal with the inner surface of the cylindrical wear sleeve 125. In addition, the material of the ring must be one which is not hazardous in the pressure of the liquefied gas being pumped. In accordance with an important feature of the present invention, the sealing ring 136 is formed of a fluorinated hydrocarbon such as polymonochlorotrifluoroethylene (a material sold under the trademark Kel-F by M. W. Kellogg Company) or polytetrafluoroethylene (a material sold under the trade name Teflon by E. I. du Pont & Company). The sealing ring 136 is split as indicated at 136a in FIG. 6 and its two ends are cut away as indicated respectively at 136b and 136c. The cutaway portions 136b and 136c are overlapped to provide a fairly good seal and, in addition, the expander ring 137 underlies the overlapped joint to prevent the escape of liquefied gas through this joint. Since the width of the expander ring 137 is approximately equal to that of the sealing ring 136, the entire joint is covered. Moreover, the split 137a in the expander ring 137 is diametrically opposed from the split 136a in the sealing ring, thus blocking the flow radially through the joint. In addition, in order to avoid a straight line path for the flow of the liquefied gas from the chamber 99 to the gas pocket 128, the splits 136a in the sealing rings of the various assemblies 130, 131 and 132 are displaced or misaligned with respect to each other. Thus, the split 136a of the assembly 130 is displaced 120 degrees from the corresponding splits in each of the assemblies 131 and 132 while the split in the assembly 131 is displaced 120 degrees from the corresponding splits in both of the assemblies 130 and 132 and so on.

In assembling the pump shown in FIG. 2, the sealing ring 136 forms an effective seal against the wear sleeve 125 at the ambient temperature of the pump and when the pump temperature is reduced the sealing ring hardens and becomes highly resistant to wear. After use of the pump, the sealing ring 136 of each assembly may wear

and, hence, in accordance with an important feature of the present invention, each sealing ring is resealed after a predetermined period of operation. It has been found that the pump will run for approximately 1500 hours before requiring reseal of the rings 136 and, hence, at the end of this period, the pump is shut down and the rings are permitted to reach ambient temperature whereupon they reseal themselves by the plastic flow referred to above. After the reseal operation is completed, the pump can be operated for another 1500 hours before the rings must be resealed again. The useful life of a set of rings can thus be extended to a period in excess of 10,000 hours whereas in pumps of prior design, replacement of these rings every few hours of operation was necessary. The expander ring 137 exerts sufficient pressure on the sealing ring 136 to accomplish the plastic flow at the ambient temperatures but this pressure is insufficient to cause excessive wear on the rings during operation at cryogenic temperatures.

In accordance with another feature of the present invention, a vent line including the manually operated valve 46 referred to above is connected from the gas pocket 128 to the upper end of the tank 21. This connection is made through a collecting ring 140 positioned adjacent the end of the end sleeve 117. The collecting ring 140 includes an inner annular recess 140a extending around the collecting ring adjacent the periphery of the piston rod 77 and an outer annular recess 140b concentric with the recess 140a and disposed adjacent the connecting sleeve 117. The annular recesses 140a and 140b are interconnected by a plurality of spaced apart apertures or openings 140c which permit the flow of gas from the pocket 128 to an opening 141 in sleeve 117 (see FIG. 7). The opening 141 is connected through a tube 142, through a connector 143 carried by the mounting flange 67 and through a suitable connecting line 144 to the valve 46. When the pump 20 is operating, the valve 46 is opened to vent the gas pocket 128 to the tank 21. It will be understood that gas may be created within the pocket 128 by vaporization of small amounts of leakage liquefied gas which may enter the pocket around the sealing ring assemblies. The venting of the gas, of course, prevents vapor binding of the pump at low suction heads.

When the pump is shut down, the valve 46 is closed with the result that liquid trapped in the pocket 128 will be vaporized due to heat infiltration from the mounting flange 67. The evolved gases create a pressure in the gas pocket 128 which forces the liquid back into the inlet chamber 99 thus isolating the liquefied gas from the mounting flange, increasing the heat leakage path and, hence, reducing the vaporization of the liquid when the pump is not running. The operation of the valve 46 to force the liquid back into the inlet chamber 99 is a particularly desirable feature when the pump is continuously immersed, that is, when the inlet chamber is continuously filled with liquefied gas from the sump 63.

Considering next the construction of the dam ring assembly 70 and referring particularly to FIGS. 4 and 9 of the drawings, it will be observed that this assembly comprises an annular cup-like sealing member 150 encircling the cylinder 69 and seated against the annular support ring 66. To this end, the member 150 includes, in the form shown in FIGS. 4 and 9, an outwardly extending flange 151 for engaging the side edge of the support ring 66 together with a pair of laterally extending lips 152 and 153 formed by an annular groove 154 in its side face. The outer lip 152 is seated against the inner edge of the ring 66 while the inner lip engages and seats against the periphery of the cylinder 69. The member 150 is urged axially of the cylinder and into engagement with the supporting ring 66 by means of a pressure exerting back-up assembly 165 which functions to prevent the member 150 from being displaced as a result of pressure differences on opposite sides of the dam ring 70. The assembly 165 includes a plurality of spaced apart biasing springs 155

acting against an annular collar 156 mounted for sliding movement upon the cylinder 69. Each of the springs 155 encircles a guide rod 157 which has one end secured to the collar 156 and has its other end extending through a guide slot or aperture formed in a fixed collar 158 secured to the cylinder 69. The ends of the guide rods may be connected together by means of a connecting wire 159 to provide for uniform expansion or contraction of the springs 155 and, hence, to exert uniformly distributed pressure upon the sliding collar 156. The springs 155 obviously urge the collar 156 toward the right as viewed in FIG. 4 so that this collar acts upon the member 150 to seat the flange 151 against the annular ring 66.

The member 150 is preferably formed of a suitable material such as polytetrafluoroethylene (Teflon) which has a coefficient of contraction somewhat higher than that of the bronze metal forming the central sleeve 73. The member 150 is dimensioned so that at ambient temperatures, it will readily slide onto the cylinder 69 but when the temperature of the pump is reduced to the cryogenic range, the Teflon member 150 contracts more rapidly than the cylinder 69, thus forming a tight seal between the inner lip 153 and the outer periphery of the cylinder. For the purpose of providing a similar seal between the outer lip 152 and the inner edge of the annular support ring 66, a seating ring 160 is disposed within the groove 154. This seating ring is preferably formed of a suitable metal such as Invar which has a coefficient of contraction considerably lower than that of the metallic support ring 66. Thus, while the member 150 can be readily inserted into the support ring 66 at ambient temperatures, when the pump reaches cryogenic temperatures the support ring 66 contracts much more than the seating ring 160 with the result that the outer lip 152 is clamped between these two members to form a liquid tight seal.

The lower edge of the member 150 adjacent the inner lip 153 is relieved as indicated at 161 by providing an outwardly tapering portion facing the cylinder 69 but extending away from this cylinder. This relieved portion permits distortion of the inner lip 153 radially with respect to the outer lip 152 without distorting the outer lip and thus avoids breaking the seal between the lip 152 and the annular ring 66. In addition, this relief allows the member 150 to absorb the vibrations of the high pressure pump without destroying the seal at the outer lip 152.

In order to prevent the existence of large differential pressure existing in the chambers 62 and 63 on opposite sides of the assembly 70, means are provided for connecting the gas chamber 62 to the chamber 63 through the upper portion of the tank 21. More specifically, the liquid sump or reservoir 63 is connected through a small bleed line 58 referred to above and illustrated in FIG. 1 to the upper end of the tank 21. In addition, the gas chamber 62 is connected through a fitting 165' and through the check valve 57 referred to previously to the upper end of the tank 21. The bleed line connection between the gas chamber 62 and the liquid sump 63 thus equalizes the pressure on opposite sides of the assembly 70 and prevents a large pressure differential thereacross which might otherwise result in rupture of the seal between the ring 66 and the member 150. Liquefied gas inadvertently conducted to the gas chamber 62 is volatilized by the heat to develop a gas pressure for automatically closing the check valve 57 in order to prevent the further flow of liquefied gas to the chamber 62.

An alternative construction of the dam ring assembly and its associated parts is illustrated in FIG. 10. This construction is somewhat similar to that shown in FIG. 9 and, hence, corresponding parts have been assigned the same reference numerals except that in the construction shown in FIG. 10, the reference numerals are in the 200 series. Thus, for example, the cup-like member has been assigned reference numeral 250, the annular groove therein has been assigned reference numeral 254, the outer lip bears the reference numeral 252, the inner lip bears the reference numeral 253, the outer flange bears the refer-

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ence numeral 251, the relieved portion bears the reference numeral 261, and so on. The main difference between the construction shown in FIG. 10 and that shown in FIG. 9 resides in the provision of an additional seating or clamping ring 262 disposed within the annular groove 254 and encircling the inner lip 253. This ring is formed of a material such as aluminum having a higher coefficient of contraction than the cylinder 69 and, as a result, the ring 262 contracts much more than the cylinder when the pump reaches cryogenic temperature. The contraction of the ring 262, of course, intensifies the seal between the inner lip 253 and the pump body 69 and, hence, prevents failure of this seal as might be caused, for example, by misalignment of the pump body and the annular support ring 66.

A still further modification of the dam ring assembly is illustrated in FIG. 11 wherein the parts corresponding to those of the previous embodiments have been assigned reference numerals in the 300 series. Thus, the cup-like member is indicated by reference numeral 350, the outer lip bears reference numeral 352, the inner lip has been assigned reference numeral 353, the annular groove has been assigned reference numerals 354, the relieved portion is indicated at 361, and the annular support ring bears the reference numeral 366. The latter support ring is identical to the ring previously described except that its inner edge is provided with a tapered portion 366a which co-operates with a correspondingly tapered portion 360a on the ring 360 to form the outer seal. The ring 360 is so dimensioned that at ambient temperatures its fits readily into the ring 366 with the surface 360a and 366a contiguous to each other. The ring 360 is again formed of a material such as Invar having a lower coefficient of contraction than the metal forming the annular support ring 366 and, as a result, the surfaces 360a and 366a are forced into film engagement when the temperature of the pump reaches the cryogenic range. The outer lip 352 in the arrangement shown in FIG. 11 seats against the ring 360 and this lip is encircled by a seating ring 363 formed of a suitable metal such as aluminum having a much higher coefficient of contraction than that of the ring 360. Thus, when the operating temperature of the pump reaches the cryogenic range, the ring 363 clamps the outer lip 352 against the ring 360 to complete the outer seal. The tapered surface 360a on the ring 360 forms an extremely tight fit with the outer lip 352 when the aluminum 363 is contracted. Due to this tapered surface, it will be very difficult, if not impossible, to pull the outer lip 352 axially toward the left as viewed in FIG. 11 and, hence, the outer seal is not likely to be broken even though a slight difference of pressure exists between the gas chamber 62 and the liquid sump 63. It has been found that a taper of two and one-half (2.5) degrees on the surface 360a and on the surface 366a provides particularly efficient holding action at the outer seal. A second ring 362 similar in construction to the ring 262 previously described may again be employed around the inner lip 353 to intensify the inner seal between the lip 353 and the cylinder 69.

A still further modification of the dam ring assembly is illustrated in FIG. 12 wherein the component parts corresponding to those of the modifications previously described have been assigned reference numerals in the 400 series. Thus, the cup-like member bears reference numeral 450, the outer lip is designated by reference numeral 452, the inner lip bears reference numeral 453, the relieved portion is indicated at 461, the annular support ring bears the reference numeral 466, the annular groove in the member 450 bears the reference numeral 464, and so on. The support ring 466 is similar to the ring 66 previously described but, in addition, it is provided with an annular groove 466b in one of its sides for receiving the outer lip 452. A metal seating ring 463 formed of aluminum or other material having a coefficient of contraction much higher than that of the material forming the

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support ring 466 is seated within the groove 466b and encircles the outer lip 452. Thus, when the temperature of the pump reaches the cryogenic range, the ring 463 contracts more rapidly than the ring 466 in order to clamp the outer lip 452 against the inner wall of the groove 466b, thus forming a tight outer seal. Here again, a metal seating ring 462 similar to the ring 262 previously described is employed to intensify the seal between the inner lip 453 and the pump body 69.

In accordance with another important feature of the present invention a new and improved sealing arrangement is employed to prevent leakage along the pump piston 77 from the pocket 128 to the outer structure of the pump including the mounting flange 67. In one form of the invention shown in FIGS. 2, 4 and 13, this sealing arrangement comprises a two part seal including an inner seal indicated generally by the reference numeral 175 and an outer seal indicated at 176. The inner seal 175 operates at cryogenic temperatures and serves as the primary seal. This seal comprises a plurality of concentric sealing assemblies 177, 178, 179 and 180 encircling the piston rod 77 and disposed outwardly of the collecting ring 140 to seat against the inner wall of the end sleeve 117 referred to above. These sealing assemblies are of identical construction and each includes a somewhat cup-shaped in particular, L-shaped or J-shaped in cross-section, sealing ring 181 (FIG. 13) formed of a material such as Teflon which is very resistant to wear at cold temperatures and which has a coefficient of contraction much higher than the metal forming the piston rod 77. Thus, when the temperature of the cup-shaped ring 181 is reduced, its inner lip 181a seats firmly against the periphery of the piston rod to form a seal. A portion of a seating ring 182 is inserted within an annular groove 181b for the purpose of forming a seal against the end sleeve 117. To this end, the ring 182 is formed of a material such as Invar having a coefficient of contraction much less than that of the bronze forming the sleeve 117. Therefore, when the temperature of the sealing assembly is reduced, the ring 182 contracts much less than the sleeve 117 and, as a result, the outer lip 181c of the seating ring 181 is forced firmly against the inner wall of the sleeve 117. The ring 182 includes an outer rim portion 182a, joined to the other portion of the ring 182 by a reduced neck, on the exterior of the groove 181b to aid in forming the outer seal by seating against the wall of the sleeve 117 when the temperature is reduced. Spacer rings 183 may be provided between the various assemblies 177, 178, 179 and 180 at the positions illustrated in FIG. 13. A coiled expansion spring 184 encircling the piston rod 77 acts to force the assemblies 179 and 180 and the collecting ring 140 axially of the piston rod towards the right as viewed in FIG. 13 to hold these units in position and to seat the collecting ring against the extreme outer end of the wear sleeve 125. The spring 184, of course, urges the assemblies 177 and 178 towards the left as viewed in FIG. 13 against a carbon wear ring 185 forming part of the outer seal 176. This wear ring is held in position by a sleeve-like collar 186 having an outwardly extending radial flange 186a secured to the sleeve 117 by a plurality of spaced apart cap screws 187. An annular collar 188 is suitably secured as by welding or brazing to the flange 186a and this collar supports one end of a bellows 189 which extends over the ball and socket assembly 78 and has its other end secured to the sleeve 87 through a second collar 190 (FIG. 2). In the form of the invention shown in FIGS. 2, 4 and 13, the bellows 189 is preferably formed of a flexible metal and provides a pressure tight seal so that it absorbs a portion of the pressure drop from the high pressure gas pockets 128 to atmosphere. The remainder of the pressure drop is, of course, distributed across the sealing assemblies 177, 178, 179 and 180. The use of a pressure sealing bellows, therefore, reduces the pressure drop across the latter assemblies and, hence, results in longer life for the

inner seal 175. However, the use of an outer seal bellows also causes the pressure drop across the inner seal assemblies to fluctuate with reciprocation of the cross head 81. While in most cases this fluctuation will not be objectionable, it can be overcome by employing a non-sealing type bellows made of a suitable material such as an impregnated fiberglass. Both of these types of bellows, however, inhibit the entry of moisture and dirt from the atmosphere, thus protecting the interior parts of the pump.

Since the inner seal 175 is exposed to the cryogenic fluid in the pocket 128, any heat created by friction at the inner seal is quickly conducted away from the seal, thus increasing the life of the inner seal assemblies. The upper seal 176 is accessible to the operator at the exterior of the tank 21 and, hence, can be adjusted to compensate for wear on the rotating elements of the pump. In the event that both of the seals 175 and 176 are damaged, a temporary repair can be effected merely by replacing the defective components of the outer seal 176 without removing the entire pump from the tank 21. In the case of high use and/or the pumping of high value products such as argon, preservation of the purity of the product within the tank is of primary importance and, hence, in such cases the feature of being able to repair the seal without disturbing the purity within the tank is a distinct advantage.

The inner seal 175 functions on the principle of progressive contraction of the sealing assemblies 177, 178, 179 and 180. Thus, since the assembly 180 is closest to the cryogenic fluid in the pocket 128, its radial contraction is greater than that of the other assemblies. If the assembly 180 leaks because of damage or wear, cold fluid then flows to the assembly 179 to intensify the seal at this assembly. The effect is, therefore, progressive from the assembly 180 to the remaining assemblies making up the inner seal 175.

The inner seal may also take the form shown in FIG. 14 where this seal is indicated generally by reference numeral 275 and comprises a plurality of side-by-side sealing ring assemblies 277, 278, etc., encircling the piston rod 77. Each of these assemblies includes a cup-like member 281 having an inner lip portion 281a and an outer lip portion 281c cooperating to define an annular groove 281b for receiving the outer rim of a seating ring 282. The member 281 is formed of a suitable material such as Teflon having a coefficient of contraction much higher than that of the piston rod 77 while the seating ring 282 is again formed of a material such as Invar having a coefficient of contraction much less than the sleeve. Thus, when the temperature of the assembly is reduced, the inner lip 281a contracts against the piston rod 77 to form a seal and, at the same time, the seating ring 282 forces the outer lip 281c against the inner wall of the sleeve 117. The outer lip 281c is relatively long and extends from both sides of a central body portion 281d. This construction not only provides a very wide sealing area but also permits the sealing assemblies to be overlapped or interlaced to intensify the seal. More specifically, that portion of the lip 281c of the assembly 278 which extends to the right of the body 281d as viewed in FIG. 14 overlies a portion of the ring 282 of the assembly 277 while the leftward extending portion of the lip 281c in this assembly 278 overlies a portion of the ring 282 in the assembly 277. Thus, when the temperature of the ring 282 of one assembly is reduced, the outer lip of two adjacent assemblies are sealed against the wall of the sleeve 117.

Another important feature of the construction shown in FIG. 14 is the provision of an additional cup-like member 285 at the right side of the stack cooperating with the axially projecting rim 286a of an element 286 to form a seal adjacent the pocket 128. The member 285 is identical to the members 281 described above and when its temperature is reduced by exposure to the cold fluid in the pocket 128, its outer lip seals against the flange 286 which is, of course, formed of a material having a

lower coefficient of contraction than the Teflon of the member 285. The inner lip of the member 285, of course, seats against the piston rod 77 to form a seal and the seating ring 282 of the sealing assembly 280 forces the leftward extending portion of the lip on the member 285 into engagement with the inner wall of the sleeve 117 to complete the seal. Of course, the flange 286a need not be formed on a member separate from the wear sleeve 125 if provision is made for venting the gas pocket 128 through some connection other than the collecting ring 140.

A further modification of the inner seal is shown in FIG. 15 where this seal is generally indicated by reference numeral 375 and the sealing assemblies making up this seal are indicated at 377, 378, etc., a sufficient number of assemblies being employed to provide the desired sealing action. Each of these assemblies includes a sealing ring 381 of L-shaped cross section having an inner lip 381a extending adjacent the piston rod 77. A seating ring 382 having an inner annular groove 382a for receiving the lip 381a is disposed between the piston rod 77 and the sleeve 117. Here again, the sealing ring is formed of a material such as Teflon having a much higher coefficient of contraction than the piston rod 77 and the seating ring 382 is formed of a material such as Invar having a much lower coefficient of contraction than the sleeve 117. Thus, when the temperature of the assembly is reduced the seating ring 382 cooperates with the sleeve 117 to form an outer seal and lip 381a is sealed against the piston rod 77. The length of the ring 382 is such that lengthwise shrinkage (towards the left or right as viewed in FIG. 15) of the Teflon member 381 is compensated for by non-shrinkage of the Invar seating ring 382, thus providing a net tightening effect on the stack of sealing assemblies when the temperature is reduced.

Another embodiment of the inner seal is illustrated in FIG. 16 where this seal bears reference numeral 475 and comprises sealing assemblies 477, 478, etc. Each of these assemblies includes a cup-like member 481 having inner and outer lips 481a and 481c defining an annular groove 481b for accommodating an axially extending flange 482a of a seating ring 482. The flange 482a includes an external cylindrical surface 482b which is tapered to provide a relatively narrow outer rim on the flange, whereby the cup-like member 481 can be moved axially onto the flange by means of a spring 284 at ambient temperatures. Spacers 483 of the type shown above may also be included in the assembly. The parts can thus be assembled very easily at ambient temperature and when the temperature is reduced, the inner lip 481a of the Teflon cup member 481 seals against the periphery of the piston rod 77 while the Invar ring 482 forces the outer lip 481c into engagement with the sleeve 117 to complete the seal.

In view of the foregoing description, the operation of the pump 20 is believed to be obvious. Moreover, it will be observed that the construction described is effective to achieve all of the enumerated objects and advantages of the invention.

While a particular embodiment of the invention has been illustrated and described, it will be understood that many modifications will readily occur to those skilled in this art and it is, therefore, contemplated by the appended claims to cover any such modifications as fall within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. In a pump for liquefied gases including a cylinder having a cylinder wall and a reciprocating piston: a seal inserted between the reciprocating piston and cylinder wall, said seal comprising a plurality of assemblies each including a seal ring having an inner portion seating against said piston and a seating ring overlying the inner portion of the seal ring, said seal rings being formed of polytetrafluoroethylene and said seating rings being

formed of nickel-steel alloy, and a coil spring encircling said piston, said assemblies being urged axially of the piston and into tight sealing engagement with one another by said spring, each seal ring being in the form of an annular member having an annular groove in one of its side faces, said seating rings being disposed within said grooves, each seating ring including a portion extending out of said groove and into engagement with said cylinder wall.

2. In a pump for liquefied gases including a cylinder having a cylinder wall and a reciprocating piston: a seal inserted between the reciprocating piston and cylinder wall, said seal comprising a plurality of assemblies each including a seal ring having an inner portion seating against said piston, said seal ring being formed of a material having a greater coefficient of contraction than said piston and a seating ring overlying the inner portion of the seal ring and being formed of a material having a smaller coefficient of contraction than said cylinder wall, and a coil spring encircling said piston, said assemblies being urged axially of the piston and into tight sealing engagement with one another by said spring, each seal ring being in the form of an annular member having an annular groove in one of its side faces, said seating rings being disposed within said grooves, each seating ring including a portion extending out of said groove and into engagement with said cylinder wall.

3. In a pump for liquefied gases at cryogenic temperatures including a cylinder having a cylinder wall and a reciprocating piston: a seal ring having a generally cup-shaped cross section, said seal ring having an inner lip engaged with said piston and an outer lip engaged with said cylinder wall, and a seating ring having a portion disposed between said inner and outer lips of said seal ring and having a portion disposed in overlying relationship with respect to said inner lip and in engagement with said cylinder wall, said seal ring being composed of a material having a greater coefficient of contraction than said piston, said seating ring being composed of a material having a smaller coefficient of contraction than said cylinder wall.

4. In a pump for liquefied gases at cryogenic temperatures including a cylinder having a cylinder wall and a reciprocating piston: a seal ring having a generally cup-shaped cross section, said seal ring having an inner lip engaged with said piston and an outer lip engaged with said cylinder, and a seating ring having a first portion disposed between said inner and outer lips of said seal ring and having a second portion in engagement with said cylinder wall, said seating ring having a reduced neck joining said first and second portions, said seal being composed of a material having a greater coefficient of contraction than said piston, said seating ring being composed of a material having a smaller coefficient of contraction than said cylinder wall.

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