

Aug. 11, 1942.

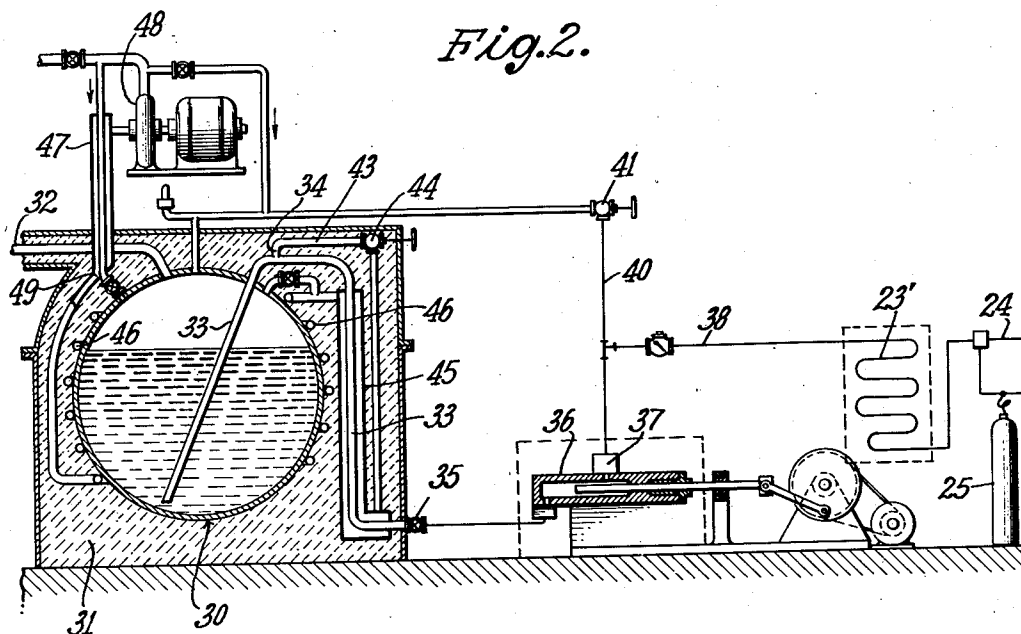
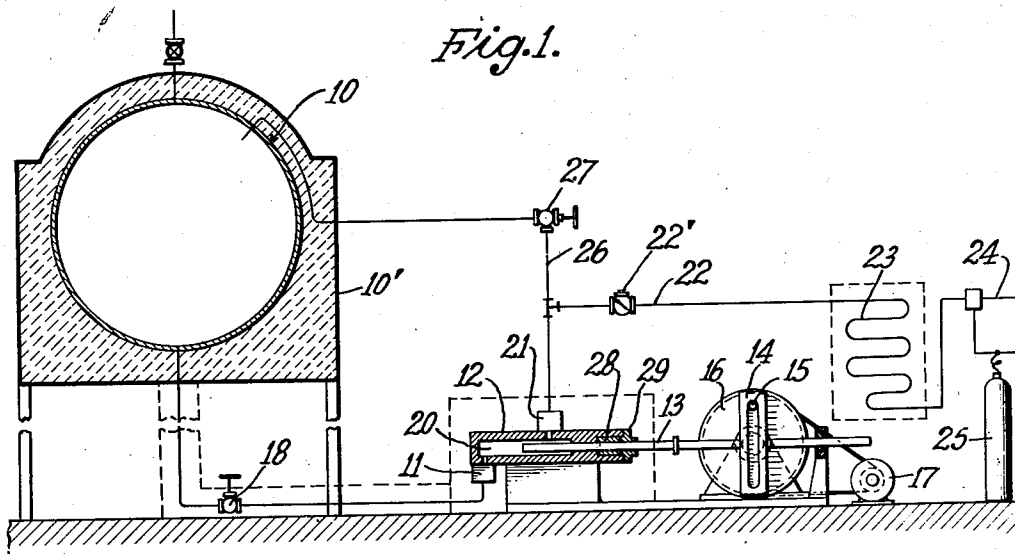
O. A. HANSEN

2,292,375

METHOD AND APPARATUS FOR PUMPING VOLATILE LIQUIDS

Filed June 15, 1940

2 Sheets-Sheet 1



INVENTOR

O. A. Hansen

BY

Watson, Bristol, Johnson & Leavenworth
ATTORNEYS

Aug. 11, 1942.

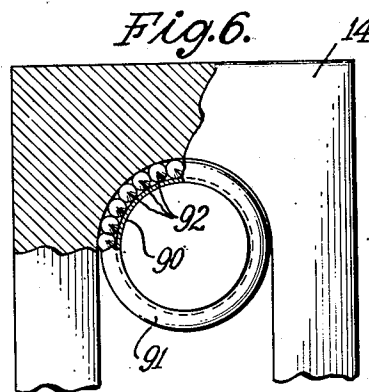
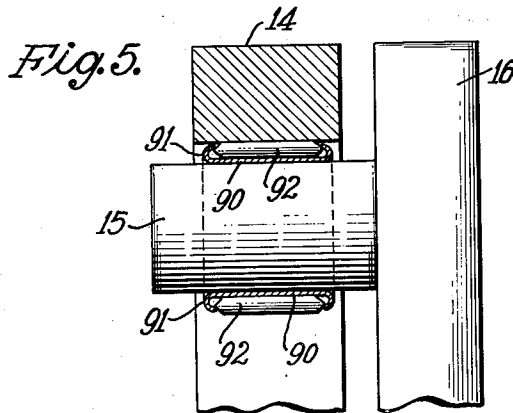
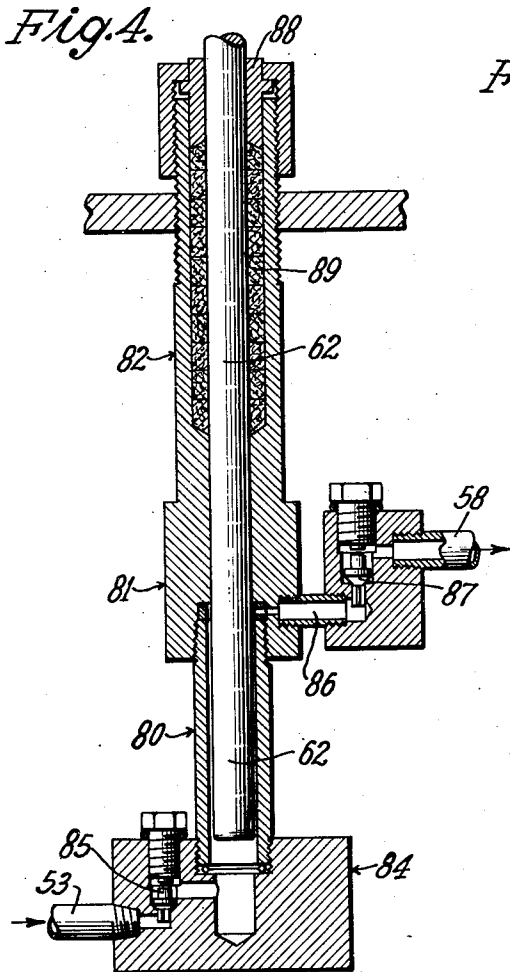
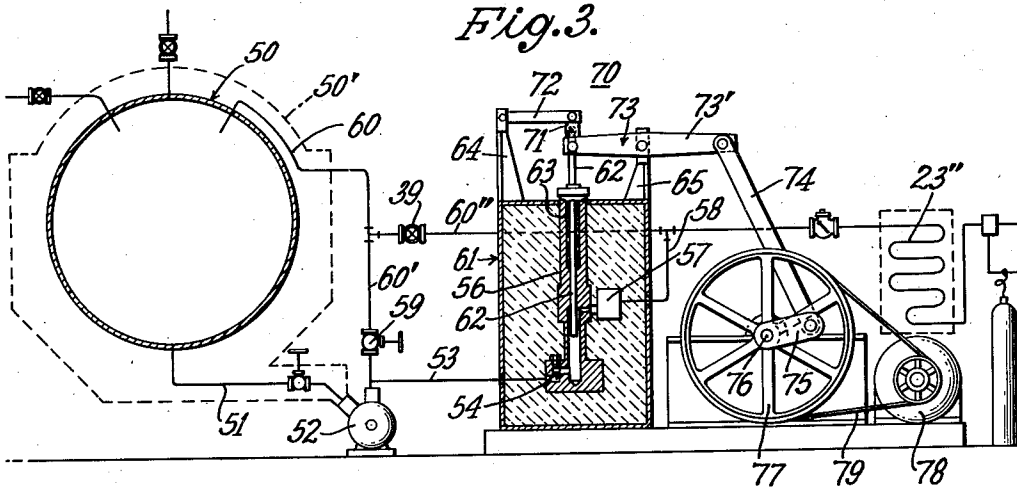
O. A. HANSEN

2,292,375

METHOD AND APPARATUS FOR PUMPING VOLATILE LIQUIDS

Filed June 15, 1940

2 Sheets-Sheet 2



INVENTOR
O. A. Hansen
BY
Watson, Bristol, Johnson & Leavenworth
ATTORNEYS

Patented Aug. 11, 1942

2,292,375

UNITED STATES PATENT OFFICE

2,292,375

METHOD AND APPARATUS FOR PUMPING VOLATILE LIQUIDS

Odd A. Hansen, Kenmore, N. Y., assignor to The
Linde Air Products Company, New York, N. Y.,
a corporation of Ohio

Application June 15, 1940, Serial No. 340,848

18 Claims. (Cl. 62—1)

This invention relates to a method and apparatus for pumping a volatile liquid and particularly to the pumping against a relatively high head of pressure of a liquid that has a boiling point temperature materially below 273° K. at atmospheric pressure, for example, liquid oxygen.

The invention has for its object generally the provision of an improved combination of pumping steps, together with suitable apparatus for effecting the same, whereby a highly volatile liquid may be positively pumped by a reciprocating type pump, particularly one having a plunger, against a relatively high head of pressure, for example, against a head of from 1000 to 2000 pounds per square inch above atmospheric pressure.

More specifically, the invention has for its object the provision of a cycle of pumping steps and apparatus for effecting the same whereby a volatile liquid, such as liquid oxygen, is, in effect, cooled and then forced out by means of a reciprocating plunger against a head of pressure in a manner which carries away and excludes the heat that may enter the liquid through conduction, and/or be introduced through friction. Such initial cooling practiced in the invention is here referred to as "subcooling", i. e., the bringing of the liquid to a temperature for a given pressure below that of the equilibrium boiling point temperature of the liquid for such pressure. The volatile liquid as a result may be pumped continuously without liability of experiencing the vaporization of the liquid within the pump or the pump becoming gas-bound.

Another object of the invention is to provide a reciprocating pump of the character indicated with parts arranged as far as practical to reduce friction and in a manner requiring the use of little or no lubricant of a composition that would tend to react with the liquid being pumped; such arrangement dispensing entirely with the use of piston rings, or similar liquid seals.

Still another object is to provide a pump cylinder and plunger arranged in a manner which employs the principle of counter-movement of liquid and plunger in order to cool the pump, whereby when the plunger is at the end of the discharge producing stroke, the liquid contacting end of the plunger is reduced in temperature to that of the liquid entering at the next suction stroke, thereby avoiding any flashing into vapor of the liquid being pumped.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the

several steps and the relation of one or more of such steps with respect to each of the others, and the apparatus embodying features of construction, combinations of elements and arrangement of parts which are adapted to effect such steps, all as exemplified in the following detailed disclosure, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed description taken in connection with the accompanying drawings, in which:

Fig. 1 is a view, partly in section and partly in elevation, showing an arrangement which effects the desired subcooling through static pressure and employs a reciprocating pump adapted for pumping the volatile liquid, here assumed to be liquid oxygen, in accordance with the invention;

Fig. 2 is a similar view showing a modification in which subcooling is achieved by means of expanding a portion of the liquid from the storage container, in order to practice subcooling in the pumping cycle of the invention;

Fig. 3 is a similar view showing still another modification employing a fore pump to achieve a subcooling effect;

Fig. 4 is an enlarged sectional view showing details of the pump illustrated in Fig. 3; and

Figs. 5 and 6 show on enlarged scale details of parts employed to achieve antifricition bearings for working elements, such as cross-heads, connecting rods, and the like, employed in the practice of the invention.

The pumping of volatile liquids which have boiling point temperatures materially below 273° K. at atmospheric pressure is taught broadly in U. S. Patent to Heylandt, Reissue No. 19,251, and the exclusion of heat from the working parts is practiced, but since all metal parts have substantial heat conductivities, difficulty is at times experienced in keeping the pump from becoming gas-bound. This difficulty, however, is avoided by the invention of H. E. Thompson, in whose Letters Patent No. 1,930,731 is taught the use of two pumps arranged to operate in successive stages. Analysis discloses readily that the pump of the first stage delivers the volatile liquid being pumped to the second stage at a temperature sufficiently below the boiling point temperature corresponding to the pressure of the liquid being delivered, that heat leakage in the second stage is insufficient to vaporize the liquid. The liquid is thus in effect subcooled, so that sub-

stantially any desired head of pressure may be readily achieved by means of a plunger pump where the liquid being pumped and the plunger are at temperatures below the equilibrium boiling point for the pressure applied; the pump structure being also arranged to conduct relatively little heat into the liquid being pumped.

In the arrangement of pumps taught in the Thompson patent, *supra*, it is, of course, important to have a connection between the first- and second-stage pumps with a relatively low pressure drop and a relatively low heat leakage, as this preserves the effect of subcooling introduced by the first-stage, or fore, pump. Otherwise, the pressure rise provided by the first-stage, or fore, pump will be neutralized and loss of prime in the second-stage pump will result.

By the present invention, the first step of the pumping cycle accomplishes the subcooling. This may be achieved in any suitable manner; for example, by elevating the storage container to a height that delivers the liquid to the pump at a pressure equivalent to the desired degree of subcooling; or by delivering the liquid from the storage container to the pump refrigerated during the passage by suitable means, such as by expanding a portion of the liquid while in heat conducting relation with the delivery conduit; or by directly increasing the supply pressure through the use of a fore pump, as taught in the U. S. patent to Thompson, above referred to. The head of pressure at which the volatile liquid is to be delivered to produce the effect of subcooling is, of course, materially less than the head against which the liquid is finally to be delivered.

As a second pumping step, the liquid under this initial pressure is introduced to the pumping chamber of a reciprocating pump which has a plunger, devoid of piston rings, working in spaced relation to the side walls of the pump chamber whereby an appreciable clearance space is provided. Such introduction is preferably accomplished through an inlet valve placed so as to deliver the liquid directly against the end of the reciprocating plunger when at the beginning of the suction stroke.

The next pumping step practiced is, of course, the filling of the pump chamber, the reciprocating plunger being moved during the step to the outermost position at the end of the suction stroke. During this stroke, the liquid is not appreciably heated, but upon the beginning of the next step the pump plunger is moved back and the exterior surface of the plunger now introduces some heat that has been generated in the plunger through frictional engagement with the packing.

The step thus begun accomplishes the displacement of the liquid from the pump chamber through an outlet valve. Here, this latter valve is connected to the pump chamber so as to communicate with the clearance space at a point remote from the inlet valve, whereby the liquid displaced does not pass out of the pumping chamber by a simple reversal of the direction of flow but continues the flow in the filling direction through the clearance space toward the outlet valve. The flow of the liquid being displaced and the motion of the piston are seen at once to be in opposite directions and will be hereinafter referred to as the counter-movement of liquid and plunger. Since the clearance space is relatively small when compared with the total volume of the pump chamber, it is evident that the velocity of this counter-movement is relatively

great and also that all of the liquid being displaced necessarily passes over the surface of the incoming pump plunger. This counter-movement of liquid and plunger is seen, in consequence, to cool the incoming plunger. Advantage of this fact is taken in the practice of the invention to absorb the heat generated frictionally in the plunger so that when the plunger reaches the end of its displacing stroke it has been cooled to a temperature close to that of the incoming liquid. The size of the clearance space and the rate of displacement are factors which determine the degree of cooling. Accordingly, these factors are so proportioned that the counter-movement of liquid and plunger causes the absorption not only of the heat generated frictionally but also any heat which passes by conduction down the plunger so that the likelihood of the next introduced liquid flashing into vapor is substantially avoided. The liquid, however, is partially heated as it passes through the pump and is then discharged at the desired high head to a receiver or vaporizer for generating gas for industrial consumption. The practice of the present invention is thus seen to render harmless the heat generated by friction, which is unavoidable, such heat being absorbed by the liquid in passing from the pump.

Referring now to the drawings, and particularly to Fig. 1, 10 denotes a storage container having an insulating envelope 10' and adapted for holding a supply of the liquid to be pumped. Such container is here disposed at an elevation, in order to provide a gravity produced pressure to achieve the desired subcooling effect on the liquid being delivered to an inlet valve, shown generally at 11, at one end of a pump cylinder 12. This cylinder is arranged to have a reciprocating plunger, as shown at 13, working therein. The plunger is driven by any suitable means which may be mechanically coupled for imparting a periodic straight-line motion and utilizes substantially a minimum of lubricated parts. Accordingly, the outer end of the plunger is shown connected to a transversely slotted cross-head 14 that is actuated by means of a crank-pin 15 on a rotatably mounted disk 16; the latter being power-driven from any convenient source of power, for example, an electric motor 17.

Both the pump cylinder and the connections conveying liquid thereto are preferably thermally insulated, the presence of such insulation being indicated by broken lines in the drawings, the inlet connections being shown as provided with a liquid control valve 18. The pump chamber is shown at 20 within the cylinder 12 and is indicated as having a diameter in excess of that of the plunger in order to provide a clearance space thereabout (the clearance space being shown with greatly exaggerated dimensions for the purpose of clearness of illustration in the drawings). The outlet valve is shown diagrammatically at 21 located at the top of cylinder 12 to assist gas escape, the valve communicating with the space 20 through the cylinder wall at a point remote from the inlet valve 11 so that the incoming plunger may force the liquid displaced from the chamber 20 past the end of the plunger through the clearance space without reversing the direction of flow, and then out through the valve 21; this motion of liquid and plunger being the counter-movement referred to above. From the valve 21 an outlet conduit 22 having a check valve 22' therein leads to a vaporizing coil 23. This latter may be connected to a service line 24 preferably

having one or more gas phase receivers or reservoirs 25 floatingly connected thereto. The portion of the conduit 22 which is immediately adjacent the pump may with advantage also be insulated.

To achieve priming of the pump and to provide for the escape of any gas that may be generated initially or otherwise, a priming connection 26 is provided, which is insulated and may with advantage be connected to the outlet conduit 22 at a point intermediate its connection to valve 21 and the vaporizer 23. The priming connection is led to the gas space of the container 10 so that such gas entering under pressure may tend to equalize and compensate for any back pressure on the liquid supply exerted by the pump. Hence the static pressure of the liquid supplied from the container is not subject to gas pressure fluctuations. A valve 27 is also provided in the connection 26 for controlling the operation of the same; the priming connection being inoperative when the valve is closed.

In this form of the invention, the pump cylinder is shown provided with a packing space about the pump plunger in the end through which the plunger enters. A packing gland, shown generally at 29, is employed to close this space and hold the packing, as shown at 28, in place. The packing here employed is preferably of special construction, and where liquid oxygen is being pumped is of a character which avoids the use of a hydrocarbon or other liquid lubricant which may react with the liquid oxygen to form dangerous or objectionable compounds. A preferred form of packing comprises one or more ring-like bodies of a suitable compressed material, such as shredded asbestos, lubricated with a solid lubricant in comminuted form, such as flake graphite, as described in copending application, Serial No. 341,126, filed June 18, 1940, in the name of J. F. Patterson.

In operation, the liquid delivered to the pump inlet valve, in this form of the invention, flows from the storage container 10 while under a gravity head of pressure sufficient to effect the subcooling of the liquid to a desired degree. The motor at 17 rotates the disk 16 and causes the plunger 13 to reciprocate in the chamber 20; priming being achieved, when starting, by opening valve 27. When the plunger is moved from the position when its inner end is at the extreme left in chamber 20, the suction stroke begins and liquid rushes in through the inlet valve to fill the chamber 20; any gas initially generated passing to the gas space in container 10 by way of connection 26. The packing at 28 prevents any liquid leakage, and, at the end of the suction stroke, the plunger is caused to reverse its direction and to begin a liquid displacing stroke by moving from right to left. This motion of the plunger produces the counter-movement of liquid through the clearance space in the chamber 20. As soon as primed, the valve 27 is closed and the ensuing discharge stroke, i. e., the stroke from right to left in the drawings, forces the liquid out through the valve 21. The liquid rushing past the incoming plunger cools the same so that substantially all heat at a temperature higher than that of the liquid is extracted therefrom by the time the plunger has reached the end of its inward motion and is ready to execute the suction stroke of another cycle. The liquid, partially warmed, passes through outlet valve 21 through the conduit 22 into the vaporizer 23, from whence it proceeds as gas at high pressure, for example,

at 2000 p. s. i. gauge, for consumption in a consumer's distributing system or use in industrial processes.

In Fig. 2, a modification is shown for achieving the effect of subcooling by means of the expansion of a portion of the liquid withdrawn from a liquid container which, when expanded and cooled, is passed in heat exchanging relation with the liquid supplied to the pump. Any suitable arrangement of this character may be employed, for example, that taught in U. S. patent to De Motte, No. 2,033,094. To this end, a container 30 is shown, provided with a heat insulating envelope 31 and a liquid supply connection 32. A liquid withdrawal connection 33, having a T-connection 34 therein and a control valve at 35 is provided leading to a pump cylinder 36 that has an outlet valve 37 located in the same manner, with reference to the cylinder clearance space, as shown at 21 in Fig. 1. An outlet conduit 38 leads to a vaporizer 23', which may be similar to that at 23, and has an associated gas distributing system for supplying gas to consumers.

A priming connection 40 for the cylinder 36 is also shown leading from a point in the outlet conduit 38 intermediate the outlet valve 37 and the vaporizer 23' and communicates with a connection leading to the gas space of the container 30; the priming connection being controlled by means of a valve, shown at 41.

To achieve the subcooling effect, a second connection 43 is led off from the T-connection at 34 and provided with an expansion valve 44, the expanded gas material being passed in counter-current fashion through the heat exchanger 45 which may comprise a jacket as shown surrounding a portion of the conduit 33. The expanded gas material from the heat exchanger 45 passes into a coil 46 disposed about the container 30 and thence through a heat exchanger 47 into a turbine pump 48 which discharges through a connection 49 into the gas space of the container 30.

In operation, this modified form of pumping system is started by opening the liquid supply valve 35 and the priming valve 41 and starting the plunger in pump cylinder 36 to operate. The suction stroke begins when the plunger is moved from left to right in the drawings, any gas initially generated finding escape through the connection 40 into the gas space of container 30. As soon as priming is completed, the valve 41 is closed. Thereafter the discharge stroke of the plunger, which is executed by movement from right to left in the drawings, accomplishes the expulsion of the liquid, causing a counter-movement of liquid and plunger, which cools the latter, as hereinbefore explained. The liquid thus forced out through the valve 37 enters the vaporizer 23' to be converted into gas for use in the distributing system.

The expansion valve at 44 is simultaneously opened at the starting with valves 35 and 41; so that a portion of the liquid is led off through connection 43 and expanded by valve 44 and passed through the heat exchanger 45, where, because of its lower temperature, heat is extracted from the liquid passing through the conduit 33. The expanded gas material is withdrawn, continuously or intermittently as desired, by the turbine pump 48. Valve 44 is maintained open during the operation of the pump in order to effect continuously the subcooling of the liquid supplied to the pump through the conduit 33.

In Fig. 3, another modification is shown, in

which a storage container 50 has an insulating jacket 50' and a liquid withdrawal connection 51 leading to the inlet of a fore pump 52, which is preferably of the turbine type and has a rotary element for the pumping of the volatile liquid. While substantially any suitable turbine type pump may be employed at 52, the rotary pump disclosed in my copending application, Serial No. 345,308, filed July 13, 1940, is advantageous. The rotary pump has a discharge connection 53 leading to an inlet valve 54 of a second-stage pump which is here shown as a vertical type plunger pump having a pump cylinder 56. The vertically arranged cylinder not only permits the liquid withdrawal valve 57 to be at a higher elevation than the inlet valve whereby a highly positive action for withdrawing the gas from the clearance space within the pump cylinder is achieved, but also permits liquid remaining in the pump to be out of contact with the packing employed, since the inlet or cold end of the pump is lowermost.

An outlet conduit 58 leads from the valve 57 to a liquid receiver comprising vaporizer 23' that supplies an associated gas distributing system. A priming connection 60 leading from the gas space of container 50 has branches 60' and 60'' leading respectively to the outlet connections of the first- and second-stage pumps. Branch 60'' is controlled by a valve 39 while branch 60' is controlled by a valve 59.

The pump cylinder 56 is here shown as mounted in a supporting frame or casing 61 that retains an insulating envelope about the pump; the pump cylinder 56 having working therein a plunger 62 and a packing sleeve 63 through which the plunger protrudes. Here the plunger 62 is coupled mechanically at its outer end to means supplying power for reciprocatingly driving the same. The coupling employed preferably involves substantially a minimum of lubricated parts. To this end, a so-called "Watt linkage" is indicated and shown generally at 70. Such linkage comprises a floating link 71 that has its midpoint pinned or otherwise articulated to the upper end of plunger 62. This floating link has one end pivotally attached to one end of a second link 72 that has its other end pivotally attached to a stationary part 64 of casing 61. To the other end of floating link 71 there is pivotally attached a walking beam 73 that is fulcrumed to another stationary part 65 of casing 61. The beam 73 has an arm 73' extending beyond the casing 61 and has pivotally attached thereto a connected rod 74 that is coupled to a crank 75 on a shaft 76 that is provided with a driving wheel or pulley 77. This latter is advantageously connected to be driven from an electric motor 78 through a belt-drive 79.

While the pump cylinder here employed may be a single element, such as a casting, it is advantageously made of separate elements. An arrangement of this character particularly adapted for vertical working, as shown in Fig. 3, is illustrated on an enlarged scale in Fig. 4.

In the arrangement of Fig. 4, 80 denotes a cylindrical element which is adapted to provide the working portion of the pump chamber. The cylinder 80 has attached at its top a second element 81 which closes the upper end of the pump chamber and has attached at its top a third element 82 comprising a hollow sleeve for the packing for the plunger 62. The elements 80 and 81 are here shown as secured together by threaded joints.

The pump chamber thus provided is here closed by means of a block-like element 84 attached at the lower end and serving as a head for the cylinder 80. This block is counterbored and channeled to connect with a liquid supply conduit, such as shown at 53, the channel in the block being formed with an offset portion that has a valve seat at its junction with the initial portion. A gravity seating valve element 85 is arranged to fit on such seat and open under the impact of incoming liquid. The offset portion of the channel leads to the space in the counterbored portion of block 84 which is under the plunger 62 when in its lowermost position.

The clearance space between the plunger and inner wall of cylinder 80 leads upwardly to an outlet connection 86 at the upper end of the pump chamber. The connection 86 leads into a casing element which has therein a valve seat controlled by a valve 87. The pump outlet connection 88 leads from the casing element to a liquid receiving device at 23''. A gland follower 89 closes the upper end of the packing sleeve and is adapted to hold packing rings, as shown at 89, in place.

In operation, this form of the invention accomplishes the subcooling effect by means of the first-stage or fore pump 52 which requires but a relatively small head of pressure on the liquid to start it. Starting is, of course, effected by opening the priming valve 59. When primed the valve 59 is closed, by which time liquid is being delivered to the inlet of the second-stage pump under a substantial head of pressure, for example, 50 to 70 p. s. i. gauge.

The second-stage pump is set operating by starting motor 78. To prime the pump at 56, the valve at 39 is opened. It is seen that when plunger 62 is moved upwardly a suction stroke is executed and liquid under the head of pressure supplied by the pump 52 flows through conduit 53 into the pump chamber and into the clearance space between the plunger 62 and the wall of the cylinder. When the pump is primed, the valve 39 is closed so that a downward movement of plunger 62 forces liquid to flow out through the conduit 58. The discharged liquid from this plunger pump is at a relatively high head of pressure, for example, 2000 p. s. i. gauge.

The driving connections for reciprocating the plungers of pumps in accordance with the invention make use of substantially a minimum of lubricated parts. To this end, antifriction bearings are employed where working parts engage. Such a bearing is preferably inserted between the crank-pin 15 and the sides of the slot in cross-head 14. While ball bearings, and other types of antifriction bearings, may be employed here, a so-called needle bearing is preferred by reason of the negligible amount of lubricant required by it while being kept in proper working order. Such needle bearing is shown on enlarged scale in Figs. 5 and 6.

In Figs. 5 and 6, a needle bearing is shown on crank-pin 15. This bearing may have any convenient form, that shown comprising an annular channel or cage element 90 arranged to have its bottom fit over the pin 15. Such bearings are advantageous by reason of their relatively small size for a given load capacity. The channel has upset sides 91 which engage with the conical ends of a plurality of relatively small needle-like roller members 92. The surfaces of these needles provide rolling surfaces that engage with the sides of the slot in cross-head 14. Substantially no

lubrication for such bearing, other than that introduced in the factory assembly, is required.

Certain other features of the cylinder construction not specifically involved in the subject matter claimed herein are disclosed and claimed in my copending application, Serial No. 340,849, filed June 15, 1940.

Since certain changes in carrying out the above method and in the constructions set forth, which embody the invention, may be made without departing from its scope, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

Having described my invention, what I claim as new and desire to secure by Letters Patent is:

1. The method of pumping a volatile liquid having a boiling point temperature not higher than 233° K. at atmospheric pressure against a relatively high head of pressure, which comprises bringing the liquid to be pumped into a state having a temperature which is below its equilibrium boiling point temperature corresponding to its pressure, introducing the liquid in said state at the suction end of a plunger pump in which an appreciable clearance space is provided between plunger and pump chamber wall, and displacing the introduced liquid from the pump by counter-movement of liquid and plunger, whereby the liquid during the whole of said displacing step moves past the end of said plunger to cool the same.

2. The method of pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, which comprises bringing the liquid to be pumped into a state having a temperature which is below its equilibrium boiling point temperature corresponding to its pressure, introducing the liquid in said state at the suction end of a plunger pump in which an appreciable clearance space is provided between plunger and pump chamber wall, displacing the introduced liquid from the pump by counter-movement of liquid and plunger, and proportioning the rate of displacement and size of said clearance space in a manner such as to cool the pump plunger when displacing liquid to a temperature such that incoming liquid is not flashed into vapor.

3. The method of pumping a volatile liquid having a boiling point temperature not higher than 233° K. at atmospheric pressure against a relatively high head of pressure, which comprises providing a liquid supply in a container arranged to give an initial pressure head less than said high head to which the liquid is intended to be pumped but equivalent to an appreciable degree of subcooling, supplying said subcooled liquid at the suction end of a reciprocating pump chamber which has a plunger spaced from the side walls of the chamber to provide an appreciable clearance space, priming said pump by venting to said container and displacing said liquid when introduced from said chamber by counter-movement of liquid and plunger.

4. The method of pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, which comprises building an initial pressure head less than said high head in the liquid intended to be pumped to a value equivalent to an appreciable degree of subcooling, introducing said subcooled liquid at the suction end of a reciprocating pump

chamber which has a plunger spaced from the side walls of the chamber to provide an appreciable clearance space, displacing said introduced liquid from said chamber by the counter-movement of liquid and plunger, and proportioning the rate of displacement to the size of the clearance space so that the counter moving liquid cools said plunger to a temperature which avoids flashing the next introduced liquid into vapor.

5. The method of pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, which comprises initially elevating the pressure of the liquid supplied in a first-stage pump to a value for a state whose temperature is below its equilibrium boiling point temperature corresponding to its pressure, introducing said liquid at said elevated pressure at the suction end of a second-stage plunger pump in which an appreciable clearance space is provided between plunger and pump chamber wall, displacing said introduced liquid from said chamber by counter-movement of liquid and plunger, and proportioning the rate of displacement to the size of the clearance space so that the counter moving liquid cools said plunger to a temperature which avoids flashing the next introduced liquid into vapor.

6. Apparatus for pumping a volatile liquid having a boiling point temperature not higher than 233° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a source supplying such liquid, of means communicating with said source and providing an initial head of pressure equivalent to an appreciable degree of subcooling, a pump having a cylinder with its suction end in communication with said pressure providing means, a plunger working in said cylinder arranged to clear the inner wall of said cylinder and provide an appreciable clearance space therein, a discharge connection communicating with said clearance space at a point remote from said suction end and adjacent the end of the suction stroke, and means for actuating said plunger.

7. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a source supplying such liquid, of means communicating with said source and providing an initial head of pressure equivalent to an appreciable degree of subcooling, a pump having a cylinder with its suction end in communication with said pressure providing means, a plunger working in said cylinder arranged to clear the inner wall of the cylinder and provide an appreciable clearance space therein, a discharge connection communicating with said clearance space at a point remote from said suction end, and means for actuating said plunger and imparting straight-line reciprocating motion thereto; said last-named means being arranged to operate at a rate proportioned both to the size of the plunger and to the size of said clearance space in a manner such that the counter-movement of the liquid through said clearance space cools said plunger when displacing liquid to a temperature not substantially greater than that of the incoming liquid.

8. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a source supplying

such liquid, of means communicating with said source and providing an initial head of pressure equivalent to an appreciable degree of subcooling, a pump having a cylinder with its suction end in communication with said pressure providing means, a plunger working in said cylinder arranged to clear the inner wall of the cylinder and provide an appreciable clearance space therein, a discharge connection communicating with said clearance space at a point remote from said suction end, and means for actuating said plunger and imparting straight-line reciprocating motion thereto; said last-named means being constructed of articulated elements having antifriction bearings that require relatively little lubrication interposed between engaging parts.

9. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a source supplying such liquid, of means communicating with said source and providing an initial head of pressure equivalent to an appreciable degree of subcooling, a pump having a cylinder with its suction end in communication with said pressure providing means, a plunger working in said cylinder arranged to clear the inner wall of the cylinder and provide an appreciable clearance space therein, a discharge connection communicating with said clearance space at a point remote from said suction end, and means for actuating said plunger and imparting straight-line reciprocating motion thereto; said last-named means being a Watt linkage and comprising a floating link attached to said plunger, a supporting link for said floating link, a walking beam attached to said floating link and power applying means coupled to said walking beam.

10. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a source supplying such liquid, of a first-stage rotary pump communicating with said source and arranged to discharge liquid with a head of pressure equivalent to a desired degree of subcooling, a second-stage pump having a cylinder and a valve controlled inlet at its suction end connected to receive the subcooled discharge from said first-stage pump, a plunger working in said cylinder and arranged to clear the inner wall of said cylinder and provide an appreciable clearance space therein, a valve controlled discharge connection leading from said clearance space at an elevated point which is remote from said suction end, and means for actuating said plunger and imparting straight-line reciprocating motion thereto.

11. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a source supplying such liquid, of a first-stage rotary pump communicating with said source and arranged to discharge liquid with a head of pressure equivalent to a desired degree of subcooling, a second-stage pump having a cylinder and a valve controlled inlet at its suction end connected to receive the subcooled discharge from said first-stage pump, a plunger working in said cylinder and arranged to clear the inner wall of said cylinder and provide an appreciable clearance space therein, a

valve controlled discharge connection leading from said clearance space at an elevated point which is remote from said suction end, and means for actuating said plunger and imparting straight-line reciprocating motion thereto; said clearance space, the size of the plunger and the rate of actuation being respectively proportioned in a manner such that the counter-movement of liquid and plunger operates to cool the latter to a temperature not substantially greater than that of the subcooled liquid.

12. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a source supplying such liquid, of a first-stage rotary pump communicating with said source and arranged to discharge liquid with a head of pressure equivalent to a desired degree of subcooling, a vertically mounted second-stage pump having a cylinder provided with a valve controlled inlet at its lower end which is connected to receive the subcooled discharge from said first-stage pump, a plunger working in said cylinder and arranged to clear the inner wall of said cylinder and provide an appreciable clearance space therein, a valve controlled discharge connection leading from the upper end of said clearance space, and means for actuating said plunger including a Watt linkage whereby a straight-line reciprocating motion is imparted to said plunger.

13. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a container for supplying such liquid, of a first-stage pump disposed below said container a distance providing a desired head of pressure and arranged to discharge liquid at an elevated pressure providing a desired degree of subcooling, a second-stage reciprocating pump connected to receive the discharge from said first-stage pump, priming connections for said pumps, each having control valves and leading from the outlets of said pumps respectively to the gas space in said container, and a liquid receiving device connected to receive the discharge from said reciprocating pump at a relatively high pressure.

14. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a container for supplying such liquid, of a first-stage pump disposed below said container a distance providing a desired head of pressure and arranged to withdraw liquid from a point relatively close to the bottom of said container, a second-stage reciprocating pump connected to receive the discharge from said first-stage pump, priming connections for each of said pumps, each having a control valve and each leading from the outlets of said pumps relatively to a common gas space in said container, a receiving system including a liquid vaporizer, and a conduit leading from the outlet of said second-stage pump to said system and provided with a check valve.

15. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a container for supplying such liquid, of a first-stage turbine pump disposed below said container a distance providing a desired

head of pressure and arranged to withdraw from a point relatively close to the bottom of said container, a second-stage reciprocating pump connected to receive the discharge from said first-stage turbine pump, a receiving system including a liquid vaporizer, a conduit leading from the outlet of said second-stage pump and provided with a check valve, and priming connections for each of said pumps comprising valved conduits communicating respectively with the outlets of said first-stage pump and said second-stage pump and leading from a common portion to the gas space of said container.

16. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a heat insulated container for holding a supply of such liquid, of a vertically arranged reciprocating pump having its cold end lowermost and connected to withdraw liquid from a point close to the bottom of said container, and provided with a plunger arranged to displace the withdrawn liquid by the counter-movement of liquid and plunger, said pump and container being relatively arranged to provide a desired initial head of pressure, an outlet connection leading from said pump to a place of use, and a valved priming connection associated with said outlet and communicating with the gas space of said container.

17. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a heat insulated container for holding a supply of such liquid, of a first-stage

pump communicating with said container at a point relatively close to the bottom of the same, a vertically arranged reciprocating second-stage pump having its inlet connected to the discharge of said first-stage pump and disposed with its cold end lowermost and provided with a plunger arranged to displace the withdrawn liquid by the counter-movement of liquid and plunger, an outlet connection leading from said second-stage pump to a consuming system, and priming connections for each of said pumps, each having a control valve and leading to the gas space of said container from the outlet connections of each of said pumps.

18. Apparatus for pumping a volatile liquid having a boiling point temperature materially less than 273° K. at atmospheric pressure against a relatively high head of pressure, comprising the combination with a container for supplying such liquid, of a first-stage rotary pump disposed below and communicating with said container in a manner adapted to withdraw liquid from a point relatively close to the bottom thereof and with a desired degree of subcooling, a second-stage reciprocating pump having an inlet connection sufficiently short to avoid substantial heat leakage and of sufficient diameter to avoid a substantial pressure drop connected to receive the discharge from said first-stage rotary pump, priming connections leading from the outlets of each of said pumps to the gas space of said container, a liquid receiving and vaporizing device connected to the discharge of said reciprocating pump, and a cylinder filling device connected to receive the material in the gas phase discharged from said vaporizing device.

ODD A. HANSEN.