Oct. 23, 1962 J. J. LOPORTO 3,059,440

FLUID TRANSFER ARRANGEMENT

Filed Jan. 19, 1960 2 Sheets-Sheet 1

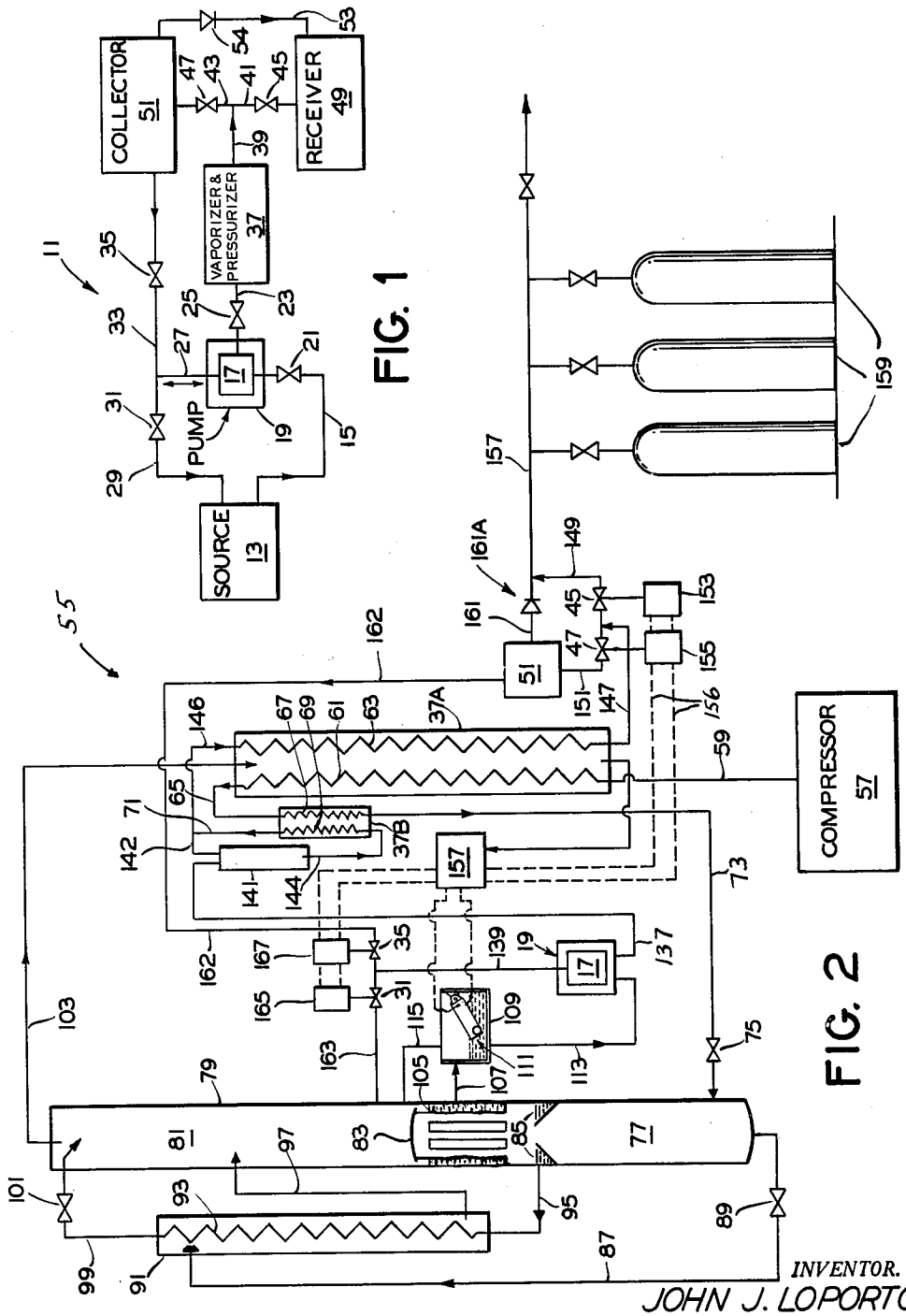


FIG. 1

FIG. 2

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FIG. 4

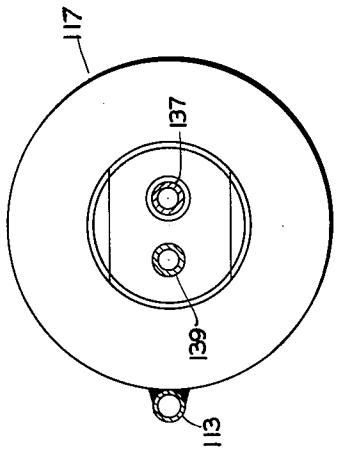


FIG. 5

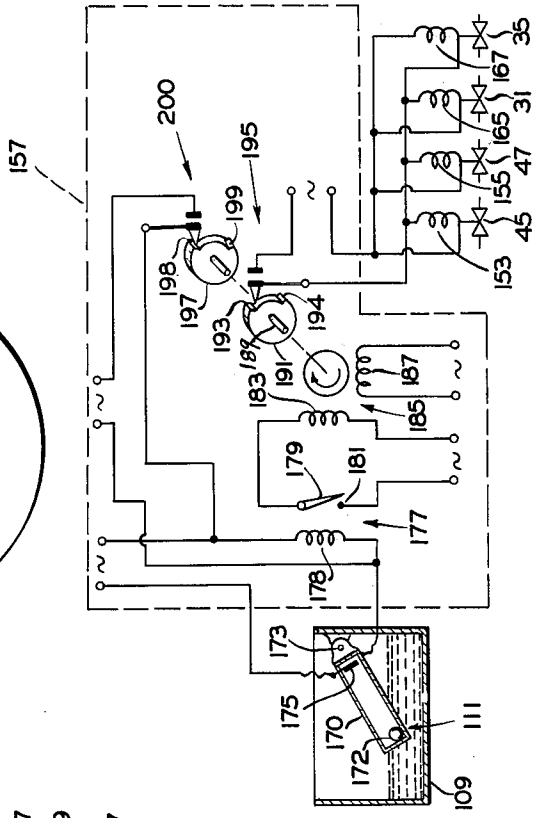
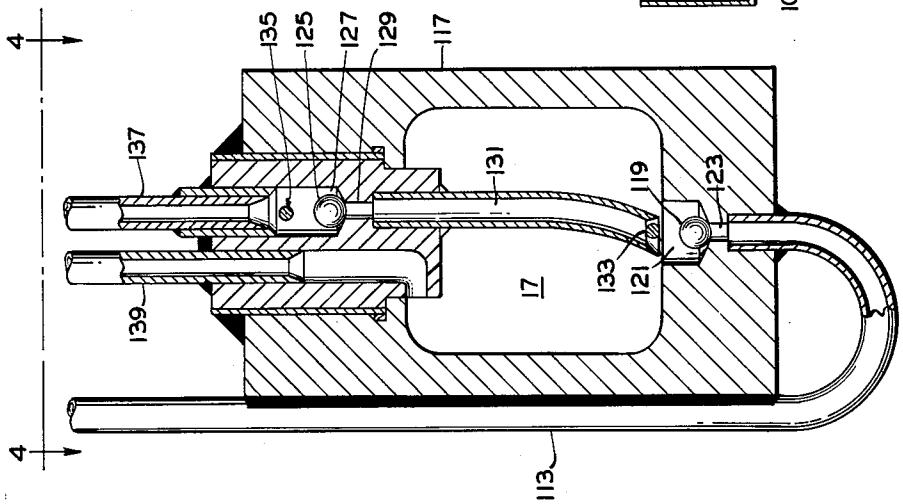


FIG. 3



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3,059,440

FLUID TRANSFER ARRANGEMENT

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Filed Jan. 19, 1960, Ser. No. 3,298
16 Claims. (Cl. 62—41)

This invention relates to the tranfer of fluids between regions of substantially different pressure and more particularly to methods and apparatus for transferring a fluid in the liquid phase and under relatively low pressure to a region which receives the fluid in gaseous phase and under relatively high pressures.

There is a great demand in present day industrial and non-industrial applications for gaseous forms of volatile cryogenic liquids as for example liquid oxygen, liquid nitrogen and various liquified petroleum components. The foregoing generally are available in gaseous form but are mixed with undesirable constituents which must be separated therefrom. In the process of separation, the desired gases as a rule, are liquified and are obtainable as such under a relatively low pressure. Consequently, in order to utilize the liquids they must be vaporized to relatively high pressure gaseous form. In one approach to this problem, the volatile liquid is vaporized at low pressure and the gas is compressed to the desired high pressure. This, however, is not entirely satisfactory because of serious compression problems such as contamination of the gas by reason of the lubricants used in the gas compressor, and in the case of liquid oxygen, explosion hazards are present. A second approach is to pump the volatile liquid in the liquid phase to the desired high pressure and then convert the high pressure liquid to gaseous form by suitable vaporization means. Again, as in the first approach, pumping the volatile liquid to the desired pressure requires the use of a mechanical device which involves the use of pistons along with the necessary packing. In addition, problems of vapor lock resulting in pump stoppages also exist. Experience has shown that liquid plunger pumps for cryogenic fluids are generally unsatisfactory as in the case of any mechanical means of transfer of a cryogenic fluid when the fluid is under pressure and is to be displaced by pistons.

It is an object of the present invention to provide novel methods and apparatus for transferring a fluid in the liquid phase and under relatively low pressure to a region which receives the fluid in gaseous phase and under relatively high pressures.

The present invention therefore contemplates novel methods and apparatus for obtaining high pressure gases from volatile cryogenic liquids. In accordance with the present invention, a volatile cryogenic liquid under relatively low pressure in a liquid source is conducted to a pump in a pumping zone whence the liquid is delivered by the pump to a vaporizing and pressurizing zone in which the liquid is changed to gaseous form under relatively high pressures. The gas in one period of operation is conducted from the vaporizing and pressurizing zone to a receiving zone for use, and in a second period of operation, the flow of gas is diverted away from the receiving zone and conducted to a collection zone. The gas in the collection zone then is utilized in said one period of operation to force the liquid from the pumping zone to the vaporizing and pressurizing zone. A novel pump is employed in the pumping zone which involves no pistons or plungers or packing and the pump is operated solely by the gas from the collection zone. Basically, the pump comprises a chamber for receiving the liquid from the liquid source, and the medium for forcing the liquid from the chamber is the gas from the collection zone which is impressed upon the surface of the liquid in the chamber.

For a better understanding of the present invention reference is made to a consideration of the following description when taken in connection with the following drawings in which:

FIG. 1 is a diagrammatic illustration of a system which embodies the novel concept of the present invention;

FIG. 2 is a diagrammatic illustration of an air separation plant and discloses one possible application of the subject invention;

FIG. 3 is an elevational view, in section, of a novel pump employed in the system of FIG. 2;

FIG. 4 is a plan view of the pump of FIG. 3; and

FIG. 5 is a schematic of a control system for operating certain valves of FIGS. 1 and 2.

Referring now to the drawings and more particularly to FIG. 1 thereof, the reference character 11 generally designates a fluid transfer system in accordance with the present invention which comprises a liquid source 13 having a volatile cryogenic low pressure liquid as for example oxygen, nitrogen or petroleum components therein. The liquid is conducted through an inlet conduit or line 15 to a pump chamber 17 of a pump 19; the liquid in line 15 being controlled by a valve 21 in the line. Pump 19 has a liquid discharge line 23 connected thereto with a valve 25 in the line which communicates with chamber 17. A gas line or conduit 27 is connected at one end with the upper portion of chamber 17 and at its other end with a gas discharge line 29 having a valve 31 therein and a gas inlet line 33 having a valve 35. As will be explained more fully hereinafter, during one period of cycle operation of pump 19 gas at a substantially higher pressure than the liquid in chamber 17 is conducted into the chamber via lines 33 and 27 and is impressed upon the surface of the liquid in the chamber to force or pump same out through liquid discharge line 23. During a second period of cycle operation of pump 19 gas previously used to force the liquid out of chamber 17 is discharged via lines 27 and 29 from chamber 17 and conducted to source 13 to which line 29 is connected. Liquid from source 13 enters chamber 17 during the second period of pump operation.

Vaporizing and pressurizing apparatus 37 is connected to receive liquid from pump 19 by way of liquid discharge line 23 and the liquid in apparatus 37 is changed to the gaseous phase and in addition, the gas is raised to a relatively high pressure. A conduit or line 39 is connected to apparatus 37 to conduct the high pressure gas therefrom, and line 39 is connected to a pair of lines 41 and 43 which are provided with valves 45 and 47, respectively. A receiver device 49 is connected to receive the gas in line 41 and such gas may be stored in the receiver or be taken therefrom to a point of use. A reservoir or collection device 51 communicates with line 43 for receiving the gas therein and device 51 is also connected to gas inlet line 33 into which the gas from device 51 is discharged. A line 53 is provided between receiver 49 and collector 51 and a spring-biased relief valve 54 is in the line 53. The valve 54 is calibrated to maintain a predetermined pressure differential between receiver 49 and collector 51 with the pressure of gas in collector 51 greater than that in receiver 49. The differential pressure is used as the driving force to transfer the liquid from the pump 19 to the high pressure region in vaporizer and pressurizer 37. In the event the pressure differential exceeds the requisite value then the gas in excess flows through the collector 51 and line 53 into receiver 49.

Considering now the operation of the system described above, let it be assumed that the high pressure gas is flowing to receiver device 49 and is not flowing to collection device 51. Furthermore, let it be assumed that pump chamber 17 contains the low pressure liquid. Under this

condition of operation the following valves are closed: valve 21 in line 15, valve 31 in line 29 and valve 47 in line 43. At this time, the following valves are open: valve 25 in line 23, valve 35 in line 33 and valve 45 in line 41. With foregoing valve position, high pressure gas from collection device 51 flows through lines 33 and 27 and enters pump chamber 17 where the gas is impressed upon the surface of the liquid in the chamber. The gas being under a pressure considerably higher than the liquid, forces the latter out of the chamber 17 and through line 23 into vaporizing and pressurizing apparatus 37. The liquid in apparatus 37 is changed to a gas which attains a considerable pressure, whence the gas flows through lines 39 and 41 and into receiver 49. When all or a majority of the liquid is discharged from pump chamber 17 the pump 19 is set to commence its second period of cycle operation wherein the gas from vaporizing and pressurizing device 37 flows to collection device 51 rather than to receiver device 49. Under this second condition of operation the following valves are closed: valve 25 in line 23, valve 35 in line 33 and valve 45 in line 41. At this time, the following valves are open: valve 21 in line 15, valve 31 in line 29 and valve 47 in line 43. Accordingly, pump chamber 17 becomes depressurized in that the gas in the pump chamber used to force the liquid out of the latter now escapes through lines 27 and 29 and is conducted to source 13. It should be understood that it is not essential to the present invention that the gas return to source 13 but the same is done in the interests of efficiency from the cost standpoint. The gas in source 13 is readily changed to liquid which then is reusable. As the gas leaves the pump chamber, liquid from source 13 enters the latter by way of line 15. Since valve 25 in line 23 is closed at this time the liquid commences to fill up pump chamber 17. Although there is no liquid flowing to apparatus 37 from pump 19 under this condition of operation, the apparatus has sufficient volumetric capacity whereby it still is changing liquid to gas from prior cycles, and such high pressure gas flows through line 43 into collection device 51 where it is stored for use during the subsequent cycle of operation of pump 19. Thus, it will apparent that a continuous cycle is provided by the system of the present invention, wherein the high pressure gas produced from low pressure volatile liquid is used in one period of time to drive the liquid to gas forming and pressurizing apparatus 37, and during another period of time is fed to the receiving device 49 for use. It also should be understood that gas is conducted to collection device 51 for a sufficient time period to allow the necessary build-up of gas therein to provide a differential pressure between collection device 51 and receiving device 49, which is sufficient to drive the liquid from pump 19 when allowed to flow from it and through vaporizer and pressurizer apparatus 37 to receiving device 49.

FIG. 2 illustrates a specific application, among others, of the fluid transfer system 11 described hereinabove to an air separation plant 55 wherein it is desired to obtain substantially pure oxygen which has to be stored in gaseous phase under high pressure and at ambient temperatures. The parts in FIG. 2 which correspond to those in FIG. 1 are given the same reference characters in order to more easily correlate FIG. 1 to FIG. 2. Air separation plant 55 comprises a compressor 57 which compresses dry and clean air and delivers it by way of a conduit 59 to a heat exchanger 37A and thence to a second heat exchanger or evaporator 37B. Heat exchangers 37A and 37B comprise the vaporizing and pressurizing apparatus 37 of FIG. 1 and exchanger 37B serves to change the liquid to a gas while exchanger 37A serves to raise the pressure of the gas. The compressed air in conduit 59 flows through a tube bundle 61 in exchanger 37A and in heat exchange with cold oxygen gas flowing through a second tube bundle 63 in the exchanger 37A. The cold oxygen in bundle 63 absorbs heat from the warmer air in bundle 61 and the cool air then flows through a line 65 and into a tube bundle 67 in heat exchanger 37B. Exchanger 37B also has a tube bundle 69 through which liquid oxygen flows and which oxygen absorbs heat from the cool air in bundle 67 whereby the oxygen is vaporized and flows out of exchanger 37B through a line 71 and into bundle 63 of exchanger 37A.

The cold air in bundle 67 flows through a line 73 and into an expansion valve 75 in the line, whence it is conducted into a high pressure column 77 of a distillation vessel 79 which corresponds to source 13 in FIG. 1. Distillation vessel 79 is shown in diagrammatic form in FIG. 2 and includes an upper low pressure column 81 which is in fluid tight relationship with high pressure column 77. The high pressure column 77 is provided with vapor-liquid contact means (not shown) which may be in the form of packing, trays, etc. A part of the cold air entering column 77, containing most of the oxygen, liquifies and falls to the bottom of the column while the nitrogen in the air remains in gaseous form; it being known that oxygen has a lower liquification point than nitrogen. For the sake of convenience in description the liquid air shall be referred to as liquid oxygen hereinafter. The nitrogen gas flows upwardly through the vapor liquid contact means (not shown) and is condensed in a condenser 83 arranged between columns 77 and 81 in vessel 79. As will be explained more completely hereinafter, a pool of liquid oxygen is provided in condenser 83 and the gaseous nitrogen passes in indirect contact with the oxygen whereby it is liquified and collects in a pool 85. The liquid oxygen in the bottom of vessel 79 flows through a line 87 and an expansion valve 89 in the latter. Line 87 is connected to a heat exchanger 91 and the liquid oxygen flows into the shell of exchanger 91 and in indirect contact with liquid nitrogen in a tube bundle 93 in the exchanger. The liquid nitrogen in tube bundle 93 flows into the latter through a line 95 connected to the pool 85 of liquid nitrogen in high pressure column 77. The liquid oxygen in exchanger 91 gives up heat to the liquid nitrogen whereby the oxygen becomes partly vaporized and the liquid nitrogen is further subcooled. A conduit or line 97 is connected for conducting the partly vaporized oxygen into low pressure column 81 and a line 99 conducts the liquid nitrogen through an expansion valve 101 and into the upper portion of column 81. In column 81 the liquid nitrogen and oxygen vapor pass in direct contact with each other whereby oxygen vapor is condensed to liquid and the liquid nitrogen is vaporized. The nitrogen vapor leaves the column 81 through a line 103 while the liquid oxygen falls into a pool 105 in condensor 83 where as explained previously it condenses the nitrogen vapor or gas in high pressure column 77.

A conduit 107 is connected to vessel 79 at one end to receive liquid oxygen and at the other end to the housing 109 of a liquid level float control switch 111. The specific function of switch 111 will be described in detail hereinafter for clarity of explanation and it will be sufficient at this point to state that it effects the control of the pumping stroke of pump 19. A conduit 113 is connected to housing 109 of switch 111 for conducting the liquid oxygen to pump chamber 17 of pump 19. A second conduit 115 is connected between housing 109 and low pressure column 81 to evacuate the vapor possibly developing in housing 109 whereby the pressure in the latter and in column 81 are constantly equalized. Pump 19 is displosed physically below switch 111 a distance sufficient to effect flow of liquid oxygen into pump chamber 17 and to the required level therein. Pump 19 is shown in detail in FIGS. 3 and 4 and comprises a housing 117 which contains the hollow pump chamber 17. The valve 21 described in connection with FIG. 1 comprises a metal ball 119 which is accommodated within a recess 121 and covers an inlet 123 in communication with conduit 113. The discharge valve 23 of FIG. 1 comprises a metal ball 125 disposed in a recess 127 in the upper portion of pump housing 117. In the position shown in FIG. 3 ball

125 covers an outlet 129 which communicates with a tubular member 131 extending downwardly into chamber 17. The lower end of tubular member 131 is disposed adjacent recess 121 and is provided with a transverse pin 133, such lower end serving to prevent escape of ball 119 out of recess 121 and still permitting flow of liquid upwardly into the tubular member as will be described. A transverse pin 135 also is provided in recess 127 and serves to limit upward displacement of the ball 125 while permitting flow of liquid out of said recess. A discharge conduit 137 communicates with recess 127 and serves to conduct the liquid from the pump chamber. A third conduit 139 is connected to the upper portion of housing 117 and serves as the gas inlet and outlet line to introduce gas into chamber 17 and discharge gas therefrom, respectively.

It will be seen that when liquid oxygen flows through conduit 113, ball 119 is unseated and the oxygen enters pump chamber 17 and builds up to a level therein determined by means to be described. It is assumed at this time that no gas is entering the chamber through conduit 139. When the pumping stroke or operation of pump 19 is to commence, high pressure gas is introduced into the top of chamber 17 through conduit 139 and impressed on the surface of the liquid oxygen in the chamber. As a result, ball 119 is seated to close off inlet 123 and the liquid oxygen is forced upwardly into tubular member 131. Ball 125 is unseated by the upwardly flowing liquid oxygen, and the latter is dicharged from the housing through outlet 129 and conduit 137. The high pressure gas used to drive out the liquid oxygen is allowed to escape through conduit 139 and during the filling or suction portion of pump cycle operation, the liquid oxygen being under a head of liquid in conduit 113, commences to flow again into pump chamber 17.

The liquid oxygen from pump 19 is conducted by discharge conduit 137 to a vapor liquid separator 141 (FIG. 2) which serves to separate any gaseous oxygen possibly in the liquid oxygen. Separator 141 is merely an empty cylindrical vessel wherein the gas separates from the liquid and leaves the top of the vessel through a conduit 142 and the liquid oxygen falls to the bottom where it is discharged through a conduit 144. Conduit 144 is connected to tube bundle 69 of heat exchanger 37B mentioned previously and the vaporized oxygen flows from the exchanger 37B through a conduit 71 which joins with conduit 142 from separator 141. Conduits 142 and 71 join with a conduit 146 which is connected to tube bundle 63 in heat exchanger 37A. The oxygen flowing through tube bundle 63 is further expanded and inasmuch as the volumetric dimension thereof is fixed the pressure of the oxygen builds up to a relatively high value. If desired, conduit 103 may be connected to discharge the cool nitrogen vapor from distillation vessel 79 into heat exchanger 37A to further aid in cooling the incoming air in tube bundle 61.

A conduit 147 is connected to tube bundle 63 and receives the high pressure oxygen gas for flow therethrough. Conduit 147 has connected thereto branch conduits 149 and 151 which contain the valves 45 and 47, respectively, mentioned in connection with FIG. 1. Valves 45 and 47 are solenoid spring-operated valves for example, and are actuated by solenoids 153 and 155, respectively. The solenoids are energized and connected by electrical lines 156 (FIG. 2) from a control apparatus 157, shown as a box in FIG. 2 and in greater detail in FIG. 5. Solenoids 153 and 155 are so constructed in their spring means that when they are deenergized valve 47 will be open while the valve 45 will be closed. When both solenoids 153 and 155 are energized the valve 47 now closes and the valve 45 opens. If it is assumed that the solenoids are energized and valve 45 is open then the gaseous oxygen flows through branch conduit 149 and not through branch conduit 151 because valve 47 is closed. It will be noted that valve 45 opens only during discharge of liquid oxygen from pump 19. Conduit 149 is connected to a line 157 which in turn serves as a manifold for supplying the oxygen to receiver device 49 which in FIG. 2 takes the form of storage receptacles or tanks 159 under high pressure. It will be understood that the oxygen in line 157 need not be sent to receptacles 159 but may be used directly off line 157 in process operations not disclosed. If it is now assumed that the solenoids are deenergized and valve 45 is closed and valve 47 is open, the oxygen in line 147 flows through branch conduit 151 which is connected to its collection or reservoir vessel 51. As will be explained later, the flow of oxygen into vessel 51 is continued until a predetermined pressure of gas is achieved. A release conduit 161 is connected to vessel 51 and conduit 157 and is provided with a spring-biased release valve 161A which is set to release oxygen from vessel 51 into conduit 157 in the event the desired pressure differential is exceeded beyond that necessary to satisfy the driving force required to force the liquid oxygen from pump 19 and through the heat exchanger 37A and 37B.

A discharge conduit 162 is connected to vessel 51 and is provided with valve 35 (FIGS. 1 and 2). Conduit 162 joins with gas conduit 139 from pump 19 and with a second conduit 163 which also communicates with low pressure column 81 of distillation vessel 79. Conduit 163 has provided therein valve 31 (FIGS. 1 and 2). Valves 31 and 35 are solenoid operated valves for example, and are actuated by solenoids 165 and 167 respectively. The solenoids are energized from control apparatus 157 to control the flow of gas in their respective conduits. As in the case of solenoids 153 and 155 when both solenoids are deenergized valve 31 will be open and the valve 35 closed and upon energization of the solenoids valve 31 will be closed while the valve 35 is open. If it is assumed that solenoids 165 and 167 are energized and valve 35 is open and valve 31 is closed, in such event, oxygen from vessel 51 flows into line 139 and pump 19 for the pumping stroke. If, on the other hand, solenoids 165 and 167 are deenergized valve 31 is open while valve 35 is closed and the oxygen gas in pump chamber 17 is allowed to escape therefrom through line 139 and through conduit 163 into low pressure column 81.

FIGURE 5 discloses in detail the schematic of control apparatus 157 as employed in connection with control switch 111. It is to be expressly understood that the control apparatus 157 shown in FIG. 5 is merely illustrative of one form of control for use with the present invention, and that many other controls may be employed which accomplish the function of such control 157. As indicated previously, switch 111 is liquid level float control and in FIG. 5 is shown more completely as including a light-weight metal cylinder 170 in housing 109 and which contains a metal ball 172 free to move within the cylinder, the latter being pivotal about a fixed pin or point 173. It will be understood that when the liquid oxygen level in housing 109 reaches a predetermined level, the cylinder 170 has pivoted about point 173 to assume an above horizontal position whereby ball 172 contacts an electrode 175. In the present arrangement when the liquid oxygen reaches the predetermined level, pump chamber 17 contains a sufficient amount of liquid to be pumped to liquid-vapor separator 141. Electrode 175 and cylinder 170 comprise part of circuit which includes a relay 177 having an energizing winding 178 and a movable armature or arm 179 engageable with a contact 181. Arm 179 and contact 181 are connected in circuit with a winding 183 of a fixed speed two-phase motor 185 which also includes a constantly energized winding 187. Secured on a shaft 189 of motor 185 is a cam wheel 191 which has a contoured surface adapted to close a switch 195 in circuit with parallel connected solenoids 153, 155, 165 and 167, the contoured surface having a leading edge 193 and a trailing edge 194. Also secured to shaft 189 is a second cam wheel 197 which has a contoured

surface formed thereon adapted to close a switch **200** connected across energizing winding **178** of relay **177**, the contoured surface having a leading edge **198** and a trailing edge **199**. Shaft **189** and cam wheels **191** and **197** are rotated by motor **185** in a clockwise direction and the leading edge **198** of cam wheel **197** is slightly in advance of the trailing edge **194** of cam **191**. On the other hand, the leading edge **193** of cam **191** lags the trailing edge of surface **198** by about 5 degrees. Consequently, upon rotation of shaft **189** clockwise and closing of switch **195** by the leading edge **193** of cam **191** the contoured surface of wheel **197** is already in engagement with switch **200** so that the latter is closed. Upon opening of switch **195** by the trailing edge **194** of wheel **191** switch **200** still is closed. Continued rotation of shaft **189** so that switch **200** is opened by trailing edge **199** of wheel **197** also leaves switch **195** open for a short period of time until cam wheel **191** rotates approximately the 5 degrees to bring the leading edge **193** of cam wheel **191** into engagement with the contacts of switch **195**, whereby the latter closes.

Considering now the operation of control apparatus **157** in conjunction with level switch **111**, when cylinder **170** passes through the horizontal position ball **172** contacts electrode **175** to complete the circuit so that winding **178** of relay **177** is energized. Armature **179** engages contact **181** to connect winding **183** with the source of alternating current shown, and thereby rotates cam wheels **191** and **197**. Switch **195** is closed by the leading edge **193** of cam **191** and thus solenoids **153, 155, 165** and **167** are energized. Continued rotation of motor **185** brings the trailing edge **194** of cam wheel **191** to the contacts of switch **195** to open same and deenergize the solenoids. However, before switch **195** opens switch **200** has been closed and remains as such because of the longer contoured surface of cam wheel **197**. It will be noted that upon closing of switch **200** a holding voltage is impressed across winding **178** of relay **177** so that arm **179** is maintained in engagement with contact **181** to maintain the motor **185** in operation. As the trailing edge **199** of wheel **197** passes the contacts of switch **200** the latter is opened whereby the holding voltage to coil **178** is discontinued. Motor **185** now stops and the cycle is completed whereby it does not commence operation again until the cylinder **170** again passes through the horizontal position. Thus, the contoured surface of cam wheel **197** maintains the switch **200** closed through the period of time that switch **195** is closed and for a period thereafter.

In the operation of the system of FIG. 2 let it be assumed that the pumping stroke of pump **19** is just about to commence. Further let it be assumed that with deenergization of solenoids **153, 155, 163** and **167** valves **45** and **35** are closed while valves **31** and **47** are opened. Conversely, upon energization of the solenoids valves **45** and **35** open while valves **31** and **47** close. Under the above assumed condition, pump chamber **17** has just filled with liquid and float cylinder **170** of switch **111** has passed through a horizontal position whereby ball **172** contacts electrode **175** to effect operation of motor **185**. Cam wheel **191** rotates to close switch **195** and solenoids **153, 155, 163** and **167** are energized. Accordingly, valves **45** and **35** open and valves **31** and **47** close. In such event, high pressure gaseous oxygen flows through line **162** and valve **35** from reservoir vessel **51** and such gas flows through gas conduit **139** to be impressed upon the surface of liquid oxygen in pump chamber **17**. The liquid oxygen thus is forced out of chamber **17** and through heat exchangers **37B** and **37A** in the form of gas as described previously. The gaseous oxygen leaves heat exchanger **37A** through conduit **147** and thence through valve **45** and line **149** to storage bottles **159**. Upon completion of the pumping stroke of pump **19** as determined by cam surface **193**, switch **195** opens and solenoids **153, 155, 163** and **167** are deenergized so that valves **35** and **45** close and valves **31** and **47** open. At this time, the oxygen gas used to force the liquid from pump **19** during the pumping stroke is allowed to escape from the chamber through gas conduit **139** and conduit **163** to the low pressure column **81**. Since valve **47** also is open and valve **45** is closed gaseous oxygen flows from heat exchanger **37A** and through conduits **147** and **151** to reservoir vessel **51**, but no further because valve **35** is now closed. As the gas leaving pump chamber **17** through conduit **139** reduces the pressure in the chamber to a valve below that which corresponds to the head of liquid oxygen in conduit **113**, liquid oxygen commences to enter the chamber whereby the suction stroke of pump **19** commences. It will be understood that during the suction stroke vaporization of the gas in collector vessel **51** continues until the pressure of the gas therein exceeds the differential pressure between vessel **51** and tanks **159**, necessary to provide the requisite driving force to discharge the liquid oxygen from pump chamber **17** during the pumping stroke. This excess pressure overcomes the spring force of valve **161A** whereby a certain amount of gas will flow to tanks **159** from vessel **51**; the spring of valve **161A** serving to close off conduit **161** in the event the pressure in vessel **51** tends to go below that necessary to maintain the required pressure differential.

As pump chamber **17** fills with liquid oxygen, housing **109** of switch **111** does not completely empty because liquid oxygen still is flowing into housing **109** from low pressure column **81**. The filling of pump chamber **17** takes less time than the filling of housing **109** so that a certain period of time, though short, elapses between the filling of chamber **17** and the restoration of the predetermined level of liquid in housing **109** necessary to bring cylinder **170** to the above horizontal position.

In practice, the cylinder **170** may be brought to an above horizontal position prematurely during depressurization of pump chamber **17** which may produce surges in liquid in housing **109** of switch **111**. Such premature closing of switch **111** would initiate a pumping stroke on the pump **19** when perhaps the chamber **17** is not filled with liquid. To overcome such condition and prevent spurious signals effecting untimely operation of pump **19** control apparatus **157** blocks the same to solenoids **153, 155, 163** and **165**. This is accomplished by control apparatus **157** in that the contoured surface of cam wheel **191** is dimensioned to correspond with the pumping cycle and the solenoids are not again energized until cam wheel **191** has again presented the leading edge **193** to switch **195**. Thus, between the time the trailing edge **194** of wheel **191** disengages switch **195** and the leading edge **193** of the surface engages the switch **195**, no energization of the solenoids can be obtained regardless of whether cylinder **170** passes through the horizontal position one or more times. The advantage of providing a lag between the trailing edge **199** of wheel **198** and the leading edge **193** of wheel **191** is to allow level switch **111** to produce energization of the solenoids to effect initiation of the pump stroke when the conditions therefor are satisfied and to prevent operation of motor **185** in the event flow of liquid oxygen from low pressure column **81** should cease for any reason. With the cam wheels **191** and **197** in positions wherein neither cam surface contacts its associated switch, motor **185** stops and the cycle is completed whereby liquid oxygen has filled pump chamber **17** and switch housing **109** to the predetermined level. It should be understood that in the depressurization period the liquid oxygen may find its way into gas conduit **139** from pump chamber **17**, and therefore, upon the pump stroke the oxygen gas may be impressed upon the liquid in such conduit rather than on the surface of the liquid in the chamber. Accordingly, where in the claims the recitation is made that the surface of the liquid in the pump

chamber has impressed thereon the pressure of the gas it shall be considered to cover those instances when the gas is impressed upon the liquid in conduit **139**.

It will be apparent from the foregoing that the present invention provides novel methods and apparatus for transferring a cryogenic fluid in the liquid phase and under relatively low pressure to a region which receives the fluid in gaseous phase and under relatively high pressure. By utilizing the gaseous fluid under high pressure to pump the liquid fluid from a low pressure region to a high pressure region in gaseous state a highly effective system is provided. Furthermore, the subject invention permits the use of a pump without plungers, pistons or packing and provides for ready application to a number of systems, one of which is an air separation plant. In addition, a constant liquid level is automatically maintained in the low pressure column **81** inasmuch as the time needed to fill pump chamber **17** and raise the cylinder **170** to a horizontal position will depend on the production rate of the plant.

As indicated hereinbefore the control apparatus **157** is disclosed herein for purposes of illustrating one example of means for operating the solenoid valves in the desired sequential manner explained. Various combinations of electrical relays including time delay relays can be used to accomplish the function of the motor controlled cams and switches whereby the latter mentioned components may be dispensed with. In addition, the solenoid actuated valves could easily be replaced by pneumatic operated valves and the liquid level switch may be of the pneumatic type rather than electrical as shown. In the claims, the means covering the control means and valve means should be given maximum construction and scope in view of the great number of equivalents suitable for accomplishing the functions thereof.

Although one embodiment of the present invention has been illustrated and described in detail, it is to be expressly understood that the invention is not limited thereto. Various changes can be made in the design and arrangement of the parts and in the steps of the methods without departing from the spirit and scope of the invention as the same will now be understood by those skilled in the art.

What is claimed is:

1. A method of transferring a fluid in the liquid phase from a low pressure region to a high pressure region where the phase of such liquid is gaseous during a cycle consisting of a suction period and a pumping period, the steps comprising, passing an amount of liquid from a low pressure region to a pumping zone during the suction period, flowing the low pressure liquid in the pumping zone during the pumping period to a vaporizing and pressurizing zone where the liquid is changed to a high pressure gas, passing the gas during the pumping period to a receiving zone for use, diverting the gas away from the receiving zone to a collection zone during the suction period, and impressing said diverted gas from the collection zone during said pumping period onto the surface of the liquid in the pumping zone to force said liquid out of the pumping zone.

2. The method of claim 1 wherein during the suction period the impressed gas in the pumping zone is discharged form the latter to enable entry of the low pressure liquid into the pumping zone.

3. A method of transferring a fluid in the liquid phase from a low pressure region to a high pressure region where the phase of such liquid is gaseous during the cycle consisting of a suction period and a pumping period, the steps comprising, passing an amount of liquid from a low pressure region to a pumping zone during the suction period, conducting liquid from the pumping zone during the pumping period to a vaporizing and pressurizing zone where the liquid is changed to a high pressure gas, discharging the gas from the vaporizing and pressurizing zone during both pumping and suction periods, passing the discharged gas during the pumping period to a receiving zone for use, passing the discharged gas to a collection zone during the suction period and allowing said gas to build up to a pressure greater than that in the receiving zone, and impressing the gas from the collection zone during the pumping onto the surface of the liquid in the pumping zone to force the liqiud from the latter and into the vaporizing and pressurizing zone.

4. The method of claim 3 wherein the impressed gas in the pumping zone during said pumping period is discharged into the low pressure region during said suction period.

5. A method of transferring a fluid in the liquid phase from a low pressure region to a high pressure region where the phase of such liquid is gaseous during a cycle consisting of a suction period and a pumping period, the steps comprising, passing an amount of liquid from a low pressure region to a pumping zone during the suction period, flowing the low pressure liquid in the pumping zone to a vaporizing zone where the liquid is changed to a high pressure gas, passing the gas from the vaporizing zone to a heating zone for heating the gas and further increasing the pressure thereof, passing the gas during the pumping period to a receiving zone for use, diverting the gas away from the receiving zone to a collection zone during the suction period, and impressing said diverted gas from the collection zone during said pumping period onto the surface of the liquid in the pumping zone to force said liquid out of the pumping zone.

6. A method of transferring a fluid in the liquid phase from a low pressure region to a high pressure region where the phase of such liquid is gaseous during a cycle consisting of a suction period and a pumping period, the steps comprising, passing an amount of liquid from a low pressure region to a pumping zone during the suction period, flowing the low pressure liquid in the pumping zone during the pumping period to a vaporizing and pressurizing zone where the liquid is changed to a high pressure gas, passing the gas during the pumping period to a receiving zone for use, diverting the gas away from the receiving zone to a collection zone during the suction period and allowing the gas to build up therein to a predetermined pressure, impressing said diverted gas from the collection zone during said pumping period onto the surface of the liquid in the pumping zone to force said liquid out of the pumping zone, and communicating the receiving zone with the collection zone when the gas pressure in the latter exceeds the predetermined value to provide passage of gas from the collection zone to the receiving zone.

7. The method of claim 6 wherein the gas flow from the collection zone to the receiving zone is arrested when the amount of gas leaving the collection zone decreases the pressure within the latter below the predetermined pressure.

8. In a fluid transfer system of the class described, a source of liquid under relatively low pressure, a pump having a fluid-tight chamber connected for receiving liquid from said source, gas forming apparatus connected for receiving liquid from said pump chamber and for changing the liquid to a high pressure gas, a gas receiving device, a collection device, said gas receiving and collection devices adapted to be connected for receiving gas from said gas forming device, means alternately connecting the collection and gas receiving devices to the gas forming apparatus, means communicating the collection device with the pump chamber for impressing gas onto the surface of the liquid therein to effect discharge of the liquid from the pump, and means effecting operation of the first mentioned means to communicate the collection device with the pump chamber concurrently with the connection of the gas receiving device to the gas forming apparatus and to cut off communication between the collection device and the pump chamber upon connection of the collection device with the gas forming apparatus.

9. In a fluid transfer system of the class described, a source of liquid under relatively low pressure, a pump having a fluid-tight chamber, liquid inlet and outlet means for said pump for introducing liquid from said source to the pump chamber and for discharging liquid from the latter, respectively, said outlet means being inoperable to discharge liquid from said pump chamber when the inlet means is operable and the inlet means being inoperable to admit liquid to the pump chamber when said outlet means is operable, gas inlet means for said pump for introducing gas into the pump chamber and being operable when the liquid inlet means is inoperable and the liquid outlet means is operable, a gas forming apparatus connected for receiving liquid from said pump chamber and for changing the liquid to a high pressure gas, a collection device, a gas receiving device, said collection and gas receiving devices adapted to be connected for receiving gas discharged from said gas forming apparatus, control means alternately connecting the gas receiving device to the gas forming apparatus, means communicating the collection device with the gas inlet means for supplying gas to the surface of the liquid in the pump chamber to force the liquid through the outlet means, second control means effecting and cutting-off communication between said collection device and said pump chamber, and means for effecting operation of said first and said second control means to communicate the collection device with the pump chamber gas inlet means concurrently with the connection of the gas receiving device to the gas forming apparatus and to cut off communication between the collection device and the gas inlet means upon connection of the collection device with the gas forming means.

10. The fluid transfer system of claim 9 wherein gas outlet means is provided for said pump to effect discharge of the gas in the pump chamber after the same is used to force the liquid from the chamber, said gas outlet means being effective when liquid is introduced into the pump chamber and being ineffective when the gas inlet means is effective for introducing gas into the pump chamber.

11. The fluid transfer system of claim 9 wherein the gas forming apparatus is a heat exchanger apparatus which heats and vaporizes the incoming liquid from the pump.

12. The fluid transfer system of claim 9 wherein valve means control the flow of liquid through the liquid outlet and inlet means of the pump, said valve means being gravity-operated.

13. The fluid transfer system of claim 9 wherein the first mentioned and second control means comprise signal operated fluid flow valves and the last mentioned means comprises a liquid level actuated control means connected for operating said valves.

14. The fluid transfer system of claim 13 wherein the liquid level actuated control means includes a vessel having a chamber which is connected to receive liquid from said liquid source, said control means further including a metal cylinder with an electrode therein and floating in the liquid of said chamber, and a metal sphere in the cylinder adapted to contact the electrode in the cylinder when the liquid in the chamber attains a predetermined level to effect operation of said signal operated fluid flow valves.

15. In a fluid transfer system of the class described, a source of liquid under relatively low pressure, a pump having a pump chamber with a liquid inlet and outlet and a gas inlet, a conduit connected at one end to the source of liquid and at the other end to the pump chamber, said conduit being arranged with respect to said source and to said pump chamber to provide a hydraulic head of sufficient potential to cause the liquid from said source to flow into said pump chamber, a gravity valve member for said pump liquid inlet for controlling flow of liquid from said conduit into said pump chamber, a second gravity valve member for said pump liquid outlet for controlling flow of liquid out of said pump chamber, gas forming apparatus connected for receiving liquid from said pump chamber and for changing the liquid to a hight pressure gas, a gas receiving device, a collection device, said gas receiving and collection devices adapted to be connected for receiving gas from said gas forming apparatus, means alternately connecting the collection and gas receiving devices to the gas forming apparatus, means communicating the collection device with the gas inlet of said pump chamber for impressing gas onto the surface of the liquid therein to effect discharge of the liquid from the pump chamber, said first mentioned valve member cutting off communication of the pump chamber with the conduit during discharge of the liquid from the pump chamber, and means effecting operation of the first mentioned means to communicate the collection device with the pump chamber concurrently with the connection of the gas receiving device to the gas forming apparatus and to cut off communication between the collection device and the pump chamber upon connection of the collection device with the gas forming apparatus.

16. An air separation plant for producing gaseous oxygen, a compressor for compressing air, a heat exchanger connected to the compressor for receiving and cooling the compressed air, a second heat exchanger connected to receive the cooled air and for further cooling it, apparatus connected to the second heat exchanger for expanding the cooled air to liquify the oxygen therein, said apparatus including a vessel under low pressure for collecting the liquid oxygen, a pump having a pump chamber connected to receive the liquid oxygen from the vessel, means communicating the pump chamber with the second exchanger to cause the liquid oxygen to pass in heat exchange with the air to change the liquid oxygen to gaseous oxygen, means communicating the second heat exchanger with the first heat exchanger to cause the gaseous oxygen to pass in heat exchange with the compressed air to further heat the gaseous oxygen and substantially increase the pressure thereof, a collection vessel, a gas receiving vessel, said collection and gas receiving vessels adapted to be connected for receiving gas from said first heat exchanger, means alternately connecting the collection and gas receiving devices to the first heat exchanger, means communicating the collection device with the pump chamber for impressing gas onto the surface of the liquid therein to effect discharge of the liquid from the pump, and means effecting operation of the first mentioned means to communicate the collection device with the pump chamber concurrently with the connection of the gas receiving device to the first heat exchanger and to cut off communication between the collection device and the pump chamber upon connection of the collection device with the first heat exchanger.

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