

Nov. 15, 1966

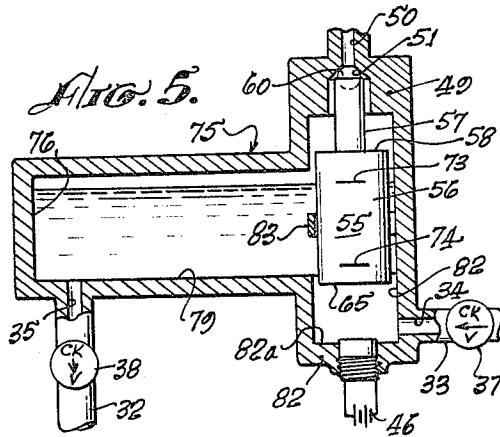
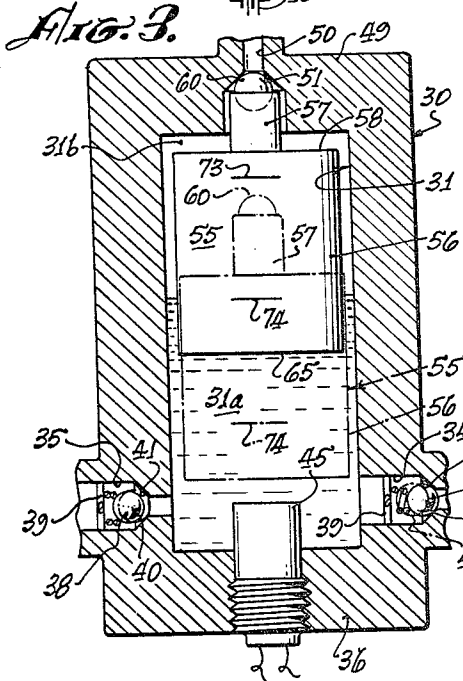
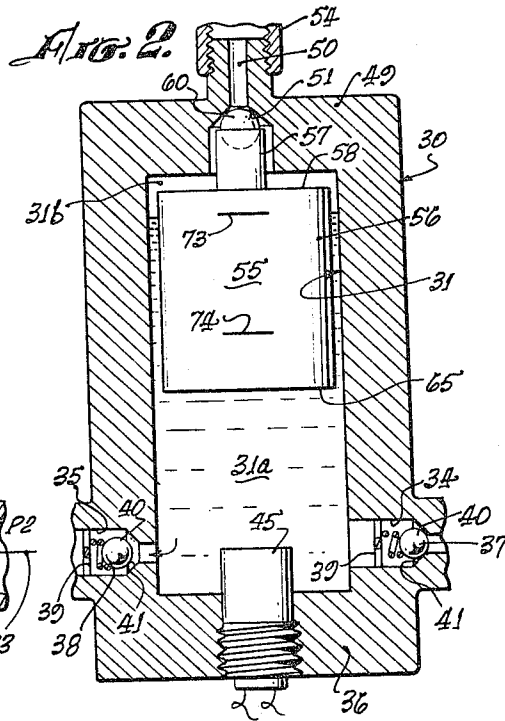
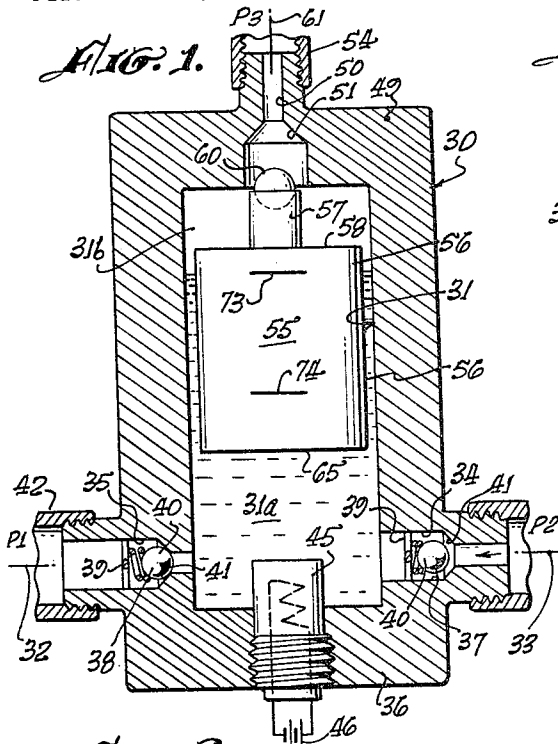
R. C. TURNBLADE

3,285,001

THERMAL FLUID MOVING APPARATUS

Filed March 4, 1965

3 Sheets-Sheet 1



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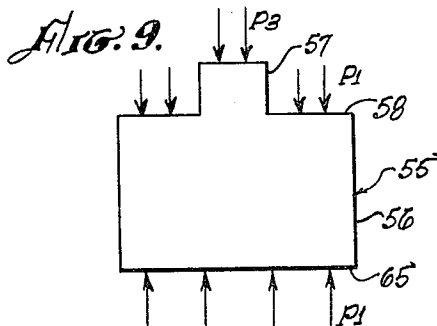
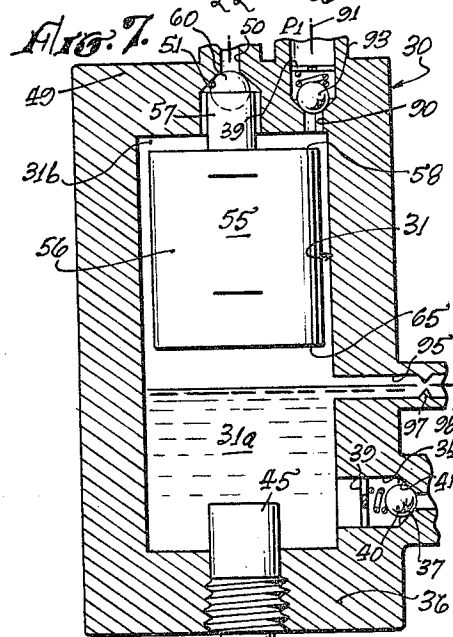
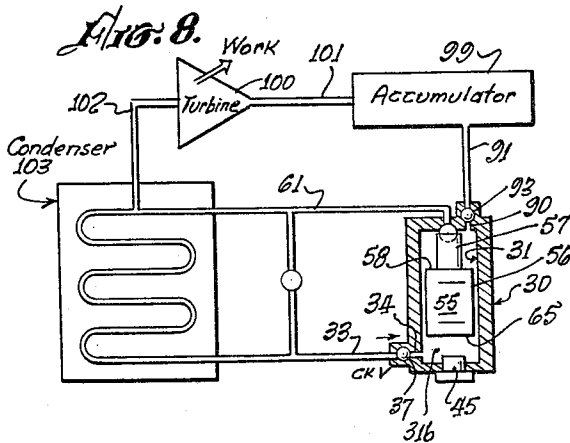
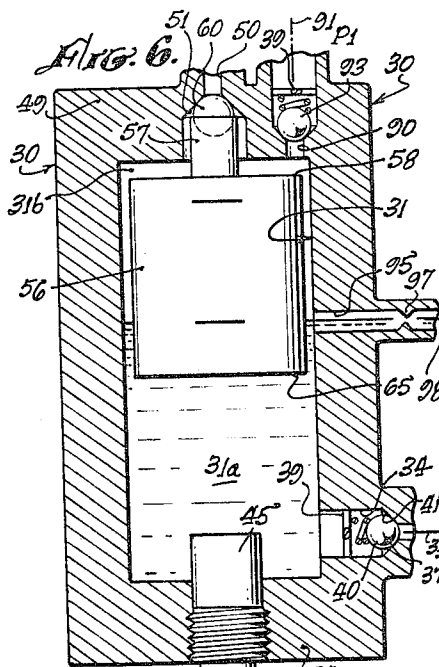
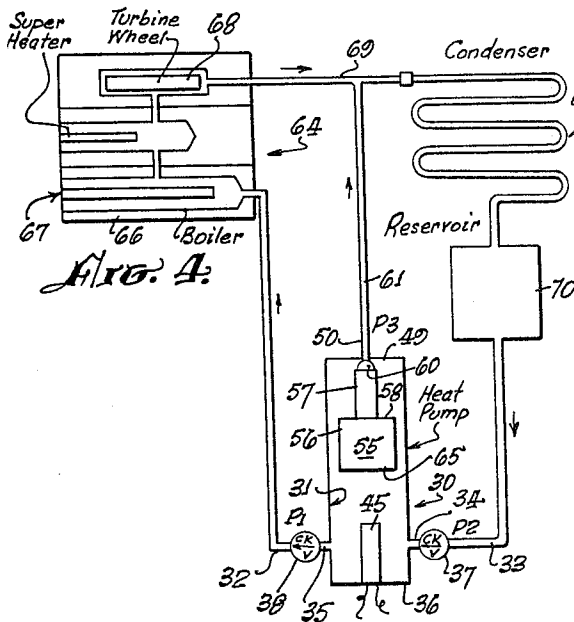
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THERMAL FLUID MOVING APPARATUS

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3 Sheets-Sheet 2



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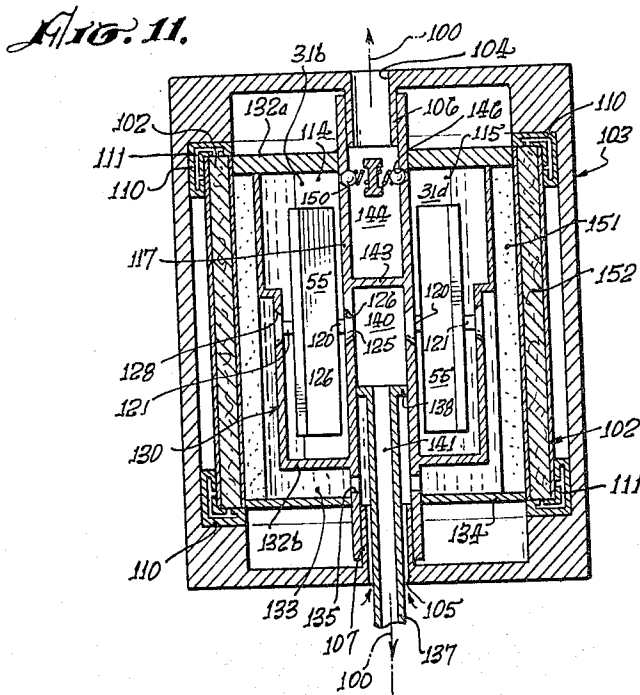
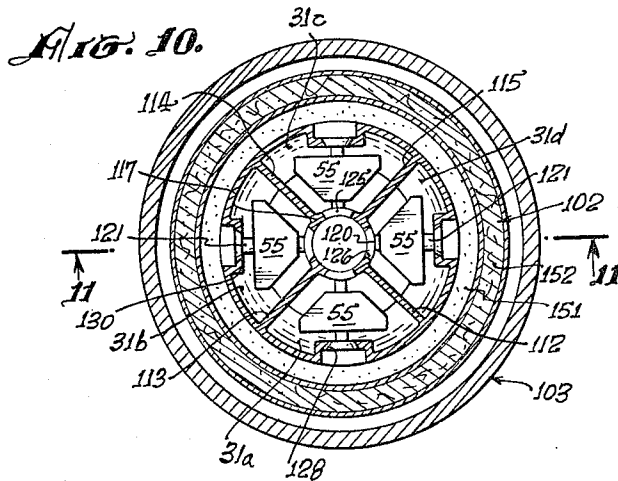
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THERMAL FLUID MOVING APPARATUS

Filed March 4, 1965

3 Sheets-Sheet 3



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**THERMAL FLUID MOVING APPARATUS**  
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ration of Delaware  
Filed Mar. 4, 1965, Ser. No. 437,319  
19 Claims. (Cl. 60-25)

This invention relates to pumps and compressors for fluids and more particularly to a fluid pump or compressor which utilizes heat as the source of power.

In the present state of technology a greater need for fluid pumping apparatus which has an extremely long operating life and which utilizes thermal energy at high efficiency has become increasingly important. In many applications, obvious ones of which are aerospace applications, the need for prime moving energy systems which are capable of utilizing available thermal energy are particularly advantageous. In such applications more conventional equipment such as typical piston or reciprocating pumps for moving fluid are unsatisfactory due to the electrical power requirements and the number of moving parts therein which are subject to wear. It is obvious that in such applications extreme reliability of the equipment and devices is essential. To be suitable for many technological applications, such prime moving energy systems must have modest heat power requirements, must have no moving parts subject to wear by mechanical contact and must be of simple, low cost design.

Thermal pumps and compressors known to the prior art have not, in general, satisfied these various criteria and requirements due in part to their complexity and relatively low efficiency. For example in many thermal pumping devices presently known to the art the efficiency of pumping is limited by the fact that all of the fluid is not exhausted from the pumping apparatus during any given cycle. When heat is the energy source for movement of fluids from the pumping apparatus, the residual fluids remaining within the apparatus at the end of a cycle are decreased from a predetermined temperature and must be increased in the next cycle to such predetermined temperature. The heat needed to produce such a temperature increase is in effect lost within the system.

Apparatus which is capable of moving fluids by means of thermal energy is also particularly advantageous in connection with machinery and equipment in which heat is available as a normally unused by-product of the system. Such machinery, equipment and systems include, for example, refrigeration systems, equipment for use with vehicles, pneumatic systems, gas lubricated devices and the like in which a long continuous life is needed and a continuous source of heat is readily available.

It is an object of the present invention to provide a fluid moving apparatus with an extremely long operating life and a minimal number of moving parts.

It is another object of the present invention to provide a fluid moving apparatus which utilizes only thermal energy as the source of power.

It is a further object of the present invention to provide a fluid moving apparatus which is of minimum size and weight.

Yet another object of the present invention is to provide a thermally operated fluid moving apparatus which operates at a higher efficiency than such devices known to the prior art.

A further object of the present invention is to provide such a fluid moving apparatus which is adapted to be used as a pump for moving liquid or a compressor for moving gas or vapor.

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A still further object of the present invention is to provide a fluid moving apparatus which is simple in operation and which can be adapted to many uses such as, for example, in the supply of liquid or gas for pneumatic power, electrical power generation, refrigeration systems, or the like.

A still further object of the present invention is to provide such a fluid moving apparatus which entails no possibility of unwanted leakage or intermixing of gas or liquid from the high pressure to the low pressure sides of the apparatus.

A still further object of the present invention is to provide such a fluid moving apparatus in which the fabrication tolerances are easily obtainable, and the design of which is simple and economical.

Yet another object of the present invention is to provide a thermally actuated fluid moving apparatus having modest heat power requirements.

A further object of the present invention is to provide such a fluid moving apparatus which has high reliability.

In general, the present invention comprises a fluid pumping apparatus in which the heat extracted from a heat source is used to vaporize a pumping fluid contained within a closed chamber. The heat available is sufficient to boil or vaporize the fluid within the chamber thus increasing the internal pressure within the chamber. When the internal pressure reaches a predetermined level an outlet valve opens and vaporization of the liquid within the chamber continues under a constant pressure process. The liquid or gas is then extracted from the chamber at this predetermined constant pressure and is used for producing work such as driving a turbine or pushing a piston. After a predetermined volume of liquid has been vaporized within the chamber the outlet valve closes and a depressurizing means is actuated to reduce the pressure within the chamber and allow a fresh supply of liquid to enter the chamber. The liquid inlet valve closes after the liquid has reached a predetermined level in the chamber and the cycle of the pumping apparatus then recommences.

It is to be understood throughout the description of the present invention that the apparatus of the present invention is equally applicable both to the pumping of liquid or the compression of gas and that when the apparatus is described in connection with the moving of fluid both are contemplated. The present invention is particularly applicable to any power loop in which liquid, gas or vapor under pressure is utilized to perform work by means of a turbine, pump, or the like. Accordingly, the present invention will be described in connection with illustrative embodiments as employed in such power loop systems.

The novel features which are believed to be characteristics of the invention, both as to its organization and method of operation, together with further objects and advantages thereof will be better understood from the following description considered in connection with the accompanying drawing in which an illustrative embodiment of the invention is shown and described by way of example. It is to be expressly understood, however, that the drawing is for the purpose of illustration and description only, and is not intended as a definition of the limits of the invention.

In the drawing:

FIGURE 1 is a sectional view in elevation of an illustrative embodiment of the present invention in a liquid pumping mode at the liquid inlet stage of the cycle;

FIGURE 2 is a view corresponding to FIGURE 1 with the pump at the commencement of the liquid outlet portion of the cycle;

FIGURE 3 is a view corresponding to FIGURES 1 and 2 with the pump at the depressurizing point of the cycle;

FIGURE 4 is a schematic view of a power loop utilizing the thermal pump of FIGURES 1, 2 and 3;

FIGURE 5 is a partially schematic view of a first alternative embodiment of the thermal pump of the present invention;

FIGURE 6 is a view in elevation similar to FIGURE 1 of an alternative by-pass embodiment of the present invention in the compressor mode;

FIGURE 7 is a view corresponding to FIGURE 6 showing the compressor at the depressurizing point of the cycle;

FIGURE 8 is a schematic view of a power loop in accordance with the present invention utilizing a thermal compressor in the embodiment of FIGURES 1, 2 and 3 but in the compressor mode;

FIGURE 9 is a schematic diagram illustrating the differential forces across the float valve.

FIGURE 10 is a partially diagrammatic view in section of an alternative multiple pump embodiment adapted for particular environmental condition; and

FIGURE 11 is a sectional view taken along line 11-11 of FIGURE 10.

A thermally operated pump as shown in FIGURES 1, 2 and 3 in its present illustrative embodiment is a self-cycling fluid pump and comprises in general a pump body 30 defining a cylindrical chamber 31 within which is positioned a float valve 55 as described more fully hereinafter. In the embodiment shown a fluid inlet port 34 and a fluid outlet port 35 communicate with the chamber 31 proximate the lower end wall 36 thereof. In the illustrated embodiment the inlet and outlet ports are shown diametrically opposed although such orientation is not necessary. Suitable inlet 37 and outlet 38 check valves are positioned in the inlet and outlet ports to allow the flow of fluid in the appropriate direction only. The check valves shown are of the type which include a check ball 40 in suitable casing 39 and are adapted to seat upon a tapered valve seat 41. Suitable connectors 42 such as threaded nipples are provided for connecting input 33 and output 32 lines to the input and output ports. A heating element 45 is provided within the chamber 31 to supply heat to the fluid within the chamber as described hereinafter. Any conveniently available source of heat can be utilized; however, for purposes of illustration an electrical resistance heater element is shown with a source of current 46.

From the upper portion of the chamber 31 a gas outlet port is provided through the top wall 49 of the housing and is operable from an open to a closed condition by the float valve 55. In the embodiment shown a gas outlet port 50, designated hereinafter as the depressurizing port 50, is located on the longitudinal axis of the chamber and has a tapered seat 51 divergent from the port diameter to the chamber. A suitable connector such as a threaded nipple 54 is affixed to the gas outlet port for connection of a depressurizing line 61.

A float valve is so formed and of suitable material as to be buoyant in the liquid within the chamber 31. When the liquid is at a first predetermined level which is sufficiently high within the chamber, the float valve is raised to a position at which it closes the gas outlet port 50 and retains it closed until the liquid level drops to a predetermined second level. Thus, in the embodiment illustrated the float valve 33 has a cylindrical body portion 56 with an upwardly extending stem 57. The stem is vertically oriented in the orientation of the figures and is positioned on the center point of the upper surface of the float valve body 56 such that it is substantially coincident with the longitudinal centerline of the pump body. In its present embodiment the float valve is formed of nylon although other materials can be employed as will become apparent in connection with the description

of the operation of the device and the function of the float valve. The length of the stem 57 is dependent upon the liquid level to be maintained in the chamber and length of stroke of the liquid-gas interface as described hereinafter. The stem has a valve element such as a metal ball 60 affixed to its upper end and mateable with the valve seat 51. The outside diameter of the float valve body 56 is substantially less than the inside diameter of the chamber 31 and is determined by the volume of liquid to be displaced to obtain the necessary buoyancy forces upon the float valve. The float valve does not function in any way to prevent passage of liquid or gas from one portion of the chamber to the other. The function of the float valve 55 is solely to open and close the gas outlet port at a predetermined point in the cycle of the pump dependent upon the combination of forces acting upon the float valve. The forces operating upon the float valve and its function can most readily be seen in connection with the description of the operation of the invention in its most rudimentary form as shown in FIGURES 1, 2, and 3.

Thus, in operation the embodiment of FIGURES 1, 2 and 3 is shown as adapted for pumping liquid from the liquid input line 33 to the output line 32. For purposes of illustration the pump of FIGURES 1, 2 and 3 is shown in FIGURE 4 in a power loop in which liquid under pressure is supplied to an apparatus designated as a converter 64. The converter 64 can be any one of many devices in which liquid under pressure is supplied to perform useful work. Such device can be, for example, a turbine, a piston, a generator, a fluid lubricated bearing, or a refrigeration compressor. After the heat and pressure have been removed from the liquid by conversion to work the resultant low pressure gas is exhausted from the converter to a condenser 65 which is at the low pressure side of the system. As an example, the liquid is shown as passing from the pump to a boiler 66 which forms part of the converter 64. The liquid is boiled by the supply of additional heat from a heat source 67. The gas is then conducted to an apparatus such as a reaction turbine wheel 68. The gas under pressure then drives the turbine wheel and is exhausted at the reduced pressure to the low pressure outlet line 69 and is conducted to the condenser 65. After passing through the condenser the cooled gas liquifies and is stored in a reservoir 70 as a source of liquid supply to the liquid inlet of the pump. The depressurizing gas line 61 is also connected to the low pressure line 69 to the condenser 65. Accordingly, the high pressure side of the pump is at the liquid inlet line 32 at a pressure designated as  $P_1$ , the depressurizing line is at the minimum pressure of the closed system shown in FIGURE 4 at a pressure designated as  $P_3$  while the liquid inlet line is also at low pressure designated  $P_2$  which is somewhat greater than  $P_3$  by the extent of the liquid head in the reservoir 70.

Thus, referring now to FIGURES 1 and 4 the pump is shown at a point in the cycle thereof where liquid is flowing into the pump from the reservoir 70 through the inlet check valve 37 which is open. The pressure within the pump chamber 31 is at the pressure of the depressurizing line 61 since the depressurizing port 50 is open. The float valve 55 is at a position intermediate along its length of travel since as shown in FIGURE 1 the liquid from the inlet has partially filled the chamber. The float valve is freely floating within the liquid to a depth in the liquid determined by the buoyancy forces on the float body 56. Thus, the float valve body will be submerged in the liquid to the depth indicated in the figures as a buoyancy line 73. As the liquid level continues to rise the float valve is carried upward until the valve element 61 on the valve stem engages and seats against the valve seat in the depressurizing line. Since some momentum is achieved by the float moving upwardly and upon closing of the depressurizing line some immediate pressure differential exists between the chamber and the depressurizing line,

a sudden closing and seating of the valve is obtained. A force is caused by this pressure differential across the float valve by reason of the fact that the upper transverse surface of the float valve against which the pressure within the chamber acts is less than the lower transverse surface by the amount of the area exposed to the depressurizing line as discussed more fully hereinafter. After the float valve is seated the liquid level ceases to rise within the chamber when the pressure of the fluid within the chamber slightly exceeds that of the fluid inlet line and causes the inlet check valve 37 to close. Since the heating element is energized throughout the operation of the pump, boiling of the fluid occurs during the latter part of the filling portion of the cycle. After the float valve closes the boiling of the liquid continues and produces vapor under pressure in the chamber above the liquid level. This pressure differential between the chamber pressure and the depressurizing line produces a differential force in the upward direction to retain the float valve in its seated position. For purposes of discussion the portion of the chamber filled with liquid is designated as 31a while that portion filled with vapor is designated as 31b. The liquid surface is an interface which moves upwardly and downwardly within the chamber comparably to the piston face in a mechanical piston pump. As boiling occurs the pressure of the gas in portion 31b increases as does the pressure of the liquid in portion 31a.

Referring now to FIGURE 2, the liquid level is shown at or near its uppermost point immediately subsequent to opening of the outlet check valve 38. That is, after the inlet check valve and float valve have closed, boiling of the liquid continues and the pressure of the vapor and liquid in pressure balance continue to increase until the pressure of the liquid reaches and exceeds the pressure in the liquid outlet line. At this point the outlet check valve opens. When the outlet check valve 38 opens, a new pressure balance is established. Since the volume of gas generated by the boiling of liquid is substantially greater than the volume of liquid which is boiled to form such vapor the pressure of the vapor and the pressure of the liquid will remain constant at the outlet pressure from the pump; i.e., the liquid pressure in the outlet line. Consequently, liquid will flow from the pump through the outlet line at a substantially constant pressure and the pressure balance within the pump chamber 31 will remain substantially constant at this pressure as additional liquid is depleted and the liquid level moves downwardly. That is, there are two sources of depletion of the liquid within the pump, the first being that passed from the pump through the outlet line and the second being the liquid transformed to gas by boiling. So long as the volumetric rate of gas generated equals the volume of liquid passing from the pump through the outlet line the pressure within the pump chamber will remain constant, liquid will flow from the outlet at such pressure, and the liquid level will move downwardly. Referring now to FIGURES 2 and 3, as the liquid level within the pump chamber 31 decreases and passes below the upper surface 58 of the float valve body 56, the buoyancy force of the liquid acting upwardly upon the float valve begins to decrease. That is, the volume of liquid displaced by the float valve body 56 decreases as the liquid level passes downwardly beyond the buoyancy line and a lesser volume of the float valve body is submerged in liquid. It can be seen, however, that the pressure forces operating upon the float valve remain constant, in that since the vapor pressure and liquid pressure are equal, the pressure exerted upwardly upon valve body 56 by the liquid acting upon the lower surface 65 of the valve body 56 is the same per unit area as the vapor pressure acting upon the upper surface 58 of the valve body. A pressure differential force thus exists since the upwardly directed forces due to pressure upon the float valve exceed the downwardly directed pressure forces. Referring to FIGURE 9 a float valve is shown schematically to illustrate the differential force which exists upon

the float valve in the seated position and it can be seen that design considerations can be introduced to vary such differential force as by varying the area upon which the lesser depressurizing line pressure acts. Thus, when the float valve is freely floating the depressurizing port is open and the pressure within the chamber is substantially equal to the depressurizing line pressure designated  $P_3$  hereinafter. At this point the upward or downward forces on the float valve due to pressure on the surfaces are in balance. When the float valve is seated and the pressure within the chamber  $P_1$  exceeds that in the depressurizing line  $P_3$  an upward force, hereinafter termed the differential force, exists due to such differential pressure. That is, the pressure  $P_1$  acts in the upward direction upon the entire transverse surface 65 of the float valve. The downwardly acting pressure forces are the pressure  $P_1$  upon the annular area 58 and the lesser pressure  $P_3$  upon the area of stem 57 in contact with the depressurizing line 61. Since the area 65 is equal to the area 58 plus area 57 and  $P_1$  is greater than  $P_3$  then  $P_1 A_{65} > P_1 A_{58} + P_3 A_{57}$ . The differential force can thus be predetermined by the design of the float valve to determine the relative areas. So long as the float valve body is partially submerged in liquid, buoyancy forces act upwardly upon the valve body. The extent of these buoyancy forces is determined by the volume of liquid displaced by the float valve body and the relative specific gravities of the liquid and the material of which the valve body is formed. At this point the forces acting downwardly upon the float valve 55 are a combination of the weight of the float valve, the vapor pressure upon the upper surface 58 of the float valve which is annular in configuration surrounding the stem 57, and additionally the pressure within the depressurizing line acting upon the transverse area of the valve stem with which it is in contact. As the liquid level continues to move downwardly these forces become unbalanced and the float valve eventually falls as shown in FIGURE 3, when the downward forces including the weight of the float valve exceed the buoyancy forces and pressure of the liquid acting upwardly upon the float valve body. Due to the pressure differential discussed above, the float will fall when the liquid level reaches a point on the valve body which is below the buoyancy line 73 and is designated as the drop line 74. The drop line can be predetermined as discussed above by varying the parameters of buoyancy forces, weight of the float valve and differential force. When the float valve falls the depressurizing port 50 is opened and the pressure within the chamber falls rapidly to that in the depressurizing line pressure  $P_3$ . Since the pressure  $P_1$  in the liquid outlet line exceeds the pressure of the depressurizing line the outlet check valve 38 closes. Similarly, when the pressure  $P_2$  in the liquid inlet line exceeds that of the depressurizing line the input check valve 37 opens and fluid from the input line flows into the pump chamber 31 and the liquid level of the fluid within the chamber begins again to rise to start a new cycle of operation. As will be apparent from the foregoing the lower limit of travel of the liquid gas interface is determined by design considerations of the float valve and is determined by the configuration, weight, and displacement of the float valve.

It should be noted at this point that although the weight of the float valve is referred to herein only as a gravity force and the device is in a vertical orientation, other force inducing means such as acceleration, centrifugal force or magnetic force can be utilized to obtain the necessary force and pressure balances in accordance with the present invention when environmental conditions or other factors so require, as more fully discussed hereinafter.

When the liquid level has dropped to its lowermost point and the pump chamber is depressurized a simultaneous decrease in temperature of the liquid remaining in the pump chamber must occur. This occurs due to boiling of the liquid caused by the decreased pressure of the liquid. The heat lost from this residual quantity of

liquid must be replaced during the next cycle and is wasted since no useful work output is obtained from this additional heat input. This residual heat loss is minimized in the present invention due to the small volume of liquid which must be reheated. Such residual heat loss or parasitic boiling is a major source of inefficiency in prior art thermal pumps. Although residual heat loss is minor in the pump as described hereinabove, it can be further minimized by design considerations which increase the distance between the uppermost and lowermost points between which the fluid level travels within the pump chamber 31. The residual heat loss can be further minimized by forming the pump chamber in such manner as to effectively provide a chamber in which the fluid available to be pumped is much greater in quantity than that required to operate the float valve through its cycle. One such illustrative pump by which this is achieved is shown partially schematically in FIGURE 5. Thus, in the embodiment of FIGURE 5 a housing 75 defines a fluid chamber 76 with a fluid outlet 32 from the bottom surface 79 and a fluid inlet 33. A depression is formed at one side thereof remote from the outlet to form a liquid well 82 within which the float valve body 56 is contained. A heating element 77 is positioned adjacent the bottom surface 82a of the well 82. The float valve is so constructed that the drop line 74 at which the float falls to open the depressurizing port 50 as previously described is within the well but preferably at a point coincident with the bottom surface 79 of the chamber. The float valve and operation of the embodiment shown in FIGURE 5 are in all other respects similar to those previously described although suitable guide means 83 can be provided to guide the float valve into an out of seating engagement with the depressurizing port 50. Thus, in this embodiment liquid will be pumped until the chamber is literally pumped dry except for the liquid which remain in the well as the operating liquid. The quantity of liquid which is residual is thus a very small percentage of the overall quantity of fluid which is pumped from the device.

It can also be seen that where large volumes of flow are necessary the function of the float valve described above can be utilized to act as a pilot valve for the operation of larger valves in the lines. For example, in a large volume pump in accordance with the present invention the depressurizing line necessary to decrease the pressure quickly in the chamber would be sufficiently large that a correspondingly large float valve would be necessary to prevent an extreme differential pressure force across the float valve. In such case the depressurizing line upon which the float valve operates is left small but acts only as a pilot line to open the valve in the main depressurizing line by means well known to the art.

The apparatus of the present invention can be adapted as a compressor by connecting the fluid outlet line in or proximate to the upper surface of the chamber so that it remains in communication with the gas portion 31b of the chamber. The operation of the apparatus is in all respects similar to the operation of the pump as previously described except that gas under pressure is forced from the chamber rather than liquid. To further illustrate the operation of the apparatus as a compressor an alternative embodiment will be described in the compressor mode, it being understood that the following described embodiment can also be used in the liquid pumping mode.

Thus, referring now to FIGURE 6 there is shown an alternative embodiment of the thermal pump of the present invention in which a by-pass construction is utilized. The fluid chamber, float valve, liquid inlet line, and depressurizing line are identical in the illustrative embodiment to those of the embodiment shown in FIGURES 1 through 4 and are correspondingly identified. The fluid outlet is, however, shown as a gas outlet port 90 to which is connected a gas outlet line 91 since this em-

bodiment is shown in the compressor mode. The gas outlet port 90 is accordingly positioned through the top wall of the housing defining the chamber 31 so that it is in communication with the gas portion 31b of the fluid chamber. An outlet check valve 93 is positioned in the port 90 and the gas outlet line 91 is the high pressure side of the compressor at a pressure  $P_1$ . A by-pass port 95 is in communication with the pump chamber 31 at a position spaced downwardly a substantial distance from the top wall of the chamber such that liquid or gas passes through the by-pass port dependent upon the liquid level within the chamber 31. The position of the by-pass port is predetermined to determine the opening point of the depressurizing line as will become more apparent hereinafter. A restrictor means 97 such as an orifice of lesser diameter than the diameter of the by-pass port, or a throttle valve, is positioned in the by-pass line to create a pressure differential under flow conditions between the chamber 31 and the by-pass line 98.

In FIGURE 6 the by-pass embodiment of the thermal compressor in accordance with this invention is shown in the condition where the liquid level within the chamber 31 has risen to a point at which the buoyant float valve 55 has been raised into sealing engagement between the valve stem element and the valve seat in the depressurizing port. At this point both the inlet check valve 37 and outlet check valve 93 are also closed. By means of the energized heating element the temperature of the liquid in the chamber 31 is raised to the point at which boiling commences and the pressure of the gas in the gas portion 31b of the chamber and also that of the fluid in the liquid portion 31a of the chamber are raised. The rise in pressure first seats the float valve firmly such that no leakage down the depressurizing line can occur. Secondly, a small quantity of liquid is by-passed from the compressor by flowing through the by-pass restrictor into the by-pass line and thence to the low pressure side of the compressor. Since the quantity of by-passed liquid is small due to the restriction in the line, the heating element continues to raise the pressure until the pressure within the compressor chamber 31 is equal to the pressure at the high pressure side of the compressor, i.e., at the gas outlet line 91, at which time the outlet check valve 93 opens and allows gas to be pumped through the gas outlet line. The gas flows through the outlet line at substantially constant pressure and at a rate at which the volume of liquid flowing during a given time interval is equal to the volume of vaporized gas formed during that time interval. This process continues until the liquid level lowers by depletion of the liquid to the point at which the liquid level is at the by-pass port. At the level of liquid within the chamber 31 at which it passes beneath the by-pass port a sudden pressure drop within the chamber occurs since the by-pass port is now in communication with the gas in the gas portion 31b of the chamber. Thus, gas rather than liquid is now forced by the high pressure through the by-pass orifice and by the proper design of the orifice size the pressure drop across the restrictor drastically decreases the pressure within the chamber 31. As this pressure suddenly decreases the float valve drops and the depressurizing line is opened. Thus, as described hereinbefore just prior to the pressure drop due to the escape of gas through the by-pass line the pressure forces operating upon the float valve to maintain it in the closed position are a combination of the buoyancy force of the liquid operating upon the float valve body together with the fluid pressure across the entire transverse lower surface of the valve body in the upper direction opposed by the weight of the float valve and the pressure of the chamber operating upon a lesser transverse surface area of the valve body. This pressure also maintains the outlet check valve open and the inlet check valve closed. When the pressure is decreased rapidly by the flow of gas through the by-pass line the pressure differential acting

upon the upper and lower surfaces of the valve body diminishes as soon as the pressure within the chamber reaches that within the depressurizing line. Thus, the weight of the float valve held in place by pressure forces causes it to fall, opening the depressurizing line and completing the depressurizing of the pump chamber to the low pressure point of the system. At this point the liquid head which feeds the inlet line to the pump chamber is sufficient to cause liquid to fill the pump chamber. As the liquid fills the chamber the float valve is again buoyantly supported and elevated to the position at which the depressurizing line is again closed and the pumping cycle is again initiated when the pressure within the chamber reaches the outlet line pressure. In this embodiment, when the liquid level is below the buoyancy line of the float valve at the by-pass level the float valve will drop and the chamber 31 will be depressurized. As shown in FIGURE 7 the by-pass level can be made to occur at a point substantially beneath the float valve. That is, in this embodiment the material of which the float valve is formed and the configuration of the valve are predetermined such that the differential pressure force upon the float valve is sufficient to overcome its weight and the float valve is maintained in the closed position although no buoyancy forces are exerted upon it. Thus, in the context of the previous description the "drop" line is not within the body of the float valve and the float valve will not fall to open the depressurizing line until the pressure drop in the chamber due to the passage of gas through the by-pass line is sufficient to reduce the upward differential force on the float valve below the weight of the float valve.

In FIGURE 8 there is shown schematically a novel power loop in accordance with the present invention to illustrate further the utility thereof. In the power loop a thermal pump as shown in FIGURES 1 through 3 is shown in the compressor mode having a gas outlet line 91 from the gas portion 31b of the chamber 31 with a gas outlet check valve 93 in the outlet line 91. The gas outlet line 91 is connected to a high pressure accumulator 99 which is in turn connected through a high pressure gas line 101 to a turbine 100 or similar work producing converter. A gas or fluid exhaust line 102 from the turbine is connected to the input of a condenser 103 as is the depressurizing line 61 from the thermal compressor. The outlet line from the condenser is connected through liquid inlet line 33 and inlet check valve 37 to the fluid chamber 31. Thus, as previously described gas or vapor is generated in the thermal compressor by the heat input from the heater 45 to thus increase the pressure in the chamber when the depressurizing port is closed by the float valve. When the pressure slightly exceeds the accumulator pressure  $P_1$  at the high side of the system the check valve 93 opens. High pressure gas or vapor flows from the chamber 31 into the accumulator. The high pressure gas is then used to drive a turbine in which the heat content and pressure of the gas are converted to mechanical work. The gas leaves the turbine at lowered pressure  $P_3$  and temperature through exhaust line 102 and liquifies in the condenser. When the liquid level in the chamber 31 drops sufficiently, the weight of the float valve overcomes the buoyancy force and the force due to the pressure differential across the depressurizing port, and the depressurizing port is opened. The pressure in the chamber 31 drops to the value in the depressurizing line  $P_3$  and a new charge of liquid at inlet line pressure  $P_2$  enters the chamber to raise the liquid level and start a new cycle.

The apparatus of the present invention has been found to be particularly suited to refrigeration due to the thermodynamic cycles involved and the fact that the pumping fluid is useful for refrigeration or compatible with a second refrigeration fluid.

As mentioned hereinbefore the embodiments shown as illustrative are rudimentary in form and are oriented

for gravity operation. From the foregoing, however, it can be seen that the present invention can be readily adapted to environmental conditions in which the force of gravity is not utilized to produce the force exerted upon the float valve in a direction away from the depressurizing port. Such environments would obviously include zero gravity, vibration and acceleration conditions in aerospace applications. In such circumstances centrifugal force can be substituted for gravity force. It can be seen further that devices in accordance with the present invention can be grouped or ganged for increased volume flow.

To illustrate briefly, in view of the foregoing descriptions, the application of the present invention to particular environmental conditions such as zero-gravity and to ganged apparatus, an illustrative alternative embodiment is shown in FIGURES 10 and 11. In this embodiment four fluid chambers 31 and float valves 55 are utilized and are symmetrically oriented about the rotational centerline of the apparatus which is designated 100—100 in the figures. In this embodiment the use of a dual seat valve is also shown to illustrate the use of such a valve to open and close the depressurizing line and liquid inlet port simultaneously.

Thus, in the embodiment shown in FIGURES 10 and 11 the cylindrical pump housing 102 is mounted for rotation within an apparatus housing 103 about the longitudinal axis 100—100. The apparatus housing 103 has a gas outlet port 104 and liquid inlet port 105 defined by stub shafts 106 and 107 respectively which are concentric with the axis of rotation. The pump housing 102 is mounted for rotation about the stub shafts by means of gas bearings 110 which support and cause autorotation of the pump housing 102. This is accomplished by supplying gas under pressure to the conduits 111, from which the gas is exhausted at such an angle as to support the pump housing 102 from the adjacent walls of the apparatus housing 103 and at the same time to achieve rotation of the pump housing 102 by reaction from the gas exhausted therefrom.

The pump housing defines a cylindrical chamber which is divided into four chambers 31a, b, c and d by the transverse walls 112, 113, 114 and 115. The walls 112—115 terminate at an inner conduit wall 117 such that the chambers 31a—31d are annular segments. Within each segment a float valve 55 is positioned and movable on a radius from the centerline. The body of each float valve is generally triangular in cross-section so as to conform to the general configuration of the annular segment within which it is positioned. Since each of the segmental chambers, float valves and valve arrangements are similar only one will be discussed in detail. As shown in FIGURES 10 and 11 the float valve 55 has a radially inwardly extending stem 120 and outwardly extending stem 121 at approximately the longitudinal midpoint of the float valve. A depressurizing valve element 125 on valve stem 120 is mateable with a depressurizing port 126 in the inner conduit wall 117 while the outer valve stem 121 has a valve element mateable within inlet port 128 in the inlet wall 130. The inlet wall 130 is cylindrical and surrounds and defines a wall of a portion of the segmental chambers. The inlet wall 130 is spaced from the end wall 132a and the inner surface 132b of the pump housing 102 to thus define a liquid inlet path 133 in communication through inlet ports 135 with the stub shaft 107 which defines an annular liquid inlet to the apparatus. The liquid inlet path is closed by an annular end wall 134.

A depressurizing line 137 is symmetrically positioned through the stub shaft 107 with a flange 138 separating the liquid inlet path from a depressurizing gas path which includes a depressurizing chamber 140 and the interior opening 141 through the depressurizing line 137. The depressurizing gas path is thus in communication with the depressurizing ports 126 through the conduit wall 117. The depressurizing chamber 140 is separated by a trans-

verse wall 143 from a gas outlet path 144 defined by the inner conduit wall 117. The gas outlet path is in communication with each pump chamber 31 at the gas portion 31b thereof through gas outlet ports 146 through the conduit wall 117. Suitable outlet check valves 150 are positioned in the inner conduit to open and close the outlet ports 146.

The depressurizing port 141 and liquid inlet port 128 are so spaced that when one is closed by the appropriate valve element on the float valve the other is also closed. The use of a dual seat valve operating both the liquid inlet valve and the depressurizing valve allows the float valve to be pressure balanced so that a small float weight can operate large area valves.

Surrounding the pump chambers is a source of heat such as a cylindrical layer of nuclear isotopes 151 or other suitable heat source which is in turn surrounded by suitable insulation 152. Fluid transfer lines of the type known to the art are connected to the appropriate liquid inlet and gas outlet lines of the apparatus.

The operation of the embodiment of FIGURES 10 and 11 is comparable to the operation of embodiments described hereinabove except for the substitution of centrifugal force for gravity force. Thus, briefly, the embodiment of FIGURES 10 and 11 will operate in zero-gravity or all attitude environments by rotation of the pump chambers about the axis 100—100 at an appropriate rate of rotation. Heat supplied to liquid in the chambers 31 vaporizes the liquid and the gas thus formed "floats" inwardly toward the axis 100—100 of the apparatus. When pressure within each of the chambers 31 equals the outlet line pressure  $P_1$  the outlet check valve 150 opens and gas is forced into the outlet line 104 to supply the system within which the device in its compressor mode operates.

When most of the liquid has been vaporized, such that buoyancy and differential pressure forces acting inwardly are insufficient to oppose the centrifugal force exerted outwardly on the float valve, the float valves move outwardly due to the unbalance of forces as previously discussed. At this point the depressurizing port is opened and the liquid inlet port is simultaneously opened. The fluid chambers 31 each depressurized rapidly through both the depressurizing port and the liquid inlet port. After pressure equalization has been attained, the liquid flows along inlet path 133 and through the inlet port 128 by centrifugal feed action. As the chambers 31 fill with liquid, the buoyancy forces move the float valves inwardly to close the inlet and depressurizing ports after which the cycle recommences.

This embodiment utilizing centrifugal force on the depressurizing valve is especially suitable for applications where compact packaging is a necessity and in applications where the devices are desired to be used in ganged or tandem operation. This embodiment also, because of the stability achieved by the rotating masses, is particularly suitable in environments of extreme shock and vibration.

To adapt the present invention in any of its embodiments to environmental conditions of extreme shock and vibration, it is sometimes advantageous to utilize magnetic or other detent forces to retain the valves in the required positions. For example, when vibration is a problem, it will be expeditious to utilize magnetic forces at the depressurizing port to retain the float valve in the seated position. Such force would then become a design consideration in the force and pressure balances discussed hereinbefore.

What is claimed is:

1. A device for moving fluid under pressure comprising:
  - a housing defining a fluid chamber;
  - means for vaporizing liquid within said chamber;
  - a liquid inlet to said chamber;
  - a fluid outlet from said chamber;
  - a depressurizing vapor outlet from said chamber;

liquid level dependent means movable between a second predetermined position and a first predetermined position in response to the liquid level within said chamber;

- 5 means in combination with said liquid level dependent means for closing said depressurizing outlet at said first predetermined position, said depressurizing outlet being open at said second position;
- 10 means in said liquid inlet for opening said inlet at said second position and closing said inlet at said first position; and,
- means in said fluid outlet for opening said outlet at said first position and closing said outlet at said second position.

2. A device for moving fluid under pressure comprising:

- a housing defining a fluid chamber;
- heating means for vaporizing liquid within said chamber;

- 20 a liquid inlet to said chamber;
- a fluid outlet from said chamber;
- a depressurizing vapor outlet from said chamber;
- a float valve movable between a first and a second position within said chamber, said float valve being buoyantly movable from said second position to said first position by liquid within said chamber as said liquid rises to a first predetermined level;

means in combination with said float valve for closing said depressurizing outlet at said first position thereof, said depressurizing outlet being open at said second position;

means in combination with said float valve for retaining said float valve at said first position until said liquid falls to a predetermined second level substantially below said first level;

means in combination with said liquid inlet for opening said inlet at said second liquid level and closing said inlet at said first liquid level; and,

40 means in combination with said liquid outlet for closing said outlet at said second liquid level and opening said outlet at said first level.

3. A device for moving fluid under pressure comprising:

- a housing defining a fluid chamber;
- heating means for vaporizing liquid within said chamber;

- 45 a liquid inlet to said chamber;
- a fluid outlet from said chamber;
- a depressurizing fluid outlet from said chamber;
- a float valve movable between a first and a second position within said chamber, said float valve being buoyantly movable from said second position to said first position by liquid within said chamber as said liquid within said chamber increases to a first predetermined volume;

means in combination with said float valve for closing said depressurizing outlet at said first position thereof, said depressurizing outlet being open at said second position;

60 means in combination with said float valve for retaining said float valve at said first position until said liquid content within said chamber falls to a predetermined second volume substantially less than said first volume;

65 means in combination with said liquid inlet for opening said inlet at said second liquid volume and closing said inlet at said first liquid volume; and

means in combination with said liquid outlet for closing said outlet at said second liquid volume and opening said outlet at said first volume.

4. A device for moving fluid under pressure comprising:

- a housing defining a closed fluid chamber;
- a liquid inlet to said chamber;
- a fluid outlet from said chamber;

a depressurizing fluid outlet from said chamber;  
 heating means for vaporizing liquid within said chamber whereby said chamber contains a volume of liquid and a volume of vapor, said heating means being adapted to supply heat sufficient to vaporize said liquid and raise the pressure of said fluids within said chamber to a high pressure  $P_1$  from a lower pressure  $P_2$ ;  
 liquid level float means within said chamber adapted to be moved to a first position by increase of the liquid volume in said chamber to a first liquid level;  
 means in combination with said float means to close said depressurizing outlet at said first liquid level;  
 fluid outlet valve means adapted to open said fluid outlet when said fluid pressure within said chamber reaches the higher pressure  $P_1$  and close said fluid outlet when said pressure is less than  $P_1$ ;  
 liquid inlet valve means adapted to open said liquid inlet when said chamber pressure is less than  $P_2$  and close said liquid inlet when said chamber pressure exceeds  $P_2$ ; and  
 means in combination with said float means to move said float means from said first position to a second position at which said depressurizing outlet is open to a pressure  $P_3$  less than  $P_2$  when said liquid volume decreases to a second liquid level substantially less than said first level.

5. A device for moving fluid under pressure comprising:

- a housing defining a closed fluid chamber;
- a liquid inlet to said chamber;
- a fluid outlet from said chamber;
- a depressurizing vapor outlet port from said chamber;
- heating means for vaporizing liquid within said chamber whereby said chamber contains a volume of liquid and a volume of vapor, said heating means being adapted to supply heat sufficient to vaporize said liquid and raise the pressure of said fluid within said chamber to a high pressure  $P_1$  from a lower pressure  $P_2$ ;
- a float valve adapted to be buoyantly supported by said liquid and moved to a first position by increase of the liquid volume in said chamber to a first predetermined liquid volume;
- said float valve being so constructed and arranged as to provide a valve element adapted to seat in and close said depressurizing port in said first position of said float valve, the pressure at the exterior of said port to which said valve element portion is exposed being at a pressure  $P_3$  less than  $P_2$  such that in said first position said float valve is urged toward said first position by the buoyancy force of said liquid and the force exerted by the pressure differential between  $P_1$  and  $P_3$  acting upon said float valve, said float valve being urged away from said first position by the weight thereof whereby said float valve is moved to a second predetermined position by decrease of the liquid volume to a second volume at which the buoyancy force and differential force are less than the weight force of said float valve, said depressurizing port being opened by movement of said float valve from said first to said second position;
- fluid outlet valve means adapted to open said fluid outlet when said fluid pressure within said chamber reaches the higher pressure  $P_1$  and close said fluid outlet when said pressure is less than  $P_1$ ; and
- liquid inlet valve means adapted to open said liquid inlet when said chamber pressure is less than  $P_2$  and close said liquid inlet when said chamber pressure exceeds  $P_2$ .

6. A device for moving fluid under pressure comprising:

- a housing defining a closed fluid chamber;
- a liquid inlet to said chamber;

a fluid outlet from said chamber;

- a depressurizing fluid outlet port from said chamber;
- heating means for vaporizing liquid within said chamber whereby said chamber contains a volume of liquid and a volume of vapor, said heating means being adapted to supply heat sufficient to vaporize said liquid and raise the pressure of said fluid within said chamber to a high pressure  $P_1$  from a lower pressure  $P_2$ ;
- a float valve within said chamber adapted to be buoyantly moved to a first position by increase of the liquid volume in said chamber to a first liquid level;
- said float valve including a valve element adapted to seat in and close said depressurizing port in said first position of said float valve, the pressure at the exterior of said port being less than  $P_2$ ;
- outlet check valve means adapted to open said fluid outlet when said fluid pressure within said chamber reaches the higher pressure  $P_1$  and close said fluid outlet when said pressure is less than  $P_1$ ;
- inlet check valve means adapted to open said liquid inlet when said chamber pressure is less than  $P_2$  and close said liquid inlet when said chamber pressure exceeds  $P_2$ ; and
- said float valve means being so constructed and arranged as to be retained in said first position by pressure differential forces exerted in the direction of the depressurizing port in opposition to the weight of said float valve which acts as a force in the direction away from said depressurizing port until the force of said weight exceeds the force exerted by said pressure differential forces.

7. A device for moving fluid under pressure comprising:

- a housing defining a closed fluid chamber;
- a liquid inlet to said chamber;
- a fluid outlet from said chamber;
- a depressurizing vapor outlet port from said chamber;
- heating means for vaporizing liquid within said chamber whereby said chamber contains a volume of liquid and a volume of vapor, said heating means being adapted to supply heat sufficient to vaporize said liquid and raise the pressure of said fluids within said chamber to a high pressure  $P_1$  from a lower pressure  $P_2$ ;
- a float valve adapted to be buoyantly supported by said liquid and moved to a first position by increase of the liquid volume in said chamber to a first predetermined liquid level;
- said float valve being so constructed and arranged as to provide a valve element portion adapted to seat in and close said depressurizing port in said first position of said float valve, the pressure at the exterior of said port to which said valve element portion is exposed being at a pressure  $P_3$  less than  $P_2$  such that in said first position said float valve is urged toward said first position by the buoyancy force of said liquid and the force exerted by the pressure differential between  $P_1$  and  $P_3$  acting upon said float valve, said float valve being urged away from said first position by the weight thereof whereby said float valve is moved to a second predetermined position by decrease of the liquid volume to a second level at which the buoyancy force and differential force are less than the weight force of said float valve, said depressurizing port being opened by movement of said float valve from said first to said second position;
- outlet check valve means adapted to open said fluid outlet when said fluid pressure within said chamber reaches the higher pressure  $P_1$  and close said fluid outlet when said pressure is less than  $P_1$ ; and
- inlet check valve means adapted to open said liquid inlet when said chamber pressure is less than  $P_2$  and

close said liquid inlet when said chamber pressure exceeds  $P_2$ .

8. A device for moving fluid under pressure comprising:

- a housing defining a closed fluid chamber; 5
- a liquid inlet to said chamber;
- a fluid outlet from said chamber;
- a depressurizing vapor outlet port from said chamber;
- a by-pass port adapted to pass vapor under pressure from said chamber said by-pass port being positioned at a second liquid level position substantially below a first liquid level position; 10

heating means for vaporizing liquid within said chamber whereby said chamber contains a volume of liquid and a volume of vapor, said heating means being adapted to supply heat sufficient to vaporize said liquid and raise the pressure of said fluids within said chamber to a high pressure  $P_1$  from a lower pressure  $P_2$ ; 15

a float valve adapted to be buoyantly supported by said liquid and moved to a first position by increase of the liquid volume in said chamber to a first predetermined liquid level; 20

said float valve being so constructed and arranged as to provide a valve element portion adapted to seat in and close said depressurizing port in said first position of said float valve, the pressure at the exterior of said port to which said valve element portion is exposed being at a pressure  $P_3$  less than  $P_2$  such that in said first position said float valve is urged toward said first position by the buoyancy force of said liquid and the force exerted by the pressure differential between  $P_1$  and  $P_3$  acting upon said float valve, said float valve being urged away from said first position by the weight thereof whereby said float valve is moved to a second predetermined position by decrease of the liquid volume to a second level at said by-pass port at which vapor passes through said by-pass port to reduce the chamber pressure such that said differential force is less than the weight force of said float valve, said depressurizing port being opened by movement of said float valve from said first to second position; 25 30 35 40

outlet check valve means adapted to open said fluid outlet when said fluid pressure within said chamber reaches the higher pressure  $P_1$  and close said fluid outlet when said pressure is less than  $P_1$ ; and inlet check valve means adapted to open said liquid inlet when said chamber pressure is less than  $P_2$  and close said liquid inlet when said chamber pressure exceeds  $P_2$ . 45 50

9. The apparatus as defined in claim 7 wherein said fluid outlet is a liquid outlet positioned in communication with the portion of the chamber in which liquid is present during vaporization thereof. 55

10. A device for moving fluid under pressure comprising:

- a housing defining a closed fluid chamber; 60
- a liquid inlet to said chamber;
- a vapor outlet from said chamber;
- a depressurizing vapor outlet port from said chamber;
- heating means for vaporizing liquid within said chamber whereby said chamber contains a volume of liquid and a volume of vapor, said heating means being adapted to supply heat sufficient to vaporize said liquid and raise the pressure of said fluids within said chamber to a high pressure  $P_1$  from a lower pressure  $P_2$ ; 65

said vapor outlet being positioned in communication with the portion of the chamber in which vapor is present during vaporization thereof; 70

a float valve adapted to be buoyantly supported by said liquid and moved to a first position by increase of the liquid volume in said chamber to a first predetermined liquid level; 75

said float valve being so constructed and arranged as to provide a valve element portion adapted to seat in and close said depressurizing port in said first position of said float valve, the pressure at the exterior of said port to which said valve element portion is exposed being at a pressure  $P_3$  less than  $P_2$  such that in said first position said float valve is urged toward said first position by the buoyancy force of said liquid and the force exerted by the pressure differential between  $P_1$  and  $P_3$  acting upon said float valve, said float valve being urged away from said first position by the weight thereof whereby said float valve is moved to a second predetermined position by decrease of the liquid volume to a second level at which the buoyancy force and differential force are less than the weight force of said float valve, said depressurizing port being opened by movement of said float valve from said first to said second position;

outlet check valve means adapted to open said fluid outlet when said fluid pressure within said chamber reaches the higher pressure  $P_1$  and close said fluid outlet when said pressure is less than  $P_1$ ; and, inlet check valve means adapted to open said liquid inlet when said chamber pressure is less than  $P_2$  and close said liquid inlet when said chamber pressure exceeds  $P_2$ .

11. The apparatus as defined in claim 8 wherein said fluid outlet is a liquid outlet positioned in communication with the portion of the chamber in which liquid is present during vaporization thereof.

12. The apparatus as defined in claim 8 wherein said fluid outlet is a vapor outlet positioned in communication with the portion of the chamber in which vapor is present during vaporization thereof.

13. The apparatus as defined in claim 7 comprising also means for exerting force on said float valve in a direction away from said depressurizing port.

14. The apparatus as defined in claim 8 comprising also means for exerting force on said float valve in a direction away from said depressurizing port.

15. A device for moving fluid under pressure comprising:

- a housing defining a closed fluid chamber;
- a liquid inlet to said chamber;
- a fluid outlet from said chamber;
- a depressurizing vapor outlet port from said chamber;
- heating means for vaporizing liquid within said chamber whereby said chamber contains a volume of liquid and a volume of vapor, said heating means being adapted to supply heat sufficient to vaporize said liquid and raise the pressure of said fluids within said chamber to a high pressure  $P_1$  from a lower pressure  $P_2$ ; 75

a float valve adapted to be buoyantly supported by said liquid and moved to a first position by increase of the liquid volume in said chamber to a first predetermined liquid level;

said float valve being so constructed and arranged as to provide a valve element portion adapted to seat in and close said depressurizing port in said first position of said float valve, the pressure at the exterior of said port to which said valve element portion is exposed being at a pressure  $P_3$  less than  $P_2$  such that in said first position said float valve is urged toward said first position by the buoyancy force of said liquid and the force exerted by the pressure differential between  $P_1$  and  $P_3$  acting upon said float valve, said float valve being urged away from said first position by the weight thereof whereby said float valve is moved to a second predetermined position by decrease of the liquid volume to a second level at which the buoyancy force and differential force are less than the weight force of said float valve, said depressurizing port being opened by movement

of said float valve from said first to said second position;

outlet check valve means adapted to open said fluid outlet when said fluid pressure within said chamber reaches the higher pressure  $P_1$  and close said fluid outlet when said pressure is less than  $P_1$ ;

inlet check valve means adapted to open said liquid inlet when said chamber pressure is less than  $P_2$  and close said liquid inlet when said chamber pressure exceeds  $P_2$ ; and

means for rotating said housing about an axis such that centrifugal force is exerted on said float valve in a direction away from said depressurizing port.

16. The apparatus as defined in claim 8 comprising also means for rotating said housing about an axis such that centrifugal force is exerted on said float valve in a direction away from said depressurizing port.

17. A power loop comprising:

- a housing defining a closed fluid chamber;
- a liquid inlet to said chamber;
- a fluid outlet from said chamber;
- a depressurizing fluid outlet from said chamber;
- heating means for vaporizing liquid within said chamber whereby said chamber contains a volume of liquid and a volume of vapor, said heating means being adapted to supply heat sufficient to vaporize said liquid and raise the pressure of said fluids within said chamber to a high pressure  $P_1$  from a lower pressure  $P_2$ ;
- liquid level float means within said chamber adapted to be moved to a first position by increase of the liquid volume in said chamber to a first liquid level; means in combination with said float means to close said depressurizing outlet at said first liquid level;
- fluid outlet valve means adapted to open said fluid outlet when said fluid pressure within said chamber reaches the higher pressure  $P_1$  and close said fluid outlet when said pressure is less than  $P_1$ ;
- liquid inlet valve means adapted to open said liquid inlet when said chamber pressure is less than  $P_2$  and close said liquid inlet when said chamber pressure exceeds  $P_2$ ;
- means in combination with said float means to move said float means from said first position to a second position at which said depressurizing outlet is open to a pressure  $P_3$  less than  $P_2$  when said liquid volume decreases to a second liquid level substantially less than said first level;
- an energy converter adapted to extract work from fluid under pressure, a high pressure line connected between said fluid outlet and a fluid inlet to said converter; and,
- a condenser, a low pressure line connected between said condenser inlet and said converter exhaust, said depressurizing port connected to said low pressure line, and said condenser outlet connected to said liquid inlet line.

18. A power loop comprising:

- a housing defining a closed fluid chamber;
- a liquid inlet to said chamber;
- a fluid outlet from said chamber;
- a depressurizing vapor outlet port from said chamber;
- heating means for vaporizing liquid within said chamber whereby said chamber contains a volume of liquid and a volume of vapor, said heating means being adapted to supply heat sufficient to vaporize said liquid and raise the pressure of said fluids within said chamber to a high pressure  $P_1$  from a lower pressure  $P_2$ ;
- a float valve adapted to be buoyantly supported by said liquid and moved to a first position by increase of the liquid volume in said chamber to a first predetermined liquid level;
- said float valve being so constructed and arranged as to provide a valve element portion adapted to seat in and close said depressurizing port at said first position of said port to which said valve element portion is exposed being at a pressure  $P_3$  less than  $P_2$  such that in said first position said float valve is urged toward said first position by the buoyancy force of said liquid and the force exerted by the pressure differential between  $P_1$  and  $P_3$  acting upon said float valve, said float valve being urged away from said first position by the weight thereof whereby said float valve is moved to a second predetermined position by decrease of the liquid volume to a second level at which the buoyancy force and differential force are less than the weight force of said float valve, said depressurizing port being opened by movement of said float valve from said first to said second position;

in and close said depressurizing port in said first position of said float valve, the pressure at the exterior of said port to which said valve element portion is exposed being at a pressure  $P_3$  less than  $P_2$  such that in said first position said float valve is urged toward said first position by the buoyancy force of said liquid and the force exerted by the pressure differential between  $P_1$  and  $P_3$  acting upon said float valve, said float valve being urged away from said first position by the weight thereof whereby said float valve is moved to a second predetermined position by decrease of the liquid volume to a second level at which the buoyancy force and differential force are less than the weight force of said float valve, said depressurizing port being opened by movement of said float valve from said first to said second position;

outlet check valve means adapted to open said fluid outlet when said fluid pressure within said chamber reaches the higher pressure  $P_1$  and close said fluid outlet when said pressure is less than  $P_1$ ;

inlet check valve means adapted to open said liquid inlet when said chamber pressure is less than  $P_2$  and close said liquid inlet when said chamber pressure exceeds  $P_2$ ;

an energy converter adapted to extract work from fluid under pressure, a high pressure line connected between said fluid outlet and a fluid inlet to said converter; and

a condenser, a low pressure line connected between said condenser inlet and said converter exhaust, said depressurizing port connected to said low pressure line, and said condenser outlet connected to said liquid inlet line.

19. A power loop comprising:

- a housing defining a closed fluid chamber;
- a liquid inlet to said chamber;
- a fluid outlet from said chamber;
- a depressurizing vapor outlet port from said chamber;
- a by-pass port adapted to pass vapor under pressure from said chamber, said by-pass port being positioned at a second liquid level position substantially below a first liquid level position;
- heating means for vaporizing liquid within said chamber whereby said chamber contains a volume of liquid and a volume of vapor, said heating means being adapted to supply heat sufficient to vaporize said liquid and raise the pressure of said fluids within said chamber to a high pressure  $P_1$  from a lower pressure  $P_2$ ;
- a float valve adapted to be buoyantly supported by said liquid and moved to a first position by increase of the liquid volume in said chamber to a first predetermined liquid level;
- said float valve being so constructed and arranged as to provide a valve element portion adapted to seat in and close said depressurizing port in said first position of said port to which said valve element portion is exposed being at a pressure  $P_3$  less than  $P_2$  such that in said first position said float valve is urged toward said first position by the buoyancy force of said liquid and the force exerted by the pressure differential between  $P_1$  and  $P_3$  acting upon said float valve, said float valve being urged away from said first position by the weight thereof whereby said float valve is moved to a second predetermined position by decrease of the liquid volume to a second level at which the buoyancy force and differential force are less than the weight force of said float valve, said depressurizing port being opened by movement of said float valve from said first to second position;

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outlet check valve means adapted to open said fluid outlet when said fluid pressure within said chamber reaches the higher pressure  $P_1$  and close said fluid outlet when said pressure is less than  $P_1$ ;  
inlet check valve means adapted to open said liquid inlet when said chamber pressure is less than  $P_2$  and close said liquid inlet when said chamber pressure exceeds  $P_2$ ;  
an energy converter adapted to extract work from fluid under pressure, a high pressure line connected between said fluid outlet and a fluid inlet to said converter; and  
a condenser, a low pressure line connected between

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said condenser inlet and said converter exhaust, said depressurizing port connected to said low pressure line, and said condenser outlet connected to said liquid inlet line.

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