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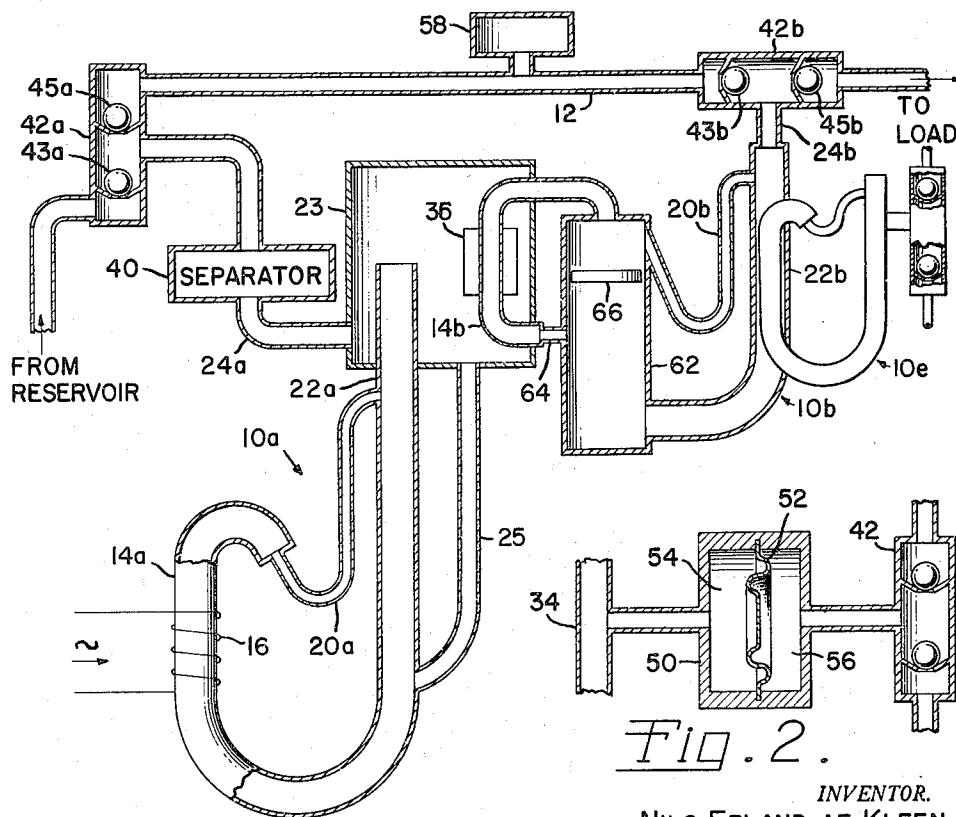
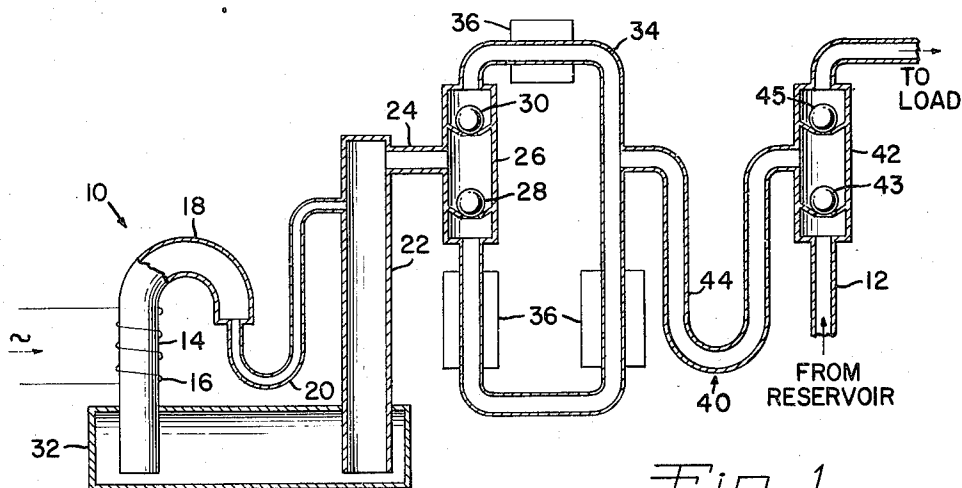
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2,954,741

PUMP SYSTEMS

Filed Aug. 24, 1955

2 Sheets-Sheet 1



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Fig. 3.

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2 Sheets-Sheet 2

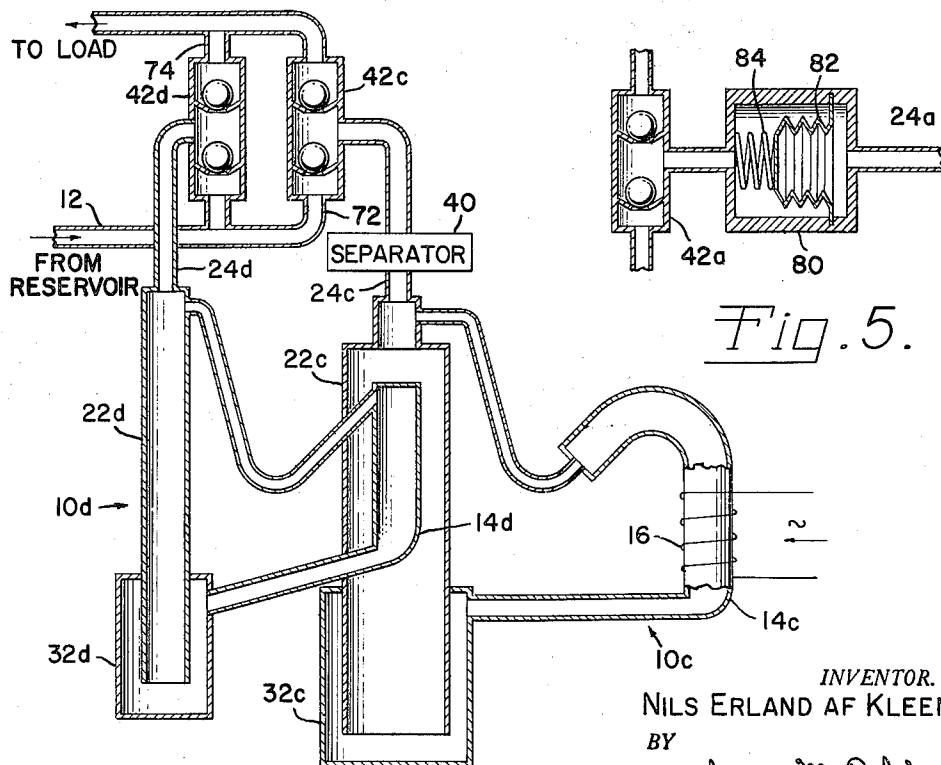
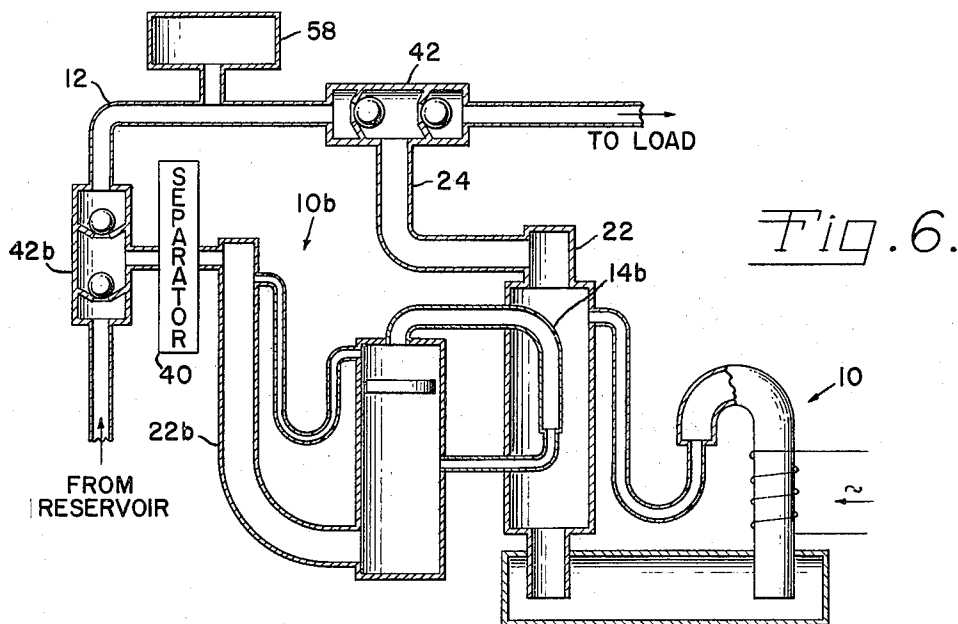


Fig. 4.

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2,954,741

PUMP SYSTEMS

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Filed Aug. 24, 1955, Ser. No. 530,387

15 Claims. (Cl. 103—255)

This invention relates to improvements in pump systems, and particularly to an improved system including a heat-actuated pump, referred to herein as a thermopump.

Briefly, a thermopump comprises a unit in which a liquid is heated to form vapor. This vapor is recurrently collected and condensed by cyclically reversing the relative rates of vaporization and condensation in the unit.

By connecting the unit to a fluid supply source and a delivery point or load through a pair of check valves, the fluid expansion and contraction accompanying this cyclical action can be utilized to effect a transfer of liquid from the source to the load.

It is among the general objects of the present invention to provide an improved heat-actuated pumping system of relatively high efficiency. Ancillary objects of the invention include the provision of a heat-actuated system for pumping liquids against relatively high load pressures, the provision of a compound pumping system making most efficient use of a plurality of individual thermopump units, and the provision of a system effectively utilizing either a plurality of different liquids or the same liquid under different operating conditions.

In accordance with one feature of the invention, certain of the foregoing objects and advantages are attained in a system wherein a thermopump is isolated from the principal liquid flow circuit, hereinafter called the "load circuit," by a separating chamber, and wherein means are provided for dissipating stored heat which might otherwise interfere with the pumping action. In accordance with a further feature of the invention, the dissipating means may comprise a second pump which is arranged to operate on heat which has already done useful work in a first pump and which would otherwise be wasted. In accordance with another feature of the invention, two serially connected thermopumps are operated in such fashion as to supply liquid at relatively high pressure for any desired purpose, and wherein the two pumps are operated in cascade with respect to the supply of heat thereto. In accordance with a further feature of the invention, two pumps can be operated in parallel with respect to the circulating effect thereof and in cascade with respect to the supply of heat thereto.

A more complete understanding of the invention, and of further objects and features thereof, can be had from the following description of illustrative embodiments thereof, when considered in connection with the accompanying drawing, wherein

Figure 1 is a schematic diagram of a thermopump system embodying the invention for circulating one liquid by vaporization and condensation of a different liquid,

Figures 2 and 5 illustrate two different types of separator elements for use in pump systems embodying the invention,

Figures 3 and 6 are schematic diagrams of compound thermopump systems embodying the invention, and wherein one pump is operated by heat extracted from another pump and the pumps are connected in series to the load circuit, and

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Figure 4 is a schematic diagram of a compound thermopump system embodying the invention wherein the pumps are connected in parallel to a load circuit.

Referring to Figure 1 of the drawing, this figure shows a system for pumping one liquid by means of a thermopump 10 containing a different liquid. For example, the pump unit 10 may be filled with water, and the pumping circuit 12 may contain some corrosive liquid such as an acid, an alkali or the like. The pump itself is shown for illustrative purposes as being of the type disclosed in U.S. Patent 2,553,817, comprising an upright heating tube or generator 14, heated by an electrical heating element 16. The upper end of the generator is provided with an inverted U-shaped bend 18. The bend 18 serves as a trap to accumulate vapor as it is formed in the heated portion of the generator. One end of the bend communicates with a U-shaped vapor tube 20 which is of considerably smaller cross-section than the generator 14 in order to insure delivery of vapor therethrough as a coherent body rather than as a series of bubbles.

The vapor tube 20 extends downwardly from the generator and then upwardly to the upper portion of an upright condensing tube or condenser 22. The condenser 22 may be of substantially the same cross-sectional size as the generator 14 and is adapted to hold a body of liquid which is in communication with the liquid in the generator. The upper end of the condenser 22 is provided with an outlet tube 24 communicating with a valve assembly 26 which controls the discharge of liquid from and the delivery of liquid to the pump unit.

The valve assembly includes two check valves 28, 30. One valve, 30, permits only the discharge of liquid from the pump unit, while the other valve, 28, permits only the entry of fresh liquid into the pump unit.

It will be noted that the valve assembly 26 maintains only a small volume of liquid between the two valves 28, 30. This arrangement appears to contribute in some instances to the smooth operation of the pump unit, since it makes it possible to draw relatively cool liquid into the top of the condenser. Only a small amount of the previously discharged warm liquid remaining in the valve assembly will be drawn back into the condenser, and this warm liquid is well cooled by admixture with the relatively large quantity of fresh liquid drawn into the unit.

Communication between the lower ends of the generator 14 and the condenser 22 is effected by means of a reservoir 32 adapted to hold a body of the pump liquid in communication with the lower portions of both the heating and condensing tubes. The reservoir 32 preferably is of such size as to hold a body of liquid of sufficient mass to minimize heat transfer from the liquid in the lower end of the generator to the liquid in the lower end of the condenser. By thus minimizing the heat transfer from the heating tube to the condensing tube it is possible to prevent elevation of the temperature of liquid in the upper portion of the condensing tube to a non-condensing value.

In the embodiment of the invention presently being described, the check valve assembly 26 is connected to a loop 34 which includes cooling means in the form of tubing fins 36 or the like. This loop 34 is connected by a separator element 40 to a valve assembly 42 in the load circuit 12. It will be understood that the pump 10 causes liquid to circulate through the load circuit 12. The circuit 12 may connect a reservoir and a load device (not shown), or may comprise a closed loop through which liquid is continually recirculated by the pump 10.

In the Figure 1 system, the separator element 40 prevents mixing of the liquids in the pump 10 and in load circuit 12. Thus, the element 40 may comprise a U tube 44 filled with mercury or some other liquid which will not mix readily with either the pump or load circuit liquids.

Of course, other comparable separating elements can be used. For example, as shown in Figure 2, the separator may comprise a diaphragm assembly, comprising a housing 50 enclosing a flexible diaphragm 52 which divides the housing into two separate compartments 54, 56. One compartment, 54, then would be coupled to the loop 34 while the other compartment, 56, would communicate with the load circuit valve assembly 42. Additional examples of separator elements are given hereinafter.

In considering the operation of the system shown in Figure 1, it will be assumed that the pump unit 10 is completely filled with a readily vaporizable liquid, such as water. When heat is applied to the generator 14 by passing current through the heating element 16, the liquid in the generator will boil, forming vapor. As the vapor is generated, it will collect in the inverted U-shaped portion 18 of the generator. The generation of vapor within the pump unit will force liquid out of the unit 10 through the outlet check valve 30. The vapor will continue to form and to displace the liquid in the generator tube 14 until the vapor reaches the lowermost point of the vapor tube 20. At this point, the liquid in the generator will be at the same level in the upright leg of the generator and in the vapor tube 20, and the taller column of liquid in the condenser 22 will be supported by the pressure of the vapor in the generator. Once vapor starts upward in the vapor tube 20, the hydrostatic balance will be upset, and liquid will flow down in the condenser 22 and up into the generator 14, forcing the vapor to flow into the relatively cool liquid in the upper portion of the condenser. The resulting contact between the small cross-sectional mass of vapor and the relatively large cross-sectional mass of liquid will initiate condensation of the vapor. As condensation of the vapor proceeds, the difference in level between the liquid in the upper portion of the condenser and the liquid in the heating zone of the generator will continue to cause the liquid to flow upwardly through the generator. The resulting ingress of relatively cool liquid into the heating zone will terminate further vaporization under these conditions and expedite the condensation taking place in the upper portion of the condenser. Thus, once condensation is initiated it will continue rapidly and quickly establish a partial vacuum in the pump unit. Under these conditions, liquid will flow into the pump through the check valve 28, with the result that relatively cool liquid will flow into the upper portion of the condenser until the pressure within the pump unit returns to normal. At this point in the operating cycle, the liquid again substantially completely fills the pump unit and is at rest. The continued application of heat to the generator once again will establish vaporizing conditions therein and the pump cycle will repeat. It will be seen, therefore, that heat continuously applied to the generator will cyclically discharge liquid from the pump unit under pressure and draw fresh liquid thereinto.

It can be seen that continued operation of the pump involves the cyclical transfer of heat from the generator 14 to the condenser 22 in the form of latent heat contained in the vapor flowing to the condenser. While the liquid in the condenser will be replaced continuously by flow through the check valve assembly 26, it can be appreciated that the temperature of the circulating liquid in the closed loop 34 will tend to increase due to the continued supply of heat until eventually the liquid in the pump 10 and in the closed circuit 34 might reach a temperature at which vapor would no longer condense rapidly, and the operation of the pump would stop. In order to prevent this from happening, the air-cooled finned tube sections 36 are provided in the closed loop circuit 34 in order that the heat coming over to the condenser can be dissipated as the liquid circulates through the closed circuit 34.

The movement of liquid back and forth in the connection line 24 between the condensing tube 22 and the check valve assembly 26 will be duplicated in the separating element 40, resulting in a corresponding liquid movement on the load circuit side of the separator. Thus, the liquid to be circulated will alternately be drawn in through the load circuit inlet check valve 43 and then forced out through the outlet check valve 45 to obtain the desired circulation.

In Figure 3, there is shown an alternative arrangement for operating a pump system with different liquids in the load and pumping circuits, together with a modified arrangement for extracting heat from a pump condenser in order to prevent overheating thereof. In this case, additional efficiency also is obtained, because the heat that is simply dissipated by the finned tubing sections 36 in the Figure 1 system is utilized in Figure 3 to operate a second pump feeding the same load circuit.

Referring to Figure 3, a first thermopump 10a is connected to a check valve assembly 42a in a load circuit 12 by a separator 40. The pump 10a differs from the pump 10 of Figure 1 in that the generator 14a is connected directly to the condenser 22a rather than being connected through a reservoir. The condenser 22a opens into a tank 23 above the condenser, and the tank 23 is also connected back to the condenser by a branch tube 25. While the reason is not clearly understood, it has been found that this arrangement of parts gives better efficiency under some conditions than the pump configuration 10 of Figure 1, particularly where it is desired to operate pumps in series with respect to heat flow, as will be explained presently.

In the pump 10a, hot liquid tends to flow to the top of the tank 23 on the vaporizing cycle, while cooler liquid returns to the pump on the suction stroke through the branch tube 25.

Beyond the check valve assembly 42a, a surge or accumulator tank 58 is connected to the load circuit 12 to absorb the fluctuations in liquid delivery which will occur due to the cyclical operation of the pump 10a, permitting the pump 10a to operate at a pressure which is lower than that imposed by the load. The accumulator 58 may alternatively comprise a flexible walled tank similar to the diaphragm chamber 50 of Figure 2 or the bellows of Figure 5. Downstream from the accumulator 58 in the load circuit 12 is a second check valve assembly 42b, through which liquid is circulated by a second thermopump 10b.

The second thermopump 10b also is shown in somewhat different form than the first pump 10a, although it is to be understood that the various types of pumps shown in the drawings are interchangeable.

The second pump 10b has a condenser 22b, a vapor tube 20b and a generator 14b, generally similar to the corresponding parts 22a, 20a, 14a of the pump 10a. However, an additional element 62 is provided in the second pump 10b for vapor collection. The vapor collector 62 comprises an elongated cylinder of substantially greater cross-section than the generator tube 14b. The generator tube 14b opens into the top of the vapor collector 62, while the vapor tube 20b slopes downwardly from a point on the upper periphery of the collector. The condenser 22b is connected to the collector 62 at or near the lower end thereof, while a small diameter inlet tube 64 connects the bottom of the generator 14b with the collector 62 at a point partway up the collector.

The collector 62 preferably contains a float element 66 which separates the liquid from the vapor phases as vapor is delivered from the generator to the vapor collector.

In the Figure 3 system, the first pump 10a will be filled with a liquid having a substantially higher boiling point than the liquid being circulated through the load

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circuit 12. The second pump 10b will operate with the same liquid as that being circulated through the load circuit. Since this second liquid has a lower boiling point than the liquid filling the first pump 10a, it is possible to operate the second pump 10b on the heat which is passed into the first pump condenser 22a with the incoming vapor. In this way, the condenser of the first pump can be cooled without a special and separate cooling circuit as in Figure 1, and at the same time the efficiency of the system as a whole will be increased by using heat which would otherwise be dissipated to operate the second pump. Accordingly, the generator 14b of the second pump is placed in heat exchange relation with the first pump condenser 22a; preferably being disposed inside the condenser tank 23 as shown. Fins 36 may be placed on the generator 14b to increase the heat transfer surface.

When the temperature of the liquid in the condenser tank 23 comes up to the boiling point of the liquid in the second pump 10b, the liquid in the generator 14b will be heated to the boiling point and will vaporize. The vapor thus formed will collect in the top of the generator 14b and also in the collecting chamber 62, and in so doing will force liquid from the generator 14b and collector 62 and through the outlet valve 45b, the principal flow of liquid being down through the collector 62 and up through the condenser 22b. Vapor will also collect in the vapor tube 20b. Once the vapor in the tube 20b reaches the lowermost point in the tube and starts up toward the condenser 22b, the hydrostatic balance in the system will be upset. The head of liquid in the condenser 22b now will force liquid to flow upwardly in the collector 62 and generator 14b. In turn, this will force the vapor out of the collector 62 and through the vapor tube 20b. Meanwhile, the vapor forced through the tube 20b will condense as it is discharged into the relatively cool condenser 22b. The hydrostatic refilling of the collector 62 will proceed very rapidly, once initiated, so that the vapor in the collector will all be delivered quite abruptly to the condenser 22b, where it can condense very quickly if the condenser temperature is low enough. The resulting pressure drop in the system will cause a fresh charge of liquid to be drawn in through the inlet valve 43b to replace the condensed vapor.

The float 66 greatly reduces the area of contact between the liquid and the vapor in the collector 62, and presents to the vapor a stable surface that needs to be heated only once rather than a changing, turbulent liquid surface that will continuously condense some vapor and thereby reduce the pumping efficiency.

In order to have the smallest possible area of liquid-vapor contact, the float 66 is preferably shaped to conform rather closely in cross-section to the inside cross-section of the collector 62, and with cross-sectional dimensions just enough smaller than the corresponding inside dimensions of the vessel 62 to allow free float movement.

The foregoing and other advantageous features of the pump 10b are described in detail and claimed in the copending application of R. E. Coleman, Serial No. 297,371, filed July 5, 1952, now Patent No. 2,744,470, and assigned to the assignee of the present invention.

It can be seen, then, that the first pump 10a will deliver liquid to the accumulator 58 at some preselected pressure, and the second pump will deliver liquid to the load at a higher pressure.

In a typical case, for example, the problem might be to use heat from a source at a temperature of the order of 750° F., to pump water against a load pressure of, say 70 p.s.i.g. While it would be possible to operate a single pump with water across the temperature range, at 750° F. the entire system would have to be able to withstand pressures far in excess of the 70 pound load pressure. Instead, using an arrangement as in

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Figure 3, the first pump might be filled with mercury and designed for operation across a temperature range of, say 750° F. (maximum generator temperature) to 350° F. (average condenser temperature) and a pressure range of 30 to 15 p.s.i.a. In this case, of course, the separator 40 may comprise a U-tube like the tube 44 of Figure 1, since the mercury in the pump 10a would not mix with the water in the load circuit 12b.

The second pump would then operate with the load circuit liquid (water) across the temperature and pressure ranges of, say, 310° F. (maximum generator temperature) to 150° F. (average condenser temperature) and 70 to 30 p.s.i.a., respectively. This assumes a temperature drop of 40° F. through the walls of the generator 14b.

In the present illustrative example, it is assumed that a moderate rise in temperature of the load circuit liquid is permissible. Accordingly, the load circuit 12 is coupled to the condenser 22b of the second pump by a short coupling line 24b so that fresh load circuit liquid will circulate in and out of the condenser 22b on each cycle to keep this condenser cool. If this is not permissible, the volume of the coupling line 24b can be made substantially greater than the volume of one stroke of the pump 10b so that the same liquid, rather than fresh liquid, will circulate in and out of the pump condenser 22b. In such case, the coupling line 24b should be provided with fins or other cooling means to prevent overheating of the condenser. Alternatively, a cooling circuit arrangement can be used such as the circuit 34 as shown in Figure 1, but with the separator 40 eliminated.

It can be seen that the downstream check valve 45b in the second check valve assembly can only be opened by a pressure of 70 lbs. absolute in the check valve assembly 42b. Hence, the accumulator 58 is necessary between the two sets of check valves 42a, 42b to absorb the output of the first pump 10a at a lower pressure than that imposed on the system by the load. On its suction stroke, the second pump 10b will draw in liquid from the accumulator and will pass it on to the load at the higher pressure as required.

The principle of operating a second pump on the rejected heat from a first pump can be applied in a number of other ways to obtain high system efficiency. For example, additional pumps for circulating different liquids in separate circuits can be coupled to each other as illustrated by pump 10e in Figure 3 to make efficient use of available heat.

Another way in which thermopumps can be used advantageously in series relation with respect to heat flow, is to connect them in parallel to a common load circuit. This is shown in Figure 4, where two check valve assemblies 42c, 42d are connected in a common load circuit 12 by parallel lines 72, 74. A first coupling line 24c extends from one check valve assembly 42c to the condenser 22c of a first thermopump 10c through a separator 40. A second coupling line 24d extends from the other check valve assembly 42d to the condenser 22d of a second thermopump 10d.

The generator 14c of the first pump 10c is arranged to receive heat from any suitable source, shown for simplicity as an electrical heating element 16. The generator 14d of the second pump 10d is placed inside the first pump condenser 22c to operate on the rejected heat of the first pump. The two pumps 10c, 10d shown in Figure 4 are of the same general type as the pump 10 in Figure 1, the principal difference being that the reservoirs 32c, 32d for cutting down transfer of heat are oriented vertically rather than horizontally to make the overall assembly more compact.

In the system shown in Figure 4, it can be assumed for one example that two liquids with different boiling points are used in the two pumps, as in the Figure 3 system. In this case, the liquid in the second pump 10d is the

same as that in the load circuit 12, while the liquid in the first pump 10c is a higher boiling point liquid, as previously discussed. In this case, however, the two pumps will operate across the same pressure differential. For example, assuming mercury and water as the two liquids, the first pump 10c might operate at generator and condenser temperatures of, say 750° F. and 300° F., while the second pump operates at generator and condenser temperatures of 250° F. and 160° F., both pumps operating against a load pressure of 30 p.s.i.a.

Another possibility in the Figure 4 system is that of using the same liquid in both pumps, and operating the pumps at different pressure levels, with a pressure reducing element at 40 separating the first pump 10c from the load circuit 12. While a variety of such pressure-reducing elements are well known per se, there is illustrated in Figure 5 one suitable type, comprising a housing 80 containing a bellows element 82, and provided with a spring 84 partially compressing the bellows for pressure balancing.

Using water as the liquid for the entire system, for example, the first pump 10c might operate at generator and condenser temperatures of 400° F. and 300° F., respectively, across a corresponding range of pressures from 250 p.s.i.a. to 68 p.s.i.a. The second pump 10d would then operate, say, at generator and condenser temperatures of 250° F. and 160° F., across a pressure range from 30 p.s.i.a. to 15 p.s.i.a. The pressure step-down ratio of the bellows element 80 would be of the order of 8 to 1 and 4 to 1 at the two pressure extremes.

It will be seen that a compound pumping system feeding a load circuit in series fashion, somewhat similar to the arrangement shown in Figure 3, and using the same liquid in both pumps, can be made by using a pressure reducing device as in Figure 5. In other words, two pumps can be operated in series for circulating liquid through a load circuit, and using the same liquid in both pumps, with the heat in the condenser of one pump furnishing the energy to operate the second pump in the same way that it does in the system of Figure 3.

This is illustrated in Figure 6, wherein the condenser 22 of a first pump 10 is connected directly to one check valve assembly 42 by a coupling line 24 of volume greater than that of one stroke of the pump, while a second pump 10b is connected to a second set of check valves 42b through a separator 40 comprising a step-up device. With this arrangement, the first pump 10 must operate against a higher pressure than the second pump 10b, which means that the boiling point of the liquid in the first pump will be substantially above the boiling point of the same liquid in the second pump. The pressure translating element 40 between the second pump condenser 22b and the check valves 42b is required because, as a practical matter, there will be some "gap" between the average temperature in the first pump condenser 22 and that inside the generator 14b of the second pump. Accordingly, there will also be a gap between the minimum pressure for the first pump and the maximum pressure generated by the second pump. This gap is covered by the pressure step-up element 40, which converts the volume changes in the second pump to similar changes at a higher pressure level in the load circuit 12.

The beneficial features of this arrangement on the efficiency of the system as a whole are related to the pressure-volume-temperature characteristics of the pump liquid, as well as to the series heat transfer arrangement.

By reference to standard steam tables, the efficiency of the thermopump, operating with water, can be computed at different pressures in accordance with the formula

$$\frac{(P_{\max} - P_{\min}) \times (V_{\text{steam}} - V_{\text{water}})}{(H_{\text{steam}} - H_{\text{water}}) \times 778}$$

where $P_{\max}$ is the maximum pressure within the pump, in pounds per sq. ft.; $P_{\min}$ is the minimum pressure within the pump, in pounds per sq. ft.; V is the specific volume

of the fluid, in cu. ft. per pound; H is the enthalpy of the fluid in B.t.u. per pound.

Such a computation shows that the pump will operate most efficiently with a pressure rise across the pump of about 450 p.s.i.a. If it is attempted to operate a single pump at any greater pressure rise, the applied heat will not be utilized at maximum efficiency. Furthermore, regardless of the efficiency (i.e. pressure rise) at which the pump is operated, the heat passing over to the condenser will be wasted.

In the Figure 6 system, therefore, a higher efficiency can be obtained for a given temperature range (say, 800° F.), because the first pump can be operated across its most efficient range at the level of, say, 845 p.s.i.g. to 445 p.s.i.g., while the second pump also is operating across its 400 pound maximum efficiency range between, say, 400 p.s.i.g. and 0. The gap in pressure between the upper limit of 400 p.s.i.g. for the second pump and the lower limit of 445 for the first pump will be taken care of by the pressure reducing element 40 between the first pump and the load circuit. Thus, maximum efficiency will be maintained across the entire available temperature range.

What is claimed is:

1. In a heat-actuated pumping system for circulating liquid through a load circuit, first and second liquid-filled pump units within which to vaporize and condense liquid to force liquid to flow out of and into said units, a coupling line connecting said first unit to said load circuit, a first pair of check valves in said load circuit located one upstream and one downstream of said coupling line through which to pass liquid from said load circuit into and out of said coupling line, a second coupling line connecting said second unit to said load circuit, a second pair of check valves in said load circuit located one upstream and one downstream of said second coupling line through which to pass liquid to and from said load circuit through said second coupling line, and means in one of said coupling lines separating the liquid in that one of said pump units which is connected to said one coupling line from the liquid in said load circuit.

2. The invention defined in claim 1, wherein said pairs of check valves are in series in said load circuit.

3. The invention defined in claim 1, wherein said load circuit includes two branches which are connected in parallel between common portions upstream and downstream of said branches, said pairs of check valves being located one pair in each of said branches.

4. In a heat actuated pumping system, in combination, a first pump unit and comprising a generator within which to vaporize said liquid by heating, a condenser within which to condense vapor by cooling and means connecting said generator and said condenser to conduct liquid and vapor therebetween, cooling means for said condenser of said first pump unit, said cooling means comprising a structure in heat exchange relation with said condenser, and a second pump unit comprising a generator within which to vaporize liquid by heating and a condenser within which to condense vapor by cooling, said cooling means for said condenser of said first pump unit constituting said generator of said second pump unit.

5. In a heat actuated pumping system, in combination, a first pump unit adapted to be filled with liquid and comprising a generator within which to vaporize said liquid by heating, a condenser within which to condense vapor by cooling and means connecting said generator and said condenser to conduct liquid and vapor therebetween, cooling means for said condenser of said first pump unit, said cooling means comprising a structure in heat exchange relation with said condenser and adapted to be filled with liquid, and a second pump unit comprising a generator within which to vaporize liquid by heating and a condenser within which to condense vapor by cooling, said cooling means for said condenser of said first pump unit constituting said generator of said second

pump unit, a circuit through which to circulate liquid, a first pair of check valves in said circuit, coupling means connecting one of said pump units to a point in said circuit between said check valves, a second pair of check valves in said circuit, and coupling means connecting the other of said pump units to a point in said circuit between said second pair of check valves.

6. In a heat actuated pumping system, a pair of liquid-filled pump units each comprising: a generator within which to vaporize liquid by heating, a condenser within which to condense vapor by contact with a cool body of liquid in said condenser, and means connecting said generator and said condenser through which to transfer vapor and liquid therebetween; said generator of one of said units being in heat exchange relation with said condenser of the other of said units to provide heating for said one unit generator and cooling for said other unit condenser; said units being charged with liquid at predetermined pressures; the boiling point of the liquid in said one unit being lower than the boiling point of the liquid in said other unit at said predetermined pressures.

7. In a heat actuated pumping system, in combination, first and second pump units each comprising a generator within which to vaporize liquid, a condenser within which to condense vapor formed in said generator, and conduit means connecting said generator and said condenser through which to transfer liquid and vapor therebetween, the generator of said second pump unit being disposed within the condenser of said first pump unit to receive heat therefrom.

8. The invention defined in claim 7 wherein said pump units are filled with the same liquid, the liquid in said first unit being maintained at a higher pressure than the liquid in said second unit.

9. The invention defined in claim 7 wherein said units are filled with liquids which boil at different temperatures, said first unit being filled with a liquid which boils at a higher temperature than the liquid in said second unit.

10. In a heat actuated pumping system, in combination, first and second pump units each comprising a generator within which to vaporize liquid, a condenser within which to condense vapor formed in said generator, and conduit means connecting said generator and said condenser through which to transfer liquid and vapor therebetween, the generator of said second pump unit being disposed within the condenser of said first pump unit to receive heat therefrom, a circuit through which to circulate liquid, a first pair of check valves in said circuit, conduit means connecting one of said pump units to a point in said circuit between said check valves, a second pair of check valves in said circuit, conduit means connecting the other of said pump units to a point in said circuit between said second pair of check valves, and liquid separating means included with said last-named conduit means to prevent mixing of the liquid in said circuit with the liquid in said other pump unit.

11. The invention defined in claim 10 wherein said separating means comprises a pressure translating device through which to transfer liquid movement at different pressure levels.

12. The invention defined in claim 10 wherein said pairs of check valves are in series in said load circuit.

13. The invention defined in claim 10 wherein said

pairs of check valves are connected in separate parallel branches of said load circuit.

14. In a heat-actuated pumping system, the combination including a first pump comprising a first vapor generator having a liquid therein and means to vaporize said liquid, a condenser having liquid therein, first conduit means connecting said generator with said condenser for alternate cyclical flow of vapor generated in said generator to said condenser for condensation therein and release of heat and thereafter flow of liquid from said condenser to said generator whereby vapor is cyclically forced by pressure into and condensed in said condenser and thereafter liquid is directed into said generator from said condenser, second conduit means having means at one end preventing flow in one direction and means at the opposite end preventing flow in said one direction, a liquid reservoir connected to said one end of said second conduit to supply liquid to said conduit, third conduit means connecting said condenser to said second conduit means intermediate the ends thereof whereby liquid flowing in from said reservoir enters said condenser and liquid forced out of said condenser by the vapor pressure during vaporization in said generator is delivered through said second conduit and out said opposite end thereof; a second pump including a second vapor generator having liquid therein, and means connecting said second generator and said first pump for utilizing the heat released by the latter for vaporizing liquid in the former.

15. In a heat-actuated pumping system, the combination including a first pump comprising a first vapor generator having a liquid therein and means to vaporize said liquid, a condenser having liquid therein, first conduit means connecting said generator with said condenser for alternate cyclical flow of vapor generated in said generator to said condenser for condensation therein and release of heat and thereafter flow of liquid from said condenser to said generator whereby vapor is cyclically forced by pressure into and condensed in said condenser and thereafter liquid is directed into said generator from said condenser, second conduit means having means at one end preventing flow in one direction and means at the opposite end preventing flow in said one direction, a liquid reservoir connected to said one end of said second conduit to supply liquid to said conduit, third conduit means connecting said condenser to said second conduit means intermediate the ends thereof whereby liquid flowing in from said reservoir enters said condenser and liquid forced out of said condenser by the vapor pressure during vaporization in said generator is delivered through said second conduit and out said opposite end thereof; a second pump including a second vapor generator having liquid therein, means connecting said second generator and said first condenser for utilizing the heat released by the latter for vaporizing liquid in the former, and means in said system for separating the liquid in one of said pumps from the rest of said system.

References Cited in the file of this patent

UNITED STATES PATENTS

60	1,848,226	Scott-Snell et al.	Mar. 8, 1932
	2,553,817	Erland af Kleen	May 22, 1951
	2,688,923	Bonaventura et al.	Sept. 14, 1954
	2,744,470	Coleman	May 8, 1956