United States Patent

[11] 3,577,880

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[21] Appl. No. 793,673
[22] Filed Jan. 24, 1969
[45] Patented May 11, 1971
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[32] Priority Feb. 2, 1968
[33] Republic of South Africa
[31] 67/6058

[54] **MEANS FOR VARYING THE PHYSICAL CONDITIONS OF A GAS**
14 Claims, 4 Drawing Figs.

[52] U.S. Cl. 62/86, 62/172, 62/401
[51] Int. Cl. F25b 9/00
[50] Field of Search 62/86, 172, 401; 230/70

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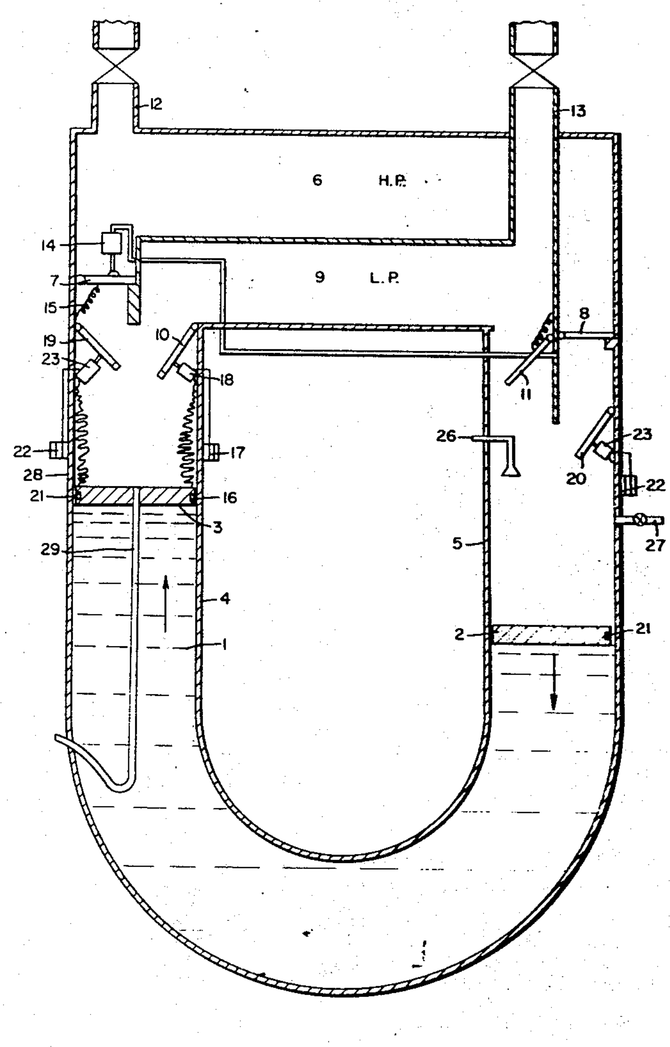
ABSTRACT: In compression and expansion compartments embodying liquid pistons reciprocating in unison but in opposite directions gas is subjected to compression in one compartment followed by expansion in the other or vice versa and subjected to a heat exchange operation during its passage between the inlet of one compartment and the outlet of the other.



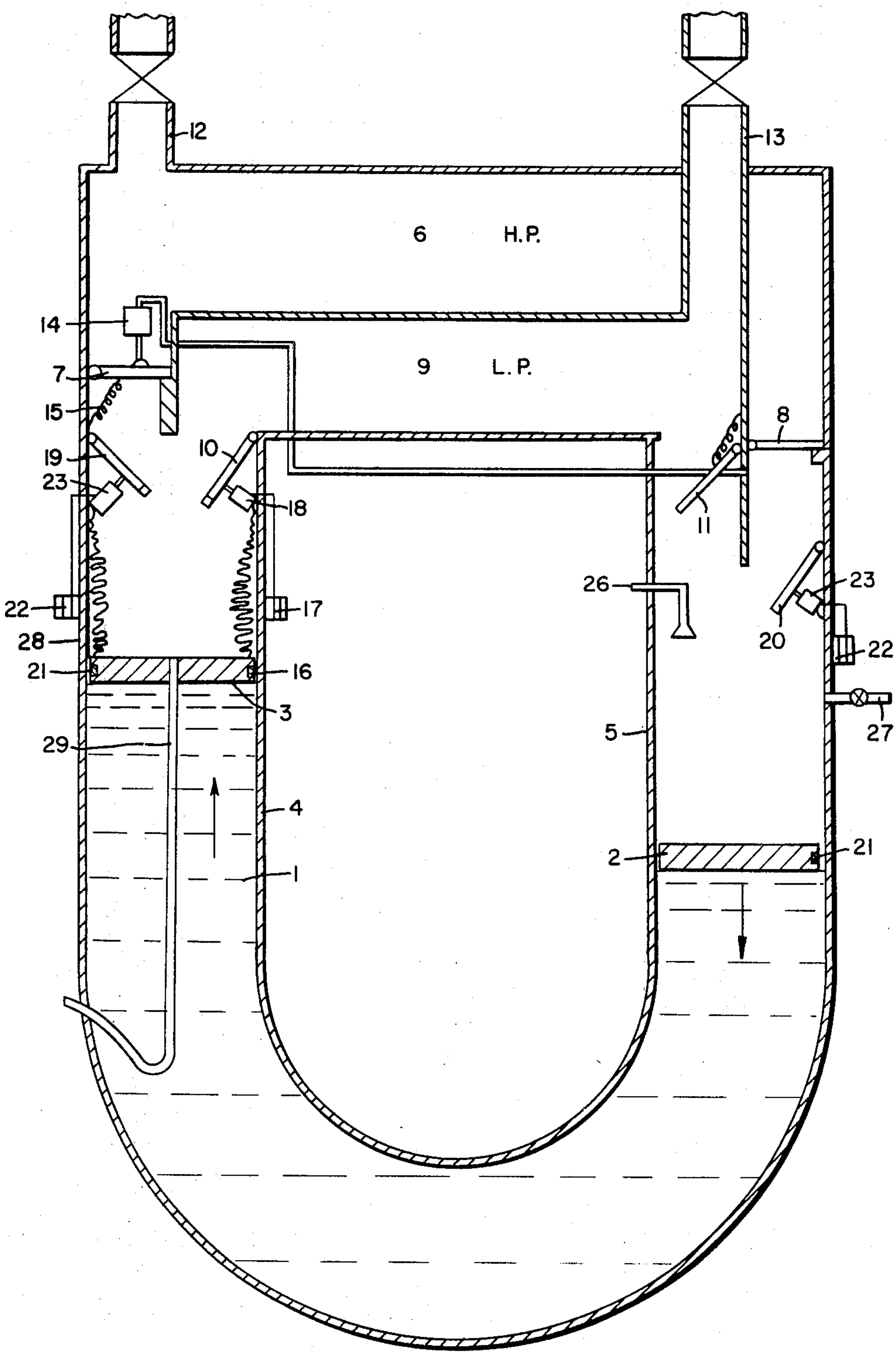


FIG. 1

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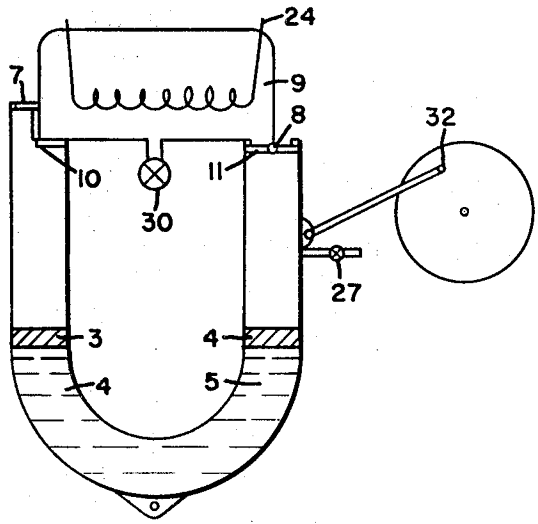

FIG. 2

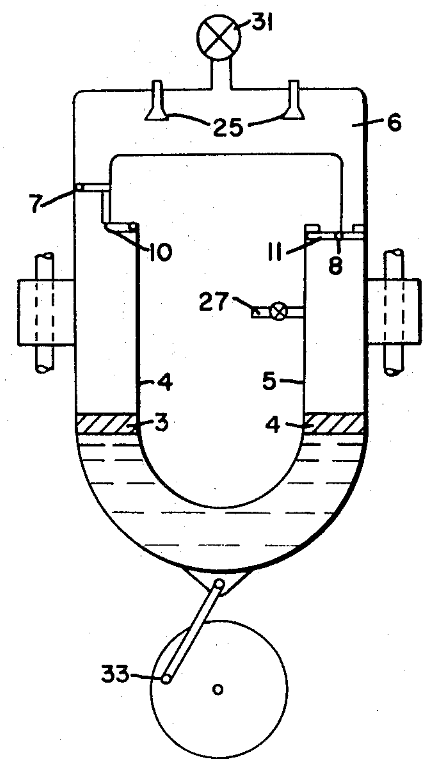

FIG. 3

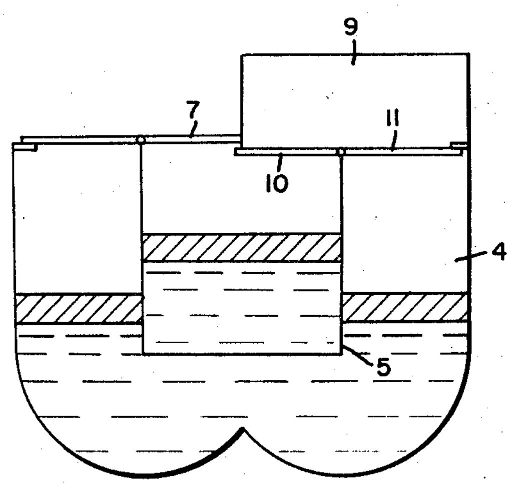

FIG. 4

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MEANS FOR VARYING THE PHYSICAL CONDITIONS OF A GAS

This invention relates to a method and apparatus for varying the physical condition or state of a gas. The basic physical conditions envisaged are temperature, and moisture content of the gas.

By variation of such physical conditions it is possible to carry out heating and cooling operations, dehumidification of moist gas, drying operations and general liquid evaporation operations such as fractionation, desalination, concentration and the like.

In accordance with this invention there is provided a method of changing the condition of a gas by means of a compression compartment and an expansion compartment having a valve controlled inlet and a valve controlled outlet, and each compartment embodying a liquid piston, comprising operating said pistons to reciprocate in unison but in opposite directions to draw gas into the one compartment at one pressure, thereafter to change the gas pressure in the same compartment and convey it at said changed pressure to the other compartment and then to restore the gas to approximately its original pressure in the latter compartment and discharge it therefrom, said gas being subjected to a heat exchange operation during its passage from the inlet of the one compartment to the outlet of the other compartment.

Further according to this there is provided apparatus for changing the condition of a gas comprising a compression and expansion compartment interconnected at the lower ends thereof, liquid in said compartments forming a liquid piston in each, an inlet and an outlet valve connected to each compartment, a connection between the outlet valve of the one compartment and the inlet valve of the other compartment, means for oscillating the liquid in said compartments, and an additional liquid level responsive outlet valve communicating with each compartment.

The invention is illustrated diagrammatically in the accompanying drawings in which:

FIG. 1 shows the apparatus with various possible attachments;

FIG. 2 shows the apparatus in the basic form used to carry out gas heating and dehumidification;

FIG. 3 shows the apparatus in the basic form used to carry out gas cooling; and

FIG. 4 shows a modification in the shape of the basic apparatus.

As shown in FIG. 1 the apparatus may comprise a U-tube partly filled with liquid **1**. Barrier floats **2**, **3**, are supported on the liquid, one in each of the arms **4**,**5**, each of which forms a separate compartment.

The arms **4**,**5**, are connected to a high pressure vessel **6** via valves **7**,**8**, and to a low pressure vessel **9** by valves **10**,**11**. The liquid is caused to oscillate in the tube by means hereinafter described, and the valves are operated generally in accordance with the pressure conditions prevailing in the apparatus.

By suitable operation of the valves **7**, **8**, **10** and **11**, air may be drawn in through connection **12** and vessel **6** and into leg **4** which forms the expansion chamber of the apparatus. The air may then be expanded in leg 4, discharged at low pressure into leg **5** via vessel **9** and compressed to approximately its original pressure in leg 5, which forms the compression chamber of the apparatus. The air at approximately its original pressure may then be discharged from leg 5 back into vessel **6**.

Conversely the gas may be drawn into leg **5** via connection **13** and vessel **9**, compressed in leg 5, discharged at high pressure into leg 4 via vessel 6, expanded in leg 4 and recirculated to vessel 9 at approximately its original pressure.

The above two cycles form the basis on which the apparatus according to this invention is operated.

Inlet valve **11** and outlet valve **8** are of a simple clack valve type operated by a pressure differential on opposite sides thereof, these valves being lightly spring loaded to close.

Valve **7** cannot be operated by an ordinary pressure differential since it is basically required to limit the amount of gas drawn into leg **4** and close before the bottom limit of the downward movement of float **3** so as to ensure expansion of gas in leg **4**.

Since the air drawn into leg **4** will always be at high pressure relative to that in vessel **9** it has been found convenient to make the operation of valve **7** dependent on the pressure in leg **5** into which vessel **9** discharges. As illustrated valve **7** is fitted with an air cylinder **14** connected to leg 4 and acting to open valve 7 against the loading of a spring **15** when the pressure in leg **4** is below a predetermined value. When the pressure in leg **5** is at a predetermined higher pressure that is at any desired predetermined upward movement of float **2**, the air cylinder **14** can no longer hold valve **7** open against its spring loading and it will accordingly close.

Valve **10** opens due to the pressure differential when the pressure in leg **4** is less than that in vessel **9** and is positively closed near the top of the stroke of float **3**. This may be done in any convenient manner such as the incorporation of a magnet **16** in float **3** which actuates a short term delay switch **17** connected to operate the valve closing solenoid **18**.

In use it has been found that due to the momentum developed by the oscillating liquid **1** the apparatus has an inherent tendency to overrun which would result in the barrier floats **3**,**4**, tending to hit up against the upper portions of legs **4**,**5**. This is prevented by trapping a body of gas in each leg in turn as the corresponding float approaches the top of its stroke. This body of gas, due to its compression, acts to cushion the upward movement of the liquid piston and absorb the momentum thereof, the energy of the compressed gas thereafter being imparted to the liquid piston on its return downward movement.

Since valves **7** and **8** open upwardly they cannot remain closed against the pressure of the compressed gas and accordingly two additional upwardly closing valves **19** and **20** are used. These are made liquid level responsive for example by the use of magnets **21**, short term delay switches **22** and solenoids **23** operating in a manner similar to that described in relation to valve **10**.

Since compression of a gas heats it and conversely expansion thereof cools it, the apparatus may be used in conjunction with a heat exchange operation for heating or cooling air or other gas.

It will be appreciated that when a vessel **6** or **9** is open to atmosphere it may be eliminated. This is shown in FIG. 2 illustrating a method of carrying out a heating process, and in which the single intermediate low pressure chamber **9** is used.

In using the apparatus of FIG. 2 to heat air, the air is drawn via valve **7** into leg **4** in a moist or humid condition but before the liquid in leg **4** has reached the bottom of its travel valve **7** is closed. Since at this stage of the cycle valve **10** is also closed the air expands in leg 4 resulting in condensation of part of the liquid in leg 4, the latent heat of condensation being transferred to the gas so that the enthalpy or total heat content of the gas itself is increased as opposed to the enthalpy of the gas vapor system.

The low pressure gas is now transferred to vessel **9** at subatmospheric temperature and pressure via valve **10** where if desired it may be subjected to a heat exchange operation using a heat exchanger **24**. During the upward movement of the liquid in leg **4** there is a corresponding downward movement of the liquid in leg **5**, which, via open valve **11**, is utilized to draw into leg **5**, at subatmospheric temperature and pressure, air which had been transferred to vessel **9** in a previous cycle.

On the return stroke of the liquid in leg **5**, valves **8** and **11** are closed and the low temperature low pressure air compressed to atmospheric pressure and discharged for use through valve **8**. It will be seen that since the enthalpy of the gas discharged has been increased by the latent heat of condensation of its original liquid content, even without the use of a heat exchanger **24** it may be discharged dryer and at appreciably higher temperature than the air drawn into leg **4**.

To cool air a reverse operation is effected as shown in FIG. 3. In this case the air is drawn in through valve 11, compressed in leg 5 and transferred at high pressure and temperature to vessel 6, vessel 9 now being eliminated.

In this condition it is subjected to a heat exchange operation preferably using water sprays 25 whereby it will give up part of its sensible heat to vaporise the water in addition to a transfer of sensible heat to the water. The cooled air, still at high pressure, is then passed via valve 7 into leg 4 where it is expanded to subatmospheric temperature and approximately atmospheric pressure during downward movement of the liquid in leg 4. On the return upward movement of the liquid in leg 4 valve 10 is opened allowing discharge of the cooled air to atmosphere.

Since the air in a hot compressed condition is suitable for evaporating liquids the apparatus may be used as an evaporator, for example for desalination of brine and in general for any like operation in which it is desired to separate a liquid component of a mixture, solution or suspension. Various cycles may be used based on compression of a gas to heat it, spraying liquid containing other components into the hot compressed gas during compression, to vaporise part of the liquid content, and subsequent sufficient expansion of the hot moist compressed gas to effect condensation of the liquid content. Thus in the apparatus of FIG. 1 for example, air may be compressed in leg 5 with brine injected through spray 26 into leg 5 during compression. The moist compressed air may then be transferred via vessel 6 to leg 4 where it is expanded and the water condensed. Provision is made in legs 5 and 4 for drawoff of the concentrated brine and condensed water respectively. This may be done in any convenient manner. Thus, for example, in the desalination of brine the liquid 1 forming the liquid piston will normally be brine so that admixture of the concentrated brine with it in leg 5 will not matter provided the volume of the liquid piston is maintained constant. Since increase in volume of the liquid piston will result in increase in maximum pressure in leg 5, surplus liquid may be automatically discharged through a suitable relief valve 27, which may be used in all applications of the invention in which the volume of the liquid piston lends to build up.

The water condensed in leg 4 must necessarily be kept separated from the liquid piston and separately drawn off. The float 3 cannot usefully be used solely as a barrier to separate the liquid 1 from the liquid condensed in leg 4 since the necessary frictional engagement of float 3 with leg 4 would materially reduce the efficiency of the apparatus. For this reason other suitable means such as, for example, the collapsible skirt 28 connecting float 3 to leg 4 may be used, the condensed liquid being drawn off through flexible tube 29.

To effect a thermodynamically satisfactory method of crop drying, low pressure chamber 9 shown in FIG. 1 may be in the form of a receptacle for the crops and also housing high pressure chamber 6, which latter is made in the form of a heat exchanger. Warm moist air is drawn into leg 5, compressed therein and transferred in a hot compressed condition to chamber 6 whence it is withdrawn via leg 4 and expanded with loss of moisture to approximately atmospheric pressure and lower temperature, since chamber 6 is in the form of a heat exchanger. It is then, in a saturated condition at this stage, circulated at approximately atmospheric pressure in a progressive sequence around chamber 6 and through the crops in chamber 9 and back to leg 5 or discharged to atmosphere. Since there is progressive exchange of heat from chamber 6 to the low temperature air it is heated and so is able progressively to absorb moisture from the crops.

Movement of the liquid 1 forming pistons in legs 4 and 5 is basically effected by the pressure difference in legs 4 and 5. While the liquid pistons have very low frictional losses energy must be supplied to the system to compensate for the total energy losses. This may be done by the use of the vacuum pump 30 shown in FIG. 2 or the compressor 31 shown in FIG. 3. In the crop drying application referred to above, steam injected into the chamber 6 near valve 8 may be used to introduce energy into the system. The energy may also be introduced by bodily movement of the U-tube using a crank 32 to effect a sideways rocking movement as shown in FIG. 2, or crank 33 to effect a vertical reciprocatory movement as shown in FIG. 3, in both cases the crank movements being in registration with the movements of the liquid 1. The input energy can also be applied by other means.

While the apparatus is effective in the the form of the U-tube illustrated in FIGS. 1 to 3 in many applications it takes up considerable space due to the large cross-sectional area required in each leg 4 and 5. To obviate this the apparatus may be made in the form shown in FIG. 4 in which the leg 4 is of annular shape surrounding the leg 5.

It will be understood that as is known with equipment serving similar functions the apparatus may be in the form of units connected in series or parallel. Units may also be interconnected, for example by compressing in leg 5 of one apparatus and expanding in a leg 4 of another apparatus.

What I claim as new and desire to secure by Letters Patent is:

I claim:

1. A method of changing the condition of a gas by means of a compression compartment and an expansion compartment each having a valve controlled inlet and a valve controlled outlet, and each compartment embodying in a liquid piston, comprising operating said pistons to reciprocate in unison but in opposite directions to draw gas into the one compartment at one pressure, thereafter to change the gas pressure in the same compartment and convey it at said changed pressure to the other compartment, and then to restore the gas to approximately its original pressure in the latter compartment and discharge it therefrom, said gas being subjected to a heat exchange operation during its passage from the inlet of the one compartment to the outlet of the other compartment.

2. A method as claimed in claim 1 in which the heat exchange operation is effected in a heat exchanger connected between the compartments.

3. A method as claimed in claim 1 in which the gas is heated by compression in the compression compartment, thereafter cooled by the heat exchange operation, and then further cooled by expansion in the expansion compartment.

4. A method as claimed in claim 1 in which the gas is introduced into the compression compartment in a moist condition, and then in sequence compressed in the compression compartment, cooled sufficiently during the heat exchange operation to effect condensation of part of the liquid content thereof, further cooled by expansion in the expansion compartment, and utilized after expansion in conjunction with the heat exchanger to effect a drying operation by absorption in said gas of further liquid.

5. A method as claimed in claim 1 in which the gas is introduced into the compression compartment in a warm moist condition, compressed in the compression compartment while being subjected to the action of water sprays during such compression, and thereafter in sequence cooled sufficiently during the heat exchange operation to effect condensation of part of the liquid content thereof, further cooled by expansion in the expansion compartment, and utilized after expansion in conjunction with the heat exchanger to effect a drying operation by absorption in said gas of further liquid.

6. A method as claimed in claim 1 in which gas is compressed in the compression compartment, liquid containing other components is sprayed into the gas during said compression to effect evaporation of part of said liquid, and the gas and vapor are then transferred to the expansion compartment to effect condensation of the vapor.

7. A method as claimed in claim 1 in which the gas is drawn into the first at atmospheric temperature and pressure, expanded in this compartment and subjected to a heat transfer process while in the expanded condition to increase the enthalpy of said gas, the gas then being transferred while in the expanded condition to the second compartment, compressed in the second compartment to super atmospheric temperature

and thereafter discharged at said super atmospheric temperature.

8. A method as claimed in claim 1 in which discharge of gas from each compartment is prevented during top part of the travel of each liquid piston by a pair of valves each controlled by the position of the corresponding liquid piston.

9. A method as claimed in claim 1 in which the pressure in the compression compartment is used to control closure of the inlet valve to the expansion compartment.

10. Apparatus for changing the condition of a gas, comprising a compression compartment, an expansion compartment, means interconnecting the lower ends of said compression and expansion compartments, liquid in said compartments and in said means interconnecting the lower ends thereof and forming a liquid piston in each compartment, means establishing fluid communication between said compartments, an inlet valve and an outlet valve in each compartment for interrupting fluid communication therebetween, a liquid level responsive valve in each compartment and adapted to close when the liquid in said compartment reaches a predetermined level, means for oscillating the liquid in said compartments, and means for controlling operation of said valves in conjunction with oscillation of said liquid to effect compression of gas in one compartment, transfer of the gas between said compartments, and expansion of the gas in the other compartment.

11. Apparatus as claimed in claim 10 in which the means for oscillating the liquid in the compartments comprises means for oscillating the compartments in unison.

12. Apparatus as claimed in claim 10 in which the one compartment is of annular shape extending around the other compartment.

13. Apparatus as claimed in claim 10 in which the connection between the outlet valve of the one compartment and the inlet valve of the other compartment is in the form of a heat exchanger.

14. Apparatus as claimed in claim 10 including the provision of means for withdrawing surplus liquid therefrom.