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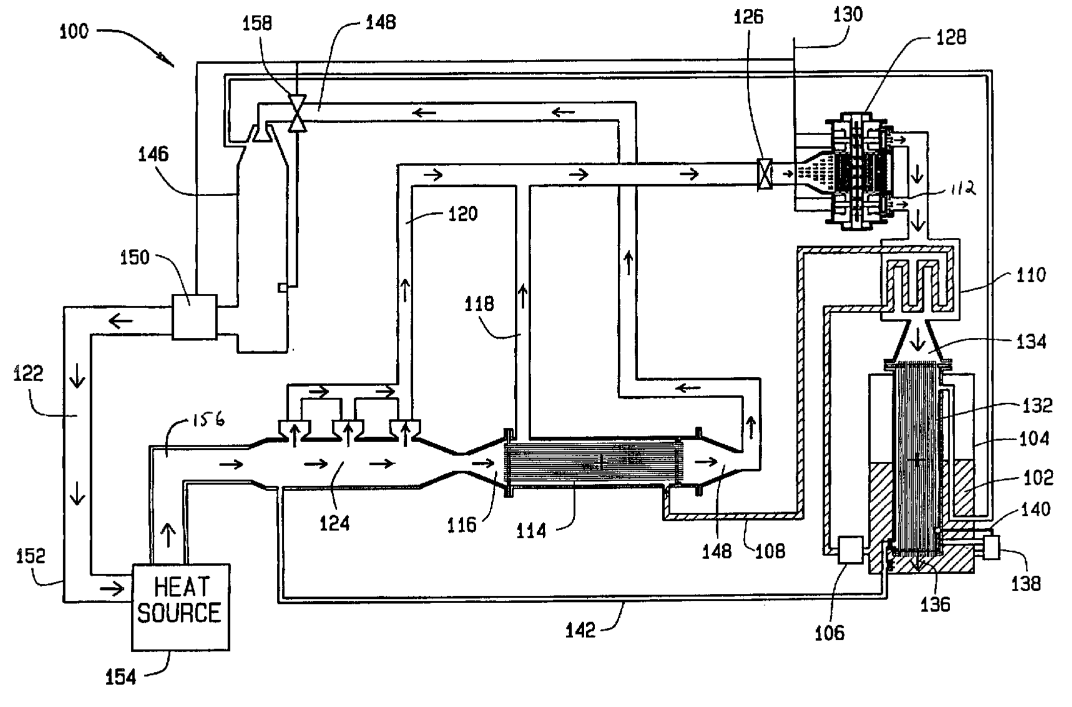
(54) Title: VAPOR POWER CYCLES



(57) Abstract: Vapor power cycles (100) capable of operating with heat sources (154) having temperatures well below those utilized in Rankine and Kalina cycles. Preferably all input heat is beneficially used without rejecting heat to the environment. The invention may be used to provide heating, cooling and/or power production.

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VAPOR POWER CYCLES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/381,075 filed May 14, 2002. This application is also related to U.S. Provisional Application No. 60/354,676 filed February 6, 2002. The entire disclosures of the aforementioned applications are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] Generally, very little power may be extracted from low temperature heat sources by known power cycles, such as the Rankine vapor cycle, because the gas phase must be cooled back into the liquid phase by heat rejection to the environment, or by heat rejection to a conventional refrigeration cycle that consumes a substantial portion of the energy produced. Due to the small temperature differential between the environment and the low temperature heat source, heat rejection is inefficient and difficult to perform in the Rankine cycle.

[0003] The Kalina cycle, which is a modified Rankine cycle that uses a mixture of water and ammonia, more efficiently uses heat via a regenerator and is therefore more efficient than the Rankine cycle. However, water is boiled to steam in a Kalina cycle, thus requiring the operating temperature to exceed 212 ºF, generally in the range of 280 ºF.

[0004] As recognized by the inventor hereof, there is a need for new vapor power cycles that efficiently operate at low temperatures substantially below 200 ºF, and preferably as low as 90 ºF and below.

SUMMARY OF THE INVENTION

[0005] The inventor hereof has succeeded at designing new vapor power cycles capable of operating with heat sources having temperatures well below those utilized in Rankine and Kalina cycles, although high temperature heat sources may also be employed. In certain preferred embodiments, all heat provided to the system is beneficially used without rejecting heat to the environment. As will be apparent, the teachings of the present invention may be used to provide heating, cooling and/or power production.

[0006] An apparatus according to one aspect of the present includes a turbine for producing power by expanding a working fluid in gaseous form, an internal low temperature reservoir connected to the turbine for condensing working fluid exiting the turbine into liquid form, and a heat source for providing heat to the working fluid before the working fluid is provided to the turbine in gaseous form. Preferably, the internal low temperature reservoir rejects substantially no heat to the external environment such that substantially all input heat is converted into useable power.

[0007] A method according to another aspect of the invention includes expanding a high pressure vapor in a turbine to produce power, transferring heat from vapor exiting the turbine to a low-boiling-point liquid to condense the vapor exiting the turbine into liquid form and vaporize the low-boiling-point liquid into gaseous form, and introducing the vaporized low-boiling-point liquid into a heat transfer medium. The heat transfer medium absorbs the low-boiling-point liquid with the low-boiling-point liquid rejecting heat to the heat transfer medium in response to the absorbing. The method further includes heating the heat transfer medium and the low-boiling-point liquid absorbed therein for producing the high pressure vapor, with the low-boiling-point liquid vaporizing in response to the heating.

[0008] Additional aspects and features of the invention will be in part apparent and in part pointed out below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Figs. 1-3 illustrate vapor power cycle systems according to several embodiments of the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0010] A vapor power cycle system according to one embodiment of the present invention is illustrated in Fig. 1 and indicated generally by reference character 100. As will be apparent, the system 100 uses an anhydrous gas to provide internal heat rejection such that substantially all heat input into the system is converted into useful work. Anhydrous gases (e.g., ammonia, lithium bromide, carbon dioxide, etc.) are capable of providing absorption cooling. These gases also have low boiling points and may therefore serve as low-boiling-point liquids in addition to providing absorption cooling. In the embodiment of Fig. 1, an absorption cooling process is incorporated into the vapor power cycle to produce internal cooling to create a variable, artificial low temperature reservoir for purposes of internal heat rejection.

[0011] Although the embodiment of Fig. 1 employs an anhydrous gas, it should be understood that any gas or gas mixture capable of being dissolved in a liquid transfer medium, and then distilled therefrom, can be advantageous used in the present invention. For low temperature applications, the gas or gas mixture is preferably one that can be released from such transfer medium at temperatures below 185 F and, even more preferably, at temperatures below 90 F. It should also be understood, however, that the teachings of the present invention are applicable to higher temperature applications as well.

[0012] In the system 100 of Fig. 1, liquid anhydrous working fluid 102 is pumped from a reservoir 104 by a pump 106. The pumped liquid working fluid 102 flows through line 108 to a pre-heater 110 where it accepts low level heat via heat exchange with spent gaseous working fluid 112 in the pre-heater 110. The liquid working fluid 102 then flows to an anhydrous fluid vaporizer 114 where it is heated by hot anhydrous fluid-poor water 116. The liquid anhydrous working fluid 102 is vaporized into high pressure anhydrous working fluid vapor 118 via heat exchange within the vaporizer 114.

[0013] The high pressure anhydrous working fluid vapor 118 is joined by additional vapor 120 released from anhydrous fluid-rich water 122 provided to an anhydrous vapor separator 124. The high pressure anhydrous working fluid vapor flows through a throttle 126 to a turbo-alternator 128 that generates electricity 130. Alternatively, other types of turbines can be employed for producing other types of output power. Suitable turbines for use in the turbo-alternator 128 include a rotary vane turbine of the type disclosed in U.S. Provisional Application No. 60/360,421 filed March 1, 2002, the entire disclosure of which is incorporated herein by reference, a Tesla turbine, and a jet turbine (i.e., a turbine which utilizes jet propulsion for rotation, and which may or may not be bladeless). Exemplary jet turbines are disclosed in applicant's U.S. Provisional Application No. 60/397,445 filed July 22, 2002, U.S. Provisional Application

No. 60/400,870 filed August 5, 2002, U.S. Provisional Application No. 60/410,441 filed September 16, 2002, and U.S. Provisional Application No. [insert no. here] filed December 10, 2002 [and entitled "Drum Jet Turbine with Counter-Rotating Ring Method of Manufacture"], the entire disclosures of which are incorporated herein by reference.

[0014] After passing through the turbo-alternator 128, the spent vapor 112 flows to the pre-heater 110 where it rejects heat to the counter-flowing liquid working fluid 102. The partially cooled spent anhydrous working fluid vapor 134 then flows into the reservoir 104 where heat is rejected to internal absorption cooling provided by the evaporation of the liquid anhydrous working fluid 102 in an evaporator 132 within the reservoir 104. The cooling provided by the evaporator 132 causes the spent anhydrous working fluid 134 to change state to the liquid phase. Such cooling also reduces the temperature of the liquid working fluid 102 in the reservoir 104 and keeps the temperature and vapor pressure very low within the reservoir 104, which helps to maintain very low back pressure for the turbine 128.

[0015] The evaporator 132 is preferably a sealed shell and tube-type heat exchange unit that is inserted into the center of the reservoir 104. The spent anhydrous vapor working fluid 134 flows through the tubes (not shown) and is cooled by evaporation that takes place in the shell surrounding the tubes. The spent working fluid 134 is cooled and changes to the liquid phase that is allowed to exit the bottom of the tubes into the center bottom 136 of the reservoir 104. Liquid working fluid 102 from the reservoir 104 is allowed to enter the evaporator 132 via an anhydrous fluid restrictor valve 138 that regulates the flow of liquid 102 into the evaporator 132. An on/off switch 140 is provided to the restrictor valve 138 to control the level of the liquid working fluid 102 within the evaporator 132. The reservoir 104 and evaporator 132 are designed to work with a low-boiling-point-liquid anhydrous working fluid, and any water condensate formed is removed to the anhydrous vapor separator 124 via a water condensate line 142.

[0016] The low pressure anhydrous vapor 143 produced in the evaporator 132 flows through line 144 through a throttle to an absorber 146 that operates at low pressure. Cool low pressure anhydrous-poor water 148 is sprayed into the absorber 146 so that the anhydrous vapor 143 may be absorbed into the water 148, which results in cool anhydrous-rich water 122 being formed.

[0017] The cool anhydrous rich water 122 is pumped under pressure via water pump 150 and is allowed to flow through line 152 to a heat source 154 (e.g., geothermal heat, solar heat, combustion of fuel, heat of compression, etc). The heat source 154 produces hot anhydrous-rich water 156 that enters the anhydrous vapor separator 124 where the anhydrous working fluid vapor 120 is released from the pressurized, hot, anhydrous-rich water 156. The removal of the anhydrous working fluid vapor 120 from the hot water 156 produces the hot anhydrous-poor water 116. The anhydrous-poor water 116 flows to the anhydrous fluid vaporizer 114 where the liquid anhydrous fluid 102 is vaporized into the high pressure anhydrous vapor 118, thereby cooling the anhydrous-poor water due to the heat given off for vaporization of the liquid anhydrous working fluid 102.

[0018] The cooled anhydrous poor water 148 flows through a throttle 158 to reduce the pressure of the water 148 as it enters the absorber 146 in order to absorb additional anhydrous vapor 143 and complete the absorption cooling cycle.

[0019] Fig. 2 illustrates an alternative system 200 to that of Fig. 1. In the system 200 of Fig. 2, separate power and refrigeration cycle loops are provided. The power cycle loop utilizes a low-boiling-point liquid 201 which is stored in the reservoir 204, and which is circulated through the vaporizer 214, the turbo-alternator 228, the pre-heater 210, and back to the reservoir 204 where heat is rejected to internal absorption cooling provided by the refrigeration cycle.

[0020] The refrigeration cycle loop utilizes an anhydrous working fluid 202 (or another gas or gas mixture capable of being absorbed into a liquid heat transfer medium) that is introduced into the anhydrous-poor water 248 via the absorber 246, and that is removed from the anhydrous-rich water 222 via the separator 224. In contrast to the system 100 of Fig. 1, the anhydrous vapor 220 output by the separator 224 is routed through a condenser 260 where it rejects heat to the anhydrous-rich water 222 prior to the heat source 254 and condenses back to the liquid state. The liquid anhydrous working fluid 202 flows from the condenser 260 to the evaporator 232 where it is evaporated in the shell surrounding tubes through which the spent low-boiling-point liquid vapor 234 flows, thereby cooling the low-boiling-point vapor 234 and causing it to change to the liquid phase.

[0021] In some embodiments, the anhydrous working fluid 202 utilized in the refrigeration cycle can also be employed as the low-boiling-point liquid 201 for the power cycle. Alternatively, different low-boiling-point liquids may be used for the power cycle.

[0022] Fig. 3 illustrates a vapor power cycle system 300 according to another embodiment of the invention. As shown in Fig. 3, water circulates through a heat source 302 which, in this particular embodiment, is a geothermal well. It should be understood, however, that any heat source having a temperature at or above approximately 185 degrees F may be used. Depending on the anhydrous working fluid employed, lower temperatures may not be capable of distilling anhydrous vapor out of solution with water.

[0023] A lift tube 304 is inserted into the center of the geothermal well 302 and liquid phase low-boiling-point-liquid 306 is injected into the lift tube 304 via an injector 308. The liquid is vaporized into high pressure gas 310 by the heat contained in the water 312. The gas then gas-lifts water 312 and gas 310 through turbine one 316. The turbine 316 is rotated and the shaft of the turbine is connected to a generator 318 to generate electrical power 320.

[0024] The vapor is separated from the water 312 within the separator vessel 322. The vapor 310 rejects heat to the water 312 via heat exchanger 324 after the water 312 has been cooled. The water 312 returns to the geothermal well 302 to be heated again in a cycle. The vapor 310 is condensed to the liquid phase by heat rejection at constant pressure within the heat exchanger 324. The liquid 326 is stored in a liquid reservoir 328 and is pumped back to an injector 308 in the well 302 by a high pressure liquid pump 330 through a throttle 332 in a cycle.

[0025] The water 312 that exits the separator vessel 322 flows through lines 334 to heat exchanger 336, which acts as an anhydrous distiller to distill anhydrous vapor 338 out of solution with water. The anhydrous water 340 is contained within a second closed loop and the water 312 from the geothermal well 302 does not mix with the anhydrous water 340. Heat is given off via heat exchange in heat exchanger 336 from the hot well water 312 to the anhydrous water 340 and the anhydrous vapor 338 is distilled from the anhydrous water 340 by the heat. The well water 312 is cooled to a lower temperature by the process and the anhydrous water 340 is heated to a higher temperature.

[0026] The well water 312 then flows to heat exchanger 342 and provides heat to vaporize a low-boiling-point-liquid 344. The process further cools the water 312. The cooler water 346 then flows to heat exchanger 348 and accepts heat rejected from the anhydrous vapor 338 produced via distillation in heat exchanger 336. The anhydrous vapor 338 is condensed to the liquid phase 350 and the well water 346 is again hotter after receiving heat from the condensation of the anhydrous vapor 338.

[0027] The well water 352 then flows to heat exchanger 354 and heat is extracted from the water 352 to vaporize liquid phase low-boiling-point-liquid 344. The process further cools the water 352. The cooler water 358 then flows to heat exchanger 324 where the water accepts heat from condensing the vapor phase low-boiling-point-liquid 310 back to the liquid phase 326 in a cycle.

[0028] The liquid anhydrous working fluid 350 that exits heat exchanger 348 flows through lines 362 to heat exchanger 364 that is both a vaporizer and a condenser. The liquid anhydrous working fluid 350 is vaporized and provides very low temperature cooling (refrigeration) that is used to condense vapor phase low-boiling-point-liquid 366 back to the liquid phase 368.

[0029] The very cold anhydrous vapor 370 that is formed via vaporization in heat exchanger 364 flows through lines 372 to heat exchanger 374 and receives heat from vapor phase low-boiling-point-liquid 376, which lowers the temperature of the vapor phase low-boiling-point-liquid 376. The anhydrous vapor 370 then flows to the absorber 378 where the vapor 370 is absorbed into cool water 380.

[0030] The water 384 containing the anhydrous working fluid is pumped via the anhydrous water pump 386 to heat exchanger 336 that is the distiller where the anhydrous vapor 338 is distilled out of the anhydrous water 384 in a cycle.

[0031] The water 388 that exits the distiller 336 contains very low concentrations of the anhydrous working fluid and is hotter due to heat given off by the hot well water 312 to the anhydrous water loop. The hot water 388 then flows to heat exchanger 390 and heat from the water] provides heat to vaporize low-boiling-point-liquid 368 within heat exchanger 390. The process further cools the water 388. The cooler water 380 can now return to the absorber 378 so that anhydrous vapor 370 may again be absorbed into the cool water 380 in a cycle.

[0032] Liquid phase low-boiling-point-liquid 368 is withdrawn from the LBPL reservoir 394 via a high pressure liquid phase low-boiling-point-liquid pump 396 and flows through lines 398 to heat exchanger 400 where heat is accepted by the liquid 368. The liquid 368 is then supplied via throttles 402 to heat exchangers 342, 354, and 390, which are all vaporizers that vaporize the liquid 368 into high pressure vapor 404. The vapor 404 is collected in lines 406 and flows to the airlift well 408 via LBPL injector 410. The vapor 404 provides gas lift for water 412 that circulates in a closed loop through the airlift well 408. The water 412 and the vapor 404 flow through turbine 416. The water 412 and vapor 404 rotate the turbine 416 that is connected to generator 418 to generate electrical power 420.

[0033] The spent vapor 422 is collected in separator vessel 424 and then flows through lines 426 to heat exchanger 374 where heat is given off from the vapor 422 and it is cooled to a lower temperature. The spent vapor 422 then flows to heat exchanger 400 and additional heat is given off from the vapor 422 to liquid phase low-boiling-point-liquid 368. The spent vapor 422 then flows to heat exchanger 364 and is condensed to the liquid phase 368 via the refrigeration effect of vaporization of the anhydrous working fluid 350 within heat exchanger 364. The liquid 368 flows into LBPL reservoir 394 in a cycle.

[0034] Importantly, the systems described above with reference to Figs. 1-3 reject no heat to the environment. Instead, all heat input to a given system is used to generate useful power (electric power in the described embodiments, though other types of power can be provided). Therefore, the vapor power cycles of the present invention are more efficient than prior art vapor power cycles, and can be used to produce useful work from low temperature heat sources. Nevertheless, it should be understood that external heat rejection or cooling may also be employed in certain embodiments and applications of the invention.

[0035] Those skilled in the art will appreciate that many changes can be made in the above embodiments without departing from the spirit and scope of the invention. Therefore, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

CLAIMS

What is claimed is:

1. An apparatus comprising:

a turbine for producing power by expanding a working fluid in gaseous form;

an internal low temperature reservoir connected to the turbine for condensing working fluid exiting the turbine into liquid form; and

a heat source for providing heat to the working fluid before the working fluid is provided to the turbine in gaseous form.

2. The apparatus of claim 1 wherein the internal low temperature reservoir rejects substantially no heat to an external environment.

3. The apparatus of claim 1 wherein the working fluid in gaseous form has a temperature below approximately 212 ºF.

4. The apparatus of claim 1 wherein the working fluid is an anhydrous gas.

5. The apparatus of claim 1 wherein the working fluid is adapted to be absorbed into a liquid heat transfer medium when introduced thereto in gaseous form.

6. The apparatus of claim 1 wherein the turbine is a jet turbine.

7. The apparatus of claim 1 wherein the internal low temperature reservoir comprises a vaporizer for vaporizing a low-boiling-point liquid into gaseous form to thereby provide absorptive cooling for the working fluid exiting the turbine.

8. The apparatus of claim 7 further comprising a first closed loop through which the working fluid circulates and a second closed loop through which the low-boiling-point liquid circulates.

9. The apparatus of claim 1 wherein the internal low temperature reservoir comprises a vaporizer for vaporizing into gaseous form the working fluid condensed into liquid form.

10. A system comprising a heat source for producing a heated high pressure anhydrous gas, and a turbine for producing power from the heated high pressure anhydrous gas, wherein the heated high pressure anhydrous gas has a temperature below approximately 212 ºF.

11. The system of claim 10 wherein the anhydrous gas comprises one of ammonia, lithium bromide, and carbon dioxide.

12. A method comprising:

expanding a high pressure vapor in a turbine to produce power;

transferring heat from vapor exiting the turbine to a low-boiling-point liquid to condense the vapor exiting the turbine into liquid form and vaporize the low-boiling-point liquid into gaseous form;

introducing the vaporized low-boiling-point liquid into a heat transfer medium, the heat transfer medium absorbing the low-boiling-point liquid with the low-boiling-point liquid rejecting heat to the heat transfer medium in response to the absorbing; and

heating the heat transfer medium and the low-boiling-point liquid absorbed therein for producing the high pressure vapor, the low-boiling-point liquid vaporizing in response to the heating.

13. The method of claim 12 further comprising separating the vaporized low-boiling-point liquid from the heat transfer medium.

14. The method of claim 13 further comprising transferring heat from the heated heat transfer medium to

the condensed vapor to vaporize the condensed vapor and thereby produce said high pressure vapor.

FIGURE 1 of 3

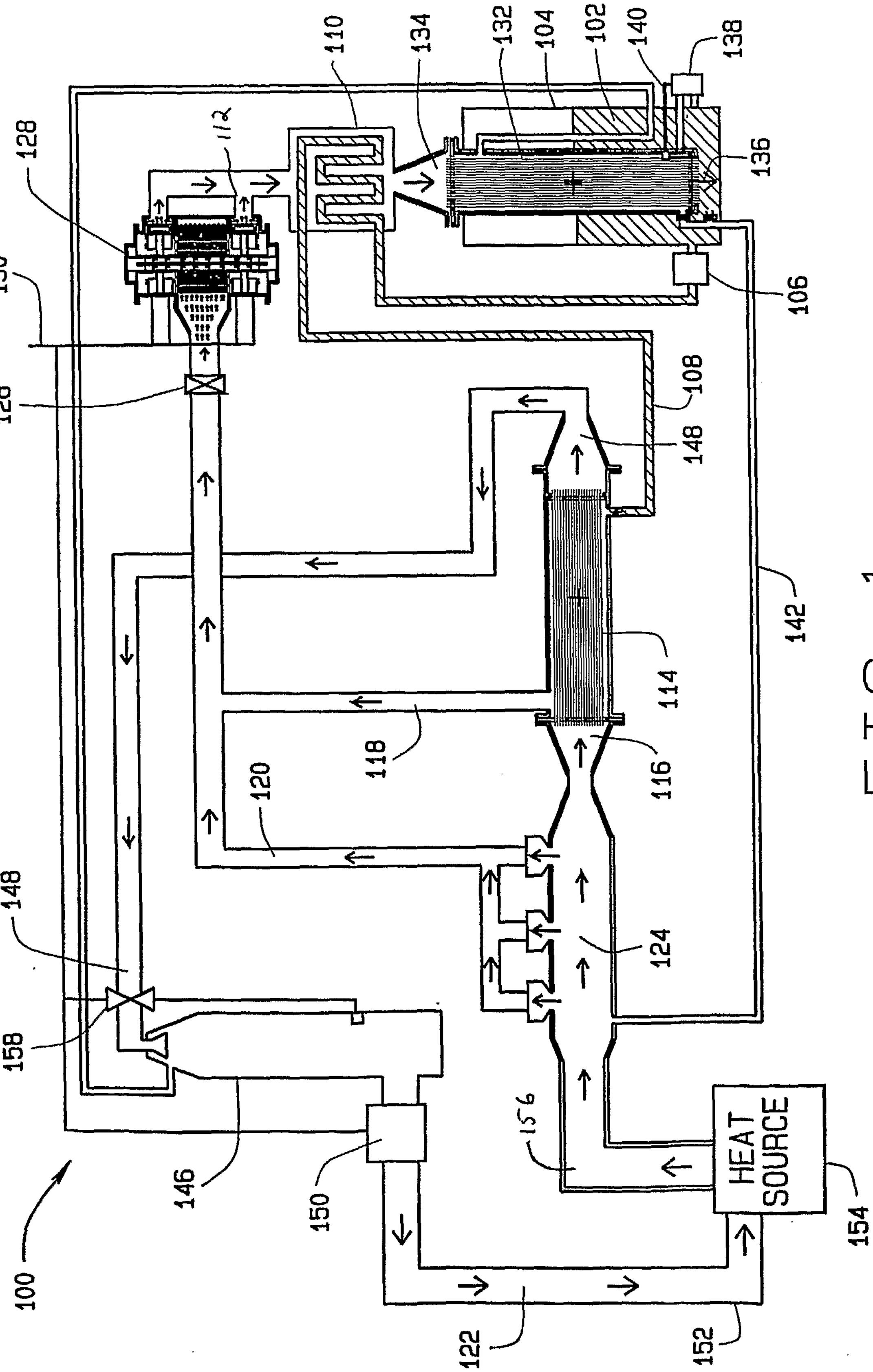

FIG. 1

FIGURE 2 of 3

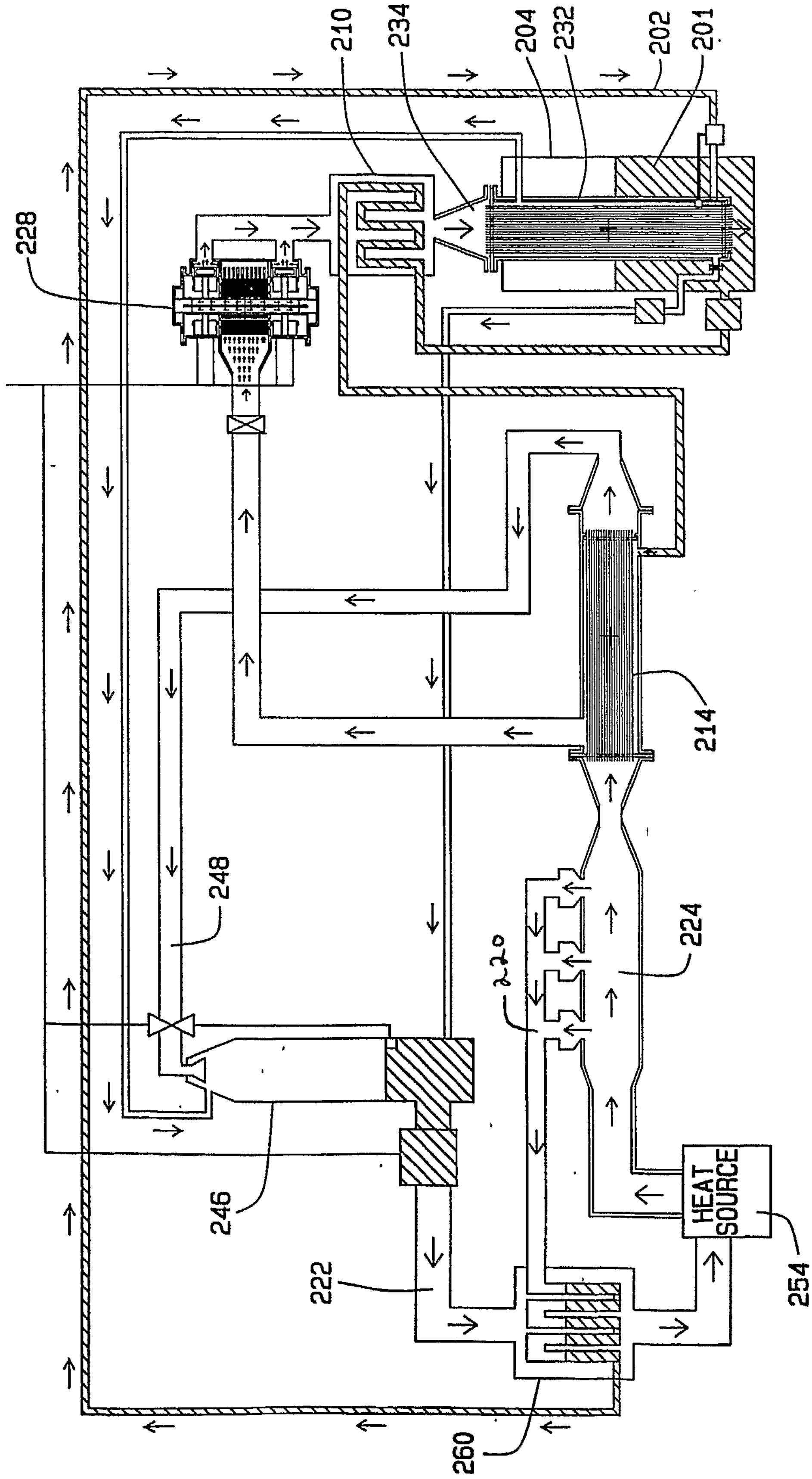

FIG. 2

FIGURE 3 of 3

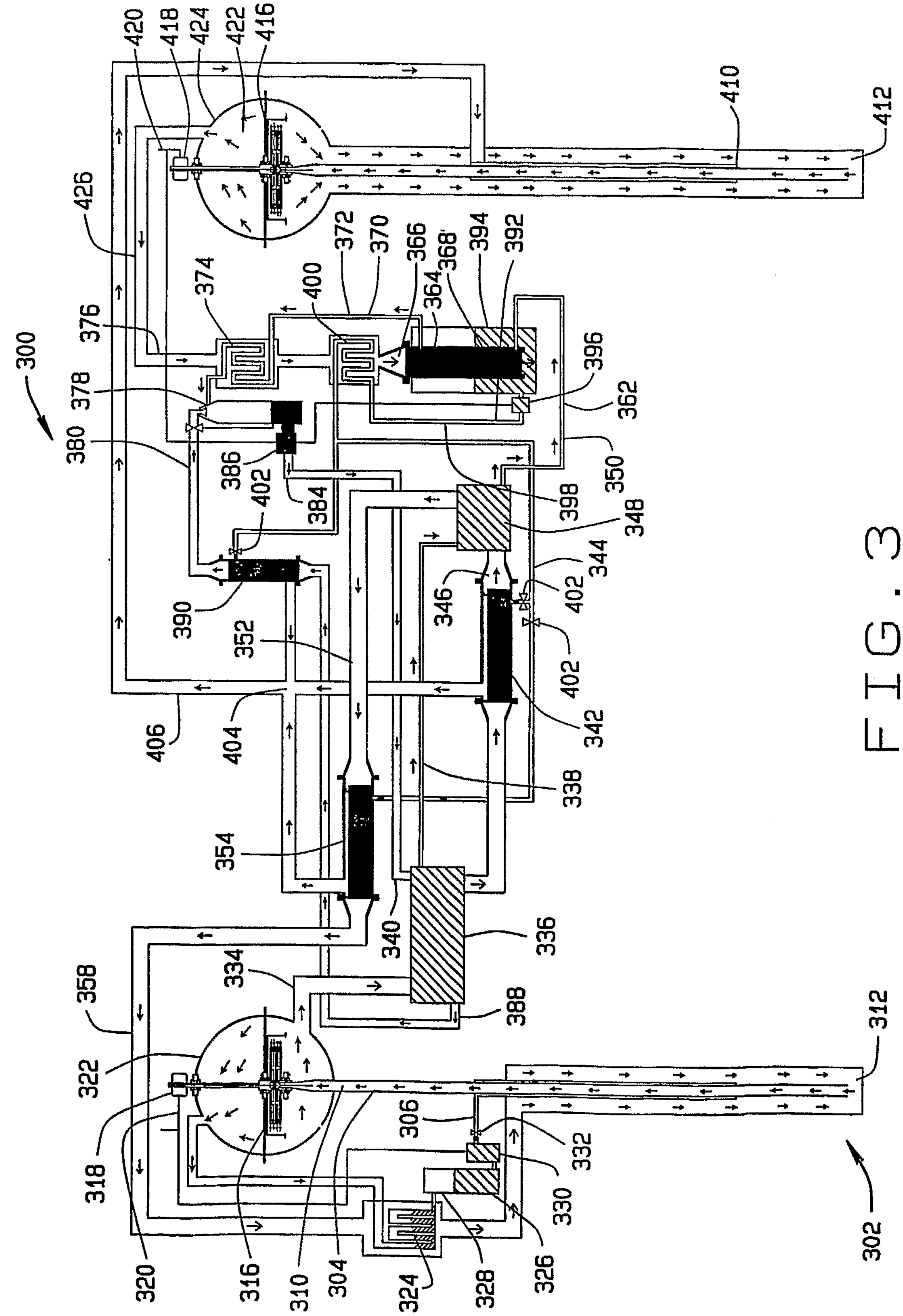

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US03/15596

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : F01K 25/08
US CL : 60/651, 670, 671
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 60/651, 670, 671

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 5,440,882 A (KALINA) 15 August 1995 (15.08.1995), see figure 1.	1-2, 4-14 ---------- 3
Y	US 4,182,131 A (MARSHALL et al) 08 January 1980 (08.01.1980), see figure 1.	3
A	US 4,311,014 A (TERRY et al) 19 January 1982 (19.01.1982), see figure 1.	1-14

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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