



(51) International Patent Classification:

F01K 27/00 (2006.01) *F03G 6/00* (2006.01)
F02G 1/04 (2006.01) *H02K 7/18* (2006.01)
F03G 4/00 (2006.01)

(21) International Application Number:

PCT/CA2016/051545

(22) International Filing Date:

28 December 2016 (28.12.2016)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/271,630 28 December 2015 (28.12.2015) US

(71) Applicant: **BREE SYSTEMS LTD.** [CA/CA]; 22, 54129
 - Range Road 275, Spruce Grove, Alberta T7X 3S4 (CA).

(72) Inventor: **FORD, Darrell**; 22, 54129 - Range Road 275,
 Spruce Grove, Alberta T7X 3S4 (CA).

(74) Agent: **NEXUS LAW GROUP LLP**; P.O. Box 9, Suite
 1140 - 625 Howe Street, Vancouver, British Columbia
 V6C 2T6 (CA).

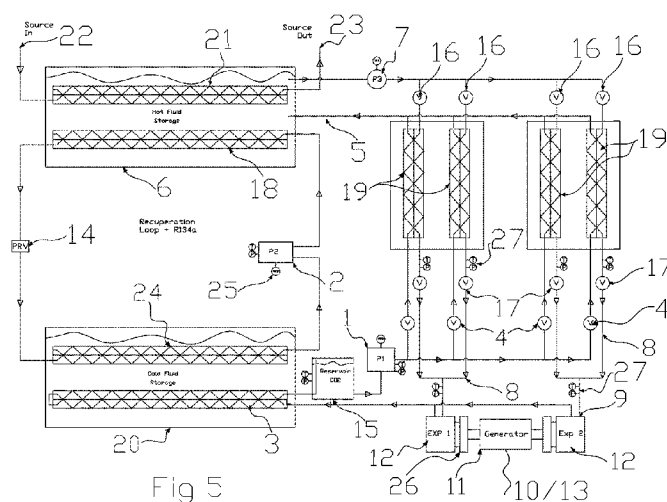
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: PROCESS AND SYSTEM FOR EXTRACTING USEFUL WORK OR ELECTRICITY FROM THERMAL SOURCES



(57) Abstract: A process and system of extracting useful work or electricity from a thermal source, wherein heat energy from the thermal source is used in the form of a heated collection fluid; a first side of a heat exchanger is filled with a liquid or supercritical working fluid; fluid flow out of the first side of the heat exchanger is closed such that a fixed volume of the working fluid is maintained in the first side; the heated collection fluid flowed through a second side of the heat exchanger that is adjacent to the first side to affect a transfer of heat from the heated collection fluid to the fixed volume of the working fluid to raise its temperature and pressure; the pressurized working fluid is released from the first side of the heat exchanger upon the working fluid reaching a threshold state; a flow of the pressurized working fluid is directed to an expander capable of converting the kinetic energy of the pressurized working fluid into useful work or electricity; and the foregoing steps are repeated. A plurality of such operably coupled heat exchangers may be used in a manner such that the timing of the pressurized working fluid from each heat exchanger to the expander is offset.

PROCESS AND SYSTEM FOR EXTRACTING USEFUL WORK
OR ELECTRICITY FROM THERMAL SOURCES

5 FIELD OF THE INVENTION

The present invention relates to a process for converting thermal energy into useful products such as mechanical work, electricity or space heating, and a power extraction system for use in the process. More particularly the present invention pertains to the field
10 of clean power production and an emission-less power extraction systems and methods for use in converting thermal energy into electricity from sources such as solar, wind, waste heat, geothermal, natural water bodies (oceans, lakes, rivers), biomass oxidation and the like.

15 BACKGROUND OF THE INVENTION

There are numerous industrial and other processes that produce waste heat, particularly waste heat that is or can be converted to a heat source in the approximate range of 34°F to 210°F. Heat in these low grade thermal ranges may also be obtained from geothermal
20 sources, including man-made geothermal sources such as those occurring in abandoned oil and natural gas wells, as well as natural water bodies (oceans, lakes, rivers), solar and wind sources. Heat in this range is difficult to utilize since it is too low to be used in conventional Rankin cycle or other vapor cycles to generate useful energy. Accordingly,

there is a need for a more efficient method of extracting useful work and electricity from heat, and particularly from heat from low grade thermal sources.

SUMMARY OF THE INVENTION

5

The present invention provides methods for utilizing a liquid or supercritical working fluid, which may be an organic fluid, refrigerant or CO₂, in such a way as to avoid complete phase change to vapor while effectively converting thermal energy into useful products such as mechanical work, electricity, or space heating. The present invention also provides power extraction systems and machinery for use in the method. An embodiment of the method or cycle comprises the employment of a working fluid, such as for example liquid R134a or R290, or liquid or supercritical CO₂, in a thermal circuit where the liquid or supercritical working fluid is first compressed to a target inlet pressure and at a relatively low temperature. The inlet liquid or supercritical working fluid is then directed to a heat exchanger until the heat exchanger is 'charged' with the working fluid. Once the heat exchanger is charged, the inlet and outlet of the heat exchanger are closed, and the working fluid is then heated while being volume restricted inside the heat exchanger. Heat from a thermal source, for example as collection fluid in the form of exhaust gases from combustion, or as a collection liquid heated from the thermal source, is flowed through the other side of the heat exchanger such that a transfer of thermal energy from the collection fluid or collection liquid into the working fluid takes places and causes a substantial increase in pressure and a nominal increase in temperature of the volume of working fluid within the heat exchanger. The outlet valve on the heat exchanger is then

10

15

20

opened allowing the heated and high pressure working fluid to enter one or more expanders (for example, piston or rotary) where expansion is allowed to take place. As the working fluid expands in the expander, useful work is extracted to an output shaft and ideally to an electric generator. As work is extracted and expansion takes place, the
5 working fluid returns to a low pressure state exiting the exhaust side of the expander. The working fluid may then travel through another heat exchanger to be further cooled by exchanging energy indirectly with a second cooling fluid, which may also be a fluid such as R134a or R225 or R290. The low pressure and cooled working fluid may be directed to a reservoir that is maintained at the target storage pressure and temperature. From the
10 reservoir, the relatively low pressure, low temperature working fluid is sent to a compressor (or compressors) where the liquid is re-compressed to the desired pressure and temperature as required at the top of the cycle. The working cycle takes place without complete phase change of the working fluid or with a partial phase change taking place due to the expansion (about 5% to about 50% or less) of the working fluid as it exits the
15 outlet of the expander.

Heat energy may be collected and stored in a thermal storage system consisting of an insulated storage container filled with water or a similar liquid where thermal energy in a range from about 34°F to about 210°F is transferred to storage liquid (or a water/ chemical mixture such as an anti-freeze agent) from a variety of thermal sources such as natural
20 water bodies (oceans, lakes, rivers), solar, wind to thermal, geothermal, waste heat from mobile or stationary processes, or in some cases, the oxidation of bio-mass or conventional type fuels.

A plurality of heat exchangers operating in the above described manner may be operably coupled to the expander such that the timing of the pressurized working fluid from each heat exchanger to the expander is offset to provide pulses of kinetic energy to the expander. As well, a plurality of expanders may be operably coupled to the heat
5 exchanger or the plurality of exchangers.

Accordingly, in some aspects the present invention provides a process of extracting useful work or electricity from a thermal source, the process comprising the steps of: filling a first side of a heat exchanger with a liquid or supercritical working fluid; closing fluid flow out of the first side of the heat exchanger such that a fixed volume of the working fluid is
10 maintained in the first side; providing a flow of a collection fluid, that is at a higher temperature than the working fluid as a result of heat from the thermal source, through a second side of the heat exchanger that is adjacent to the first side to affect a transfer of heat from the collection fluid to the fixed volume of the working fluid to raise its temperature and pressure; releasing the pressurized working fluid from the first side of
15 the heat exchanger upon the working fluid reaching a threshold state; directing a flow of the pressurized working fluid to an expander capable of converting the kinetic energy of the pressurized working fluid into useful work or electricity; and repeating foregoing steps.

In some embodiments, the collection fluid is a collection liquid, and the process further includes transferring heat energy from the thermal source to the collection liquid. In some
20 embodiments, collection liquid is heated to a temperature within the range of about 34°F to about 210°F to yield a heated collection liquid.

In some embodiments, the working fluid at prior to the filling of the first side of the exchanger is at a pressure in the range of about 50 to about 5000 psi and at a temperature in the range of about -10°F to about 210°F.

5 In some embodiments, the working fluid becomes supercritical during step of being heated in the first side of the heat exchanger, and after passing through the expander the working fluid is about 50% to about 90% or more in a liquid phase.

In some embodiments, the process further may comprise the step of recirculating the working fluid from the expander to the first side of the heat exchanger.

10 In some embodiments, the process may further comprise the step of recirculating the collection liquid from the second side of the heat exchanger to a second heat exchanger where the step of transferring heat energy from the thermal source to the collection liquid takes place prior to the heated collection liquid flowing through the second side of the heat exchanger.

15 In some embodiments, the process may further comprise the step of transferring heat from the working fluid to another liquid after passing through the expander to bring the temperature of the working fluid within the range of about -10°F to about 210°F. In some embodiments, said another liquid is the collection liquid. In some embodiments, the process may further comprise transferring heat from said another liquid to the collection liquid prior to it entering the second side of the exchanger.

In some embodiments, the process may comprise performing the aforementioned steps on a plurality of heat exchangers, each in fluid communication with the expander, and temporally offsetting the release of the pressurized working fluid from at least one of the plurality of heat exchangers to the expander.

- 5 In some aspects, the present invention provides system for extracting useful work or electricity from a thermal source, the system comprising: a heat exchanger having a first side and an adjacent second side that is fluidly separate from the first side; a supply of a liquid or supercritical working fluid that is fluidly coupled to the first side of the heat exchanger; a valve system operable to close flow of working fluid in and out of the first
10 side in response to a close signal to enclose a volume of working fluid within the first side, and being further operable to open flow of working fluid out of the first side in response to an open signal; a flow of a collection fluid through the second side of the heat exchanger, wherein the collection fluid is at a higher temperature than the working fluid as a result of heat from the thermal source, the flow of collection liquid operable to affect a transfer of
15 heat from the collection liquid to the volume of working liquid within the first side to raise its temperature and pressure; a controller operable to send the close signal to the valve system when the first side of the heat exchanger is full of working fluid, and operable to send the open signal to the valve system upon the working fluid reaching a threshold state to release the pressurized working fluid from the first side of the heat exchanger;
20 and an expander fluidly coupled to the first side of the heat exchanger to receive the pressurized working fluid and operable to convert the kinetic energy of the pressurized working fluid into useful work or electricity.

In some embodiments, the working fluid may be at a pressure in the range of about 50 to about 5000 psi and at a temperature in the range of about -10°F to about 210°F.

In some embodiments, the system may further comprise a first recirculation conduit to recirculate the working fluid from the expander to the first side of the heat exchanger.

- 5 In some embodiments, the system may further comprise a second heat exchanger fluidly coupled to the first recirculation conduit downstream from the expander and operable to transfer heat from the working fluid to another liquid to bring the working fluid to a temperature in the range of about -10°F to about 210°F. In some embodiments, said another liquid may be the collection liquid.
- 10 In some embodiments, the system may comprise a second recirculation conduit fluidly coupled to the second side of the heat exchanger, and a third heat exchanger fluidly coupled to the second recirculation conduit and to the thermal source to enable a transfer of heat from the thermal source to the flow of collection liquid before flow into the second side of the heat exchanger.
- 15 In some embodiments, the system may comprise a plurality of heat exchangers, each having a first side that receives a flow of working fluid and a second side that receives a flow of collection fluid, and each first side being in fluid communication with the expander and operably connected to the valve system, and the controller is operable to send open signals to the valve system in a manner to temporally offset the release of pressurized
- 20 working liquid from at least one of the plurality of heat exchangers to the expander.

The foregoing is intended as a broad summary only and of only some of the aspects of the invention. It is not intended to define the limits or requirements of the invention. Other aspects of the invention will be appreciated by reference to the detailed description of the preferred embodiment.

5

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of the invention will become more apparent from the following
10 description in which reference is made to the appended drawings and wherein:

Fig. 1 is a process flow diagram of an emission-less power extraction system utilizing a hydraulic pulse cycle for the conversion of thermal energy into electricity from sources such as natural water bodies (oceans, lakes, rivers), solar, wind, waste heat, geothermal, biomass oxidation in conventional fuels according, to an embodiment of the present
15 invention.

Fig. 2 is a schematic representative view of the system of Fig. 1 connected to various thermal heat sources such as geothermal, solar and wind.

Fig. 3 is a table showing an example of working liquids physical properties (in this case R134a) and the changes to those properties at various locations and times during the
20 cycle of operation of the system of Fig. 1.

Fig. 4 is a process flow diagram showing an example of the working fluid conditions at various locations in a hydraulic pulse cycle according to an embodiment of the present invention.

Fig. 5 is a process flow diagram of another embodiment of an emission-less power extraction system utilizing a hydraulic pulse cycle for the conversion of thermal energy into electricity from sources such as natural water bodies (oceans, lakes, rivers), solar, wind, waste heat, geothermal, biomass oxidation and conventional fuels, according to another embodiment of the present invention.

Fig. 6 is a table showing an example of working liquids physical properties (in this case CO₂) and the changes to those properties at various locations and times during the cycle of operation of the system of Fig. 5.

DETAILED DESCRIPTION

Referring to Figure 1 there is shown an embodiment of a hydraulic pulse cycle system for the conversion of thermal energy into electricity from sources such as natural water bodies (oceans, lakes, rivers), solar, wind, waste heat, geothermal, biomass oxidation. The system may extract useful work from thermal source, and particularly from a low grade thermal source capable of being delivered at temperatures in the range of about

34°F to about 210°F. More specifically, the system may be used to extract useful work from thermal sources such as natural water bodies (oceans, lakes, rivers), solar, wind, waste heat, geothermal, biomass oxidation, as well as other sources of heat in these temperature ranges. However, the system may also be used to extract useful work from
5 thermal sources having temperatures higher than 210°F.

A critical feature of the hydraulic pulse cycle of the present invention is in the unique employment of a three step power cycle involving three distinct and separated thermal and pressure stages: 1) charge/recharge; 2) pressurize; and 3) power. These three
10 stages result in a 'pulsating' flow to the expander unit. For example, in the case of a system utilizing four heat exchangers as described herein – one heat exchanger is in power stage; one heat exchanger is in pressurize stage; one heat exchanger is in recharge stage; and one heat exchanger is in a ready or exhausted mode prior to recharge. A programmable logic controller (PLC) manages the timing of the valve system
15 to effectively coordinate the cycles of the four heat exchanger units as needed to accommodate a steady and pulsing flow of pressurized working fluid to the expander. This pulsating characteristic results in the expander experiencing a rapidly swinging pressure gradient ranging from the high pressure of the cycle to the low pressure of the cycle – in this case about 1200 psi to about 15 psi - an average in this example of about
20 606 psi at the inlet to the expander. This pulsation characteristic also results in a corresponding pulsation of power output from the expander output shaft. To accommodate this unique feature, the system may employ DC generators sending DC

electrical energy to DC batteries which are not negatively affected by the pulsation feature – which appears as a wave of amperage at a set voltage (controlled by a voltage regulator which looks at the shaft RPM and increases or decreases the load on the alternator windings as needed to maintain the target voltage as well as the shaft rpm). AC current is then drawn from the DC batteries via standard inverter equipment thereby delivering a very high quality AC power to the end use.

In Figure 1, the working liquid begins the cycle from reservoir 15. During the charge phase of the cycle, working liquid travels to the first compressor 1, where it is compressed to desired heat exchanger inlet conditions – for example about 50 psi and about 19°F – and then the working liquid then travels to the inlet of single or multiple heat exchangers via the working liquid inlet valves 4. The heat exchangers have two fluidly separate sides as is known in the art. While the working liquid is entering (charging) one side of a particular heat exchanger, raising the pressure from approximately 16 psi to about 50 psi, the outlet valve 17 and the collection or storage fluid circuit valve 16 remain closed. Once the pressure reaches the desired level (about 50 psi in this case) the working liquid inlet valve 4 is closed to restrict the working fluid to a fixed volume.

During the pressurize phase of the cycle, the storage fluid inlet valve 16 is opened and the heat exchanger outlet valve 17 remains closed allowing the working liquid to absorb thermal energy from the storage fluid flowing in the other side of the heat exchanger, and thereby to experience a temperature increase while being restricted to a fixed volume in

the heat exchanger 19, causing a pressure increase of the working liquid to about 1200psi or more and its temperature to reach about 33-38 °F. The given heat exchanger 19 is now storing potential energy, which is then released during the power or discharge phase of the cycle.

5

During the power phase, inlet valve 16 remains open and inlet valve 4 remains closed, but outlet valve 17 is opened to allow the high pressure working fluid to travel via the manifold system 8 to the inlet of the expander 9. The working liquid enters the expander 12 where expansion takes place and work is extracted, resulting in a pressure and temperature drop in the working liquid. Although the working liquid experiences significant expansion (approximately 2-8 times) with corresponding pressure and temperature drop, the working liquid remains in a substantially multiphase phase state (about 50% to about 90% or greater liquid).

15 After the power phase, the working liquid then passes from the exhaust conduit of the expander 12 through the recuperator/cooler heat exchanger 3 where the working liquid temperature is further reduced in internal energy to about 81 btu/lbm by transferring energy to the cooling fluid circuit. The working liquid then travels to the system reservoir 15, where it is stored for the repeat of the cycle.

20

The hydraulic pulse cycle system in Figure 1 integrates three distinct circuits or loops: water as the energy storage and transfer medium (collection liquid); a working liquid used

as a multi-phase expansion medium for the extraction of energy from the water; and a cooling/recuperator circuit employing a fluid, which may be the same kind of liquid as the working liquid or a different fluid could be used, to remove the unused energy from the bottom end of the working liquid loop (expanders are only 20-70% efficient) and to effectively re-set the working liquid temp and pressures as needed to be pumped back to the top of the working liquid loop (as required at inlet to each exchanger). The cooling/recuperator loop functions as a 're-set' function – it effectively salvages and then concentrates the energy extracted from the working liquid and delivers it back into the water/energy storage loop so that it is not wasted/lost from the energy balance. The cooling/recuperation loop is important to both the overall function of some embodiments of the cycle as well as being key to the superior thermal efficiency of the overall cycle.

In the illustrated embodiment, the cooling circuit consists of a compressor 2, two heat exchanger units – one for absorbing energy from the working liquid coming from the outlet of the expander 3, and one for the transfer of absorbed energy into the water circulation system 18, and a Pressure Reduction Valve (PRV) 14. The cooling circuit functions as a standard refrigeration cycle where the cooling fluid (typically a commercial fluid such as R134a, R290 or other common refrigeration fluids) operates in substantially a vapor phase (can also be mixed – liquid to vapor) where the vapor is first compressed to about 50 - about 1000 psi in the recuperator compressor 2. The cooling fluid then exits at elevated temperatures and it then passes through the heat exchanger 18 where energy is given up to the storage/water circuit (energy is absorbed by the flow of water coming

from the storage system), thereby retaining the recovered thermal energy in the system for reuse. The cooling fluid then leaves the heat exchanger 18 at reduced temperatures and passes through the PRV valve 14 where the pressure is substantially reduced causing the cooling fluid to further expand effectively causing a significant drop in temperature. The cooling fluid then travels through heat exchanger 3 at reduced temperatures where it absorbs energy from the exhaust flow of the working liquid coming from the outlet of the expander – thus cooling the working liquid fluid traveling from the expander 12 to the reservoir 15. The cooling fluid is then re-compressed in compressor 2 and repeats the cooling cycle. Compressor 2 is throttled (via the use of a Variable Frequency Drive or hydraulic flow valve controlled by a PLC) to deliver the required amount of cooling fluid to cool the working liquid coming from expander 12 and traveling through heat exchanger 3 and then to the reservoir 15.

While examples of the working liquid have been described herein, other liquid or supercritical working fluids would be suitable for use in the present invention. The present invention operates at least in part on the principle that liquids are generally not compressible. Therefore, according to the present invention, the working fluid does not completely change phase to a gas during the operation of the expander. Any fluid that undergoes an expansion or contraction with a change in temperature may be utilized according to the present invention. Among the characteristics that may be considered in selecting a working fluid are the coefficient of expansion, the ability to absorb energy, and the speed at which heat is transferred to the fluid. For example, if a liquid quickly absorbs

energy, the speed of the system may be faster. However, in some cases, a liquid that quickly responds to changes in temperature may have a low coefficient of expansion. Therefore, these factors must be balanced in order to achieve the desired effect for the expander. Figures 3 and 4 provide examples of these factors at various locations throughout an embodiment of the hydraulic pulse cycle system. Other factors that may be considered in selecting a working fluid include any caustic effects that the fluid may have on the apparatus through which it travels, the environment, and/or people working with the system.

Referring to Fig. 4, there is a process flow diagram showing a working fluid conditions at various locations in the hydraulic pulse cycle according to an embodiment of the present invention. The pressure and temperature differences shown therein demonstrate specific points along the pressure gradient that each exchanger will go through from high pressure to low pressure as the exchanger discharges into the expander(s) over a very short interval. This happens very quickly from high pressure to low pressure – around a 1-10 second interval. The four exchangers are timed in sequence – ie: #1 is opened to expander and discharges from high pressure to low pressure. Once the #1 pressure sensor see's the low set-point (meaning exchanger #1 is empty or exhausted), the #1 discharge valve is close and #1 goes into the recharge phase. At the same moment, #2 discharge valve opens and the cycle is identical – then #3, then #4 and then back around to #1. The total duration of the loop is approximately 4-40 seconds or less depending on the flow and output of the system. Hence, the pulse characteristics of the cycle.

Referring to Figure 5, there is shown another embodiment of a hydraulic pulse cycle in accordance with the present invention. Energy enters the system via conduit 22 in the form of hot collection fluid from a thermal source, preferable in the form of a collection
5 liquid at a temperature range of about 180°F to about 200°F. The flow of thermal energy into the cycle is achieved via the circulation of the hot collection fluid and can be delivered from any number of sources including large engine waste heat recovery, industrial stack waste heat recovery, concentrated solar energy heating fluid, wind energy transferring kinetic wind energy to heating fluid, shallow low-grade geothermal energy, and the like.

10

Cooled working fluid is drawn from the working fluid reservoir 15 by pump 1, which may be any commercially available centrifugal, scroll or plunger pump unit such as those made by Cat Pumps of Minneapolis, MN. The working fluid then travels from the outlet of pump 1 to the inlet of two of the four heat exchangers 19 shown in Fig. 5, and under a set
15 pressure regulated by a system programmable logic controller (PLC) that controls a variable-frequency drive (VFD) affecting speed control of the drive motor to pump 1. The PLC and VFD employed may be any appropriate commercially available unit that would receive temperature and pressure information from commercially available temperature and pressure transducers shown at 27, such as sold by the WIKA group of companies
20 and the like.

During a complete cycle, each of the heat exchangers 19 alternate between at least three distinct modes. In the recharge mode, valve 4 is open and valve 17 is closed, the internal pressure of heat exchanger 19 is at the lowest point of the cycle, and the working fluid is also in a low pressure and sub cooled state. Under these conditions the recharge pump 1 transfers working fluid from the reservoir 15 and 'recharges' the specific heat exchanger(s). During the recharge mode, the respective valve 16 remains closed eliminating an incoming thermal energy to the heat exchanger during recharge. In the configuration shown in Fig. 5, there are four valves 16, which effectively control the flow of hot fluid from storage tank 6 being pumped by pump 7 and flowing across the low-pressure side or non-working fluid side of heat exchangers 19. This sequence allows for the recharge of each heat exchanger 19 at the lowest possible pressure and temperature minimizing the amount of parasitic work required by pump 1.

The second mode is the pressurize mode where the appropriate valves 4 and 17 are both closed and the appropriate valve 16 is opened allowing hot collection fluid to circulate between pump 7 through the outside of the heat exchanger 19 and back to the hot storage tank 6 thereby coming into contact with the outside surface of heat exchangers 19 resulting in the transfer of thermal energy from the hot collection fluid into the working fluid via conduction through the wall of heat exchanger 19. The thermal or hot collection fluid can be water, brackish water, saline water, water glycol or any other inert liquid capable of storing thermal energy and having a boiling temperature above about 210°F. As the thermal energy transfers from the hot collection fluid into the working fluid, the

pressure and temperature of the working fluid rapidly increase, and in some cases can reach pressures in excess of 5,000 psi or even 8000 psi.

The third mode is the discharge or power mode whereby, after the pressurize mode, valve 5 17 of the appropriate exchanger 19 is opened allowing for the high pressure and temperature working fluid to travel via conduit 8 into the inlet of the respective expander 12. The high pressure/high temperature working fluid travels through the specific type of expander being used in the system, where work is then extracted by the expander in the form of mechanical energy rotating an output shaft that can then be used to drive any 10 mechanical processes or to drive an electrical generator. There are various types of commercial expanders that may be used with the system, including without limitation, plunger, in-line piston, rotary piston, axial turbine, vane turbine, tesla turbine, and regenerative turbine.

15 As work is extracted from the working fluid via the function of the expander being employed, the working fluid exits the expander 12, and due to the extraction of work energy via the expander, it experiences a significant expansion, and pressure and temperature drop as thermal energy is converted to mechanical work. The lower pressure, expanded and cooled working fluid then flows via appropriate piping, such as 20 for example stainless steel tubing commercially available from companies such as DKLok and the like, to heat exchanger 3 where it is further cooled resulting in a complete subcooled state. Heat exchanger 3 effectively serves to transfer the excess energy

contained in the working fluid into the cold fluid stored in reservoir 20. As the excess energy is transfer into the cold fluid the working fluid is fully condensed to a sub cooled liquid and enters reservoir 15 where it is drawn into pump 1 then being at the top of the cycle.

5

Figure 5 show a configuration utilizing two 'sets' of heat exchangers 19 and two expanders 12. In any configuration, a PLC will control the timing and sequencing of the three modes making up a complete cycle in such a way as to even the torque oscillation being delivered to generator 11 via each freewheeling clutch system 26. This offset of the
10 peak and low points of at least two expanders sets driving the generator 11 serves to even out the pulse effect or oscillation experienced by the generator input shaft. In other configurations, there could be any number of expanders or expander sets, coupled to a single or multiple generators via various drive arrangements, providing for an essentially even flow of torque/work to the generator shaft(s) while each expander would be
15 delivering its share of the work via the distinct pulse characteristic of the thermal cycle. A freewheel clutch system 26 can be any commercially available type mechanism capable of allowing the employed expander to de-couple from the generator on the low side of its pulse as the expanders RPM drops below the static RPM of the generator shaft and then to instantly recouple the generator shaft at the beginning of the pulse during which work
20 is delivered via high torque and rpm.

To enhance overall thermal efficiency, the system employs an energy recuperation circuit. The working fluid travels through exchanger 3 where it gives up its excess thermal energy to the cold fluid in storage 20. A separate recuperation circuit employing a second refrigeration fluid, preferably a refrigerant fluid such as R134a, is circulated through heat exchanger 24 via pump 2 causing the fluid to flow, under a set pressure, through heat exchanger 18. The recuperation fluid is held at a target pressure as it flows through heat exchanger 18 via the backpressure function of pressure reduction valve (PRV) 14. This PRV is PLC controlled by the system to hold the appropriate pack pressure on the refrigerant to achieve an elevated temperature in the refrigerant passing through the inside of heat exchanger 18. Preferably the temperature of the refrigerant would maintain a temperature delta adequate to transfer excess thermal energy from the refrigerant to the collection fluid. The hot collection or storage fluid is stored at a temperature around 180°F which allows energy to transfer from the higher temperature refrigerant into the hot fluid in storage 6 effectively cooling or dropping the temperature and energy content in the refrigerant as it exits heat exchanger 18 and flows toward PRV 14. As the refrigerant passes through PRV 14, the pressure is substantially reduced resulting in a temperature drop as the refrigerant flows into heat exchanger 24. As the low pressure and cooled refrigerant flows through exchanger 24, it absorbs thermal energy from the cool fluid in storage 20. This exchange results in the refrigerant increasing in energy content and corresponding temperature, while remaining in a substantially liquid state, as it is drawn into the inlet of pump 2. The above described cycle effectively recuperates the excess energy entrained in the working fluid from the power cycle as it exits expanders 12 as well

as the work energy coming in from refrigerant pump 2, back into the hot fluid storage 6 at a thermal quality and temperature level appropriate to be returned into the power side of the cycle via pump 7, via valve 16 and through exchangers 19 and into the working fluid during the pressurize mode of the cycle.

5 Referring to Figure 6, there is shown a table exemplifying using CO₂ as the working fluid and showing its physical properties and the changes to those properties at various locations and times during the cycle of operation of the system described in Figure 5.

10 While the above description and illustrations constitute preferred or alternate embodiments of the present invention, it will be appreciated that numerous variations may be made, such as altering the perimeter shape, without departing from the scope of the invention. It is intended that the invention be construed as including all such modifications and alterations.

15

CLAIMS

1. A process of extracting useful work or electricity from a thermal source, the
5 process comprising the steps of:
- (a) filling a first side of a heat exchanger with a liquid or supercritical working fluid;
 - (b) closing fluid flow out of the first side of the heat exchanger such that a fixed volume of the working fluid is maintained in the first side;
 - 10 (c) providing a flow of a collection fluid, that is at a higher temperature than the working fluid as a result of heat from the thermal source, through a second side of the heat exchanger that is adjacent to the first side to affect a transfer of heat from the collection fluid to the fixed volume of the working fluid to raise its temperature and pressure;
 - 15 (d) releasing the pressurized working fluid from the first side of the heat exchanger upon the working fluid reaching a threshold state;
 - (e) directing a flow of the pressurized working fluid to an expander capable of converting the kinetic energy of the pressurized working fluid into useful work or electricity;
 - 20 (f) repeating steps (a) - (e).
2. The process as claimed in claim 1 wherein the collection fluid is a collection liquid, and the process further includes transferring heat energy from the thermal source to the collection liquid.

3. The process as claimed in claim 2 wherein collection liquid is heated to a temperature within the range of about 34°F to about 210°F to yield a heated collection liquid.
4. The process as claimed in any one of claims 1 - 3 wherein the working fluid at
5 step (a) is at a pressure in the range of about 50 to about 5000 psi and at a temperature in the range of about -10°F to about 210°F.
5. The process as claimed in any one of claims 1 - 4 wherein the working fluid becomes supercritical during step (c), and after step (e) the working fluid is about 50% to about 90% or more in a liquid phase.
- 10 6. The process as claimed in any one of claims 1 - 5 further comprising the step of recirculating the working fluid from the expander to the first side of the heat exchanger.
7. The process as claimed in any one of claims 2 - 6 further comprising the step of recirculating the collection liquid from the second side of the heat exchanger
15 to a second heat exchanger where the step of transferring heat energy from the thermal source to the collection liquid takes place prior to the heated collection liquid flowing through the second side of the heat exchanger.
8. The process as claimed in claim 6 further comprising the step of transferring heat from the working fluid to another liquid after step (e) to bring the

temperature of the working fluid within the range of about -10°F to about 210°F.

9. The process as claimed in claim 8 wherein said another liquid is the collection liquid.
10. The process as claimed in claim 9 further comprising transferring heat from said
5 another liquid to the collection liquid prior to step (c).
11. The process as claimed in any one of claims 1 - 10 further comprising performing steps (a) - (f) on a plurality of heat exchangers, each in fluid communication with the expander, and temporally offsetting the release of the pressurized working fluid from at least one of the plurality of heat exchangers
10 to the expander.
12. A system for extracting useful work or electricity from a thermal source, the system comprising:
- (a) a heat exchanger having a first side and an adjacent second side that is fluidly separate from the first side;
 - 15 (b) a supply of a liquid or supercritical working fluid that is fluidly coupled to the first side of the heat exchanger;
 - (c) a valve system operable to close flow of working fluid in and out of the first side in response to a close signal to enclose a volume of working fluid within the first side, and being further operable to open flow of working
20 fluid out of the first side in response to an open signal;

- (d) a flow of a collection fluid through the second side of the heat exchanger, wherein the collection fluid is at a higher temperature than the working fluid as a result of heat from the thermal source, the flow of collection liquid operable to affect a transfer of heat from the collection liquid to the volume of working liquid within the first side to raise its temperature and pressure;
- (e) a controller operable to send the close signal to the valve system when the first side of the heat exchanger is full of working fluid, and operable to send the open signal to the valve system upon the working fluid reaching a threshold state to release the pressurized working fluid from the first side of the heat exchanger; and
- (f) an expander fluidly coupled to the first side of the heat exchanger to receive the pressurized working fluid and operable to convert the kinetic energy of the pressurized working fluid into useful work or electricity.

13. The system as claimed in claim 12 wherein the collection fluid is a collection liquid at a temperature within a range of about 34°F to about 210°F as a result of heat from the thermal source.

14. The system as claimed in any one of claims 12 and 13 wherein the working fluid is at a pressure in the range of about 50 to about 5000 psi and at a temperature in the range of about -10°F to about 210°F.

15. The system as claimed in any one of claims 12 - 14 further comprising a first

recirculation conduit to recirculate the working fluid from the expander to the first side of the heat exchanger.

16. The system as claimed in claim 15 further comprising a second heat exchanger fluidly coupled to the first recirculation conduit downstream from the expander and operable to transfer heat from the working fluid to another liquid to bring the working fluid to a temperature in the range of about -10°F to about 210°F.

17. The system as claimed in claim 16 wherein said another liquid is the collection liquid.

18. The system as claimed in any one of claims 13 - 17 further comprising a second recirculation conduit fluidly coupled to the second side of the heat exchanger, and a third heat exchanger fluidly coupled to the second recirculation conduit and to the thermal source to enable a transfer of heat from the thermal source to the flow of collection liquid before flow into the second side of the heat exchanger.

19. The system as claimed in any one of claims 12 - 18 further comprising a plurality of heat exchangers, each having a first side that receives a flow of working fluid and a second side that receives a flow of collection fluid, and each first side being in fluid communication with the expander and operably connected to the valve system, and the controller is operable to send open signals to the valve system in a manner to temporally offset the release of pressurized working

liquid from at least one of the plurality of heat exchangers to the expander.

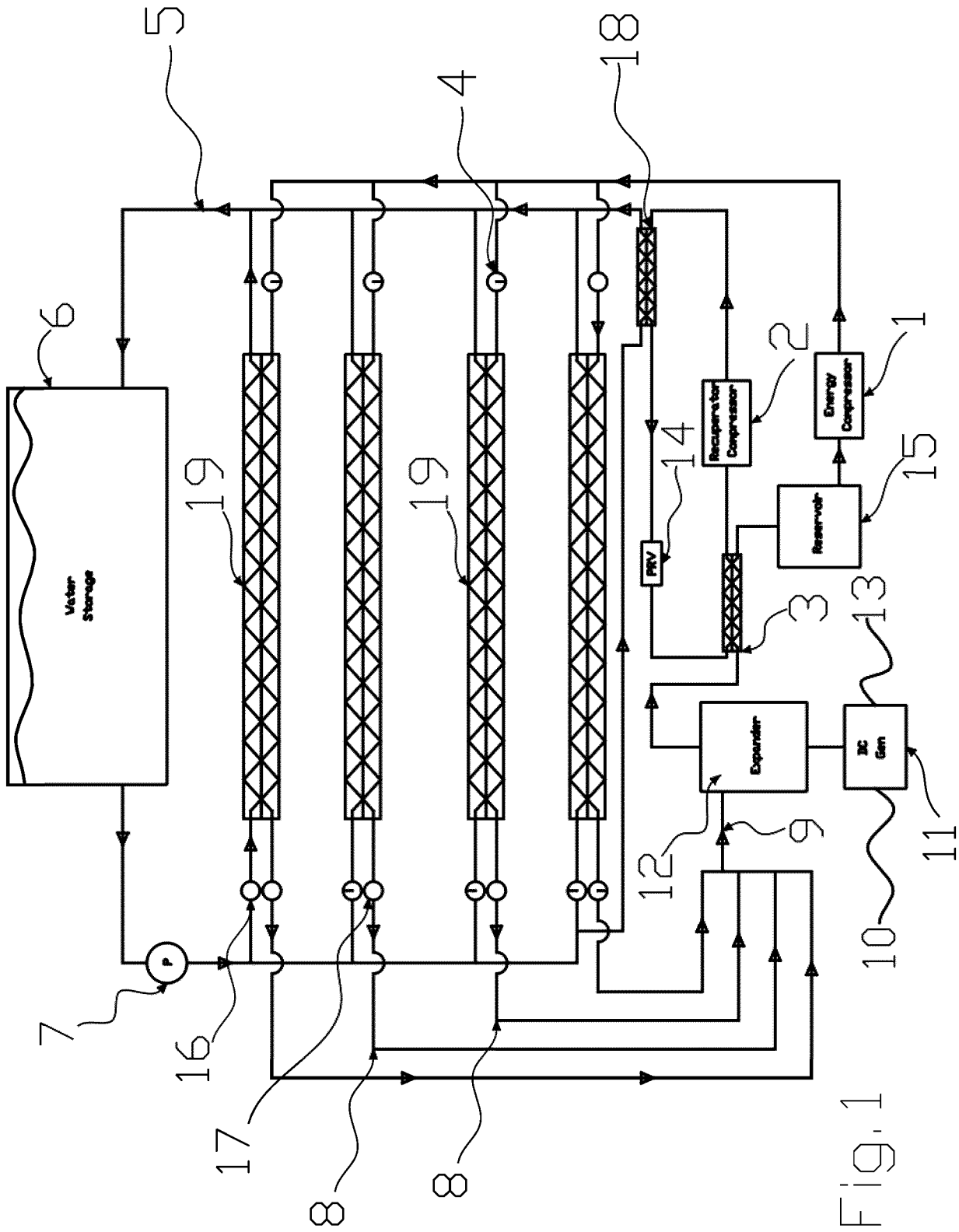


Fig. 1

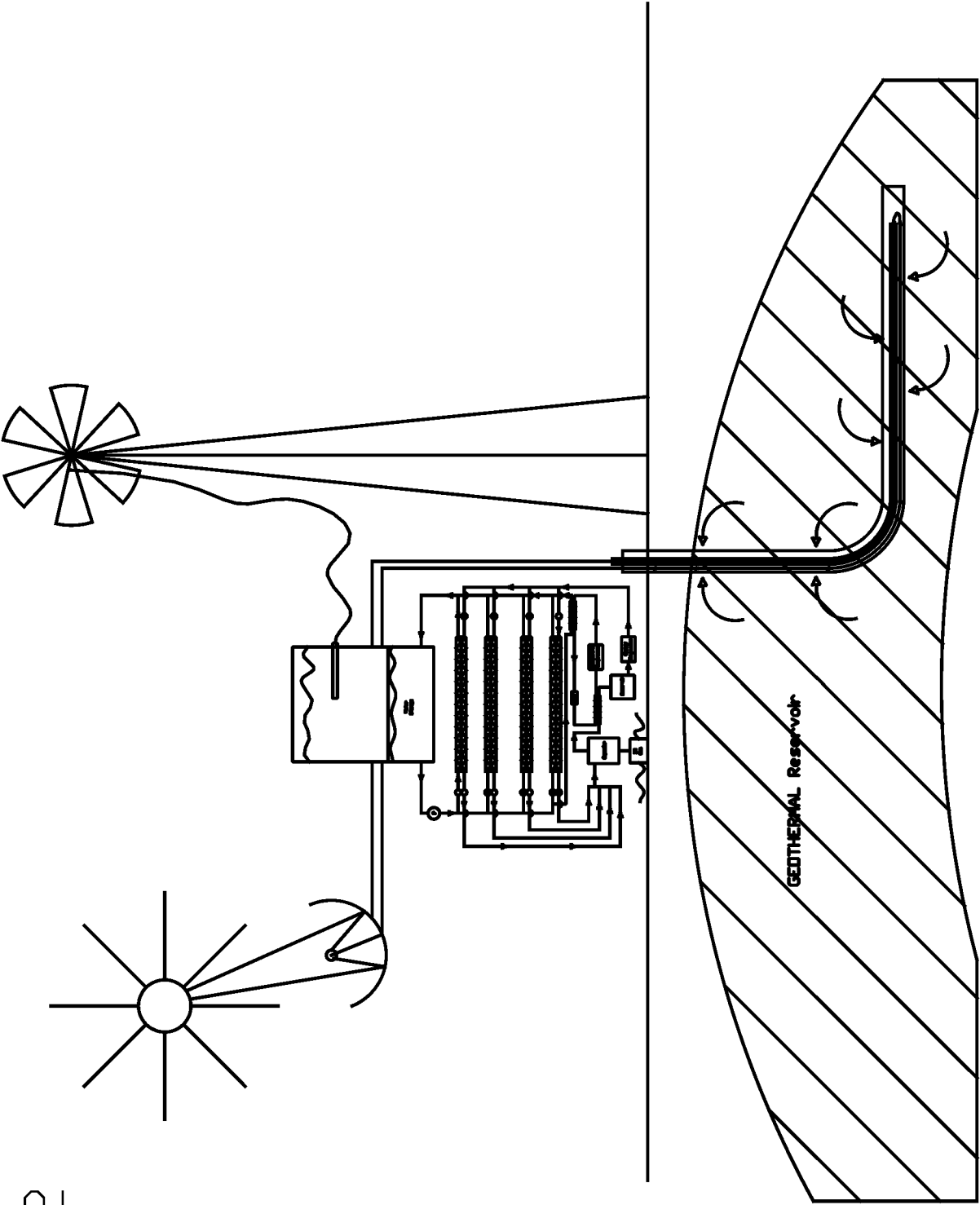


Fig. 2

OHPC Power Cycle - R134a Working Fluid									
Cycle	Temperature (°F)	Pressure (psig)	Density (lbm/ft³)	Volume (ft³/lbm)	Int. Energy (Btu/lbm)	Enthalpy (Btu/lbm)	Quality (lbm/lbm)		
Location									
At Inlet to Exchanger 19 (pre expansion)	19.3	50.0	82.32	0.0121	81.9	82.0	Subcooled		
Inside Exchanger 19 (post expansion)	35.1	1197	82.29	0.0122	85.2	87.9	Subcooled		
At outlet of Expander 12	16.5	16.0	22.51	0.0444	82.7	83.0	0.021487		
At inlet to Reservoir 15	16.5	16.0	82.29	0.0122	81.0	81.1	Subcooled		
At Exit of Compressor 1	19.3	50.0	82.32	0.0121	81.9	82.0	Subcooled		
Cooling Circuit - R134a - Refrigeration/Cooling									
Cycle	Temperature (°F)	Pressure (psig)	Density (lbm/ft³)	Volume (ft³/lbm)	Int. Energy (Btu/lbm)	Enthalpy (Btu/lbm)	Quality (lbm/lbm)		
Location									
At inlet of Exchanger 18	146.3	250	8.39	0.1192	160.0	165.8	0.687		
At exit of Exchanger 18	120.0	250	69.49	0.0144	115.3	116.0	Subcooled		
At exit of PRV Valve 14	6.7	10	1.16	0.8625	115.3	119.3	0.45909		
At exit of Exchanger 3	6.7	10	0.55	1.8276	157.7	166.1	0.98		
At exit of Recuperator Compressor 2	146.3	250	8.39	0.1192	160.0	165.8	0.68714		

Fig. 3

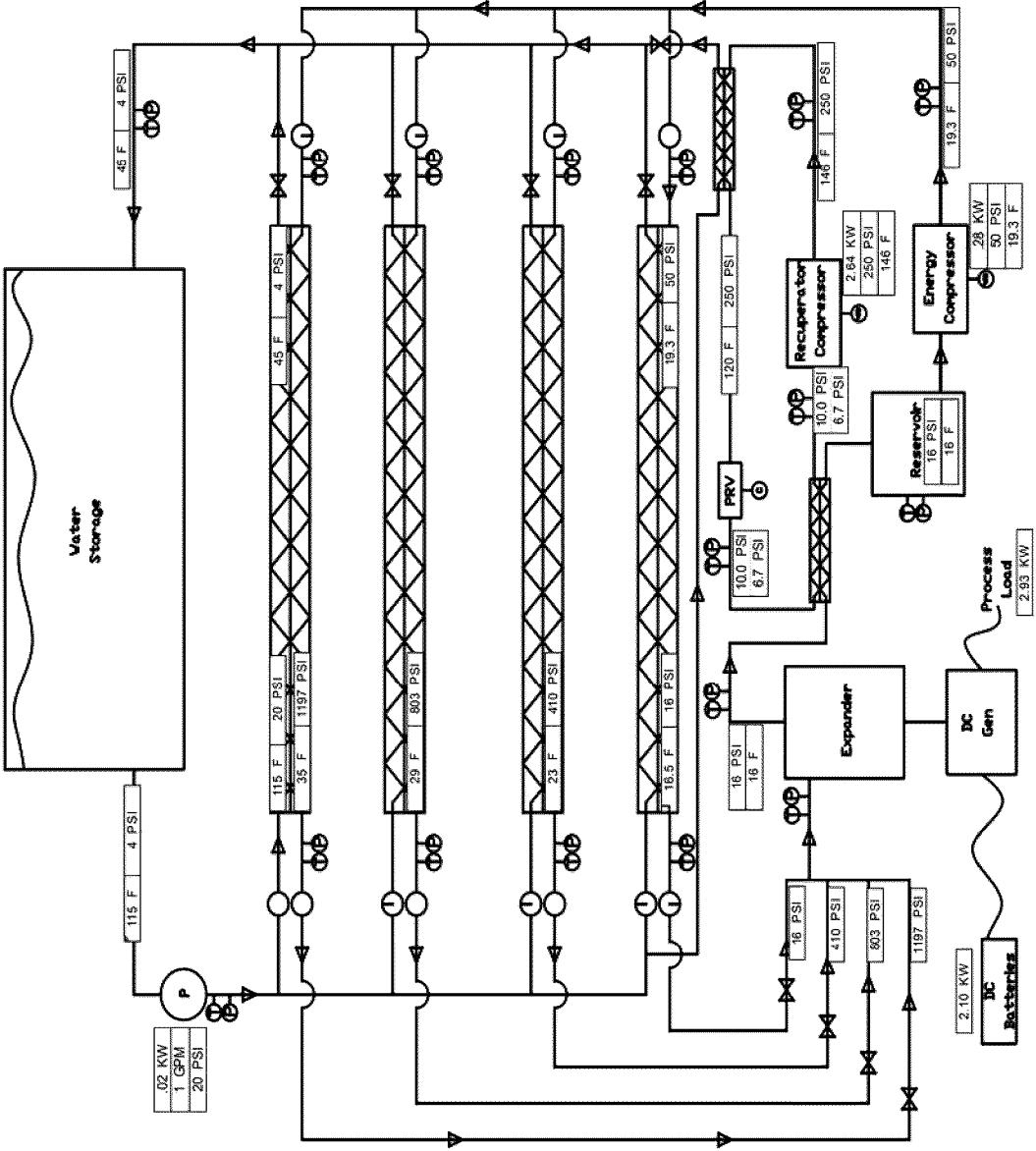
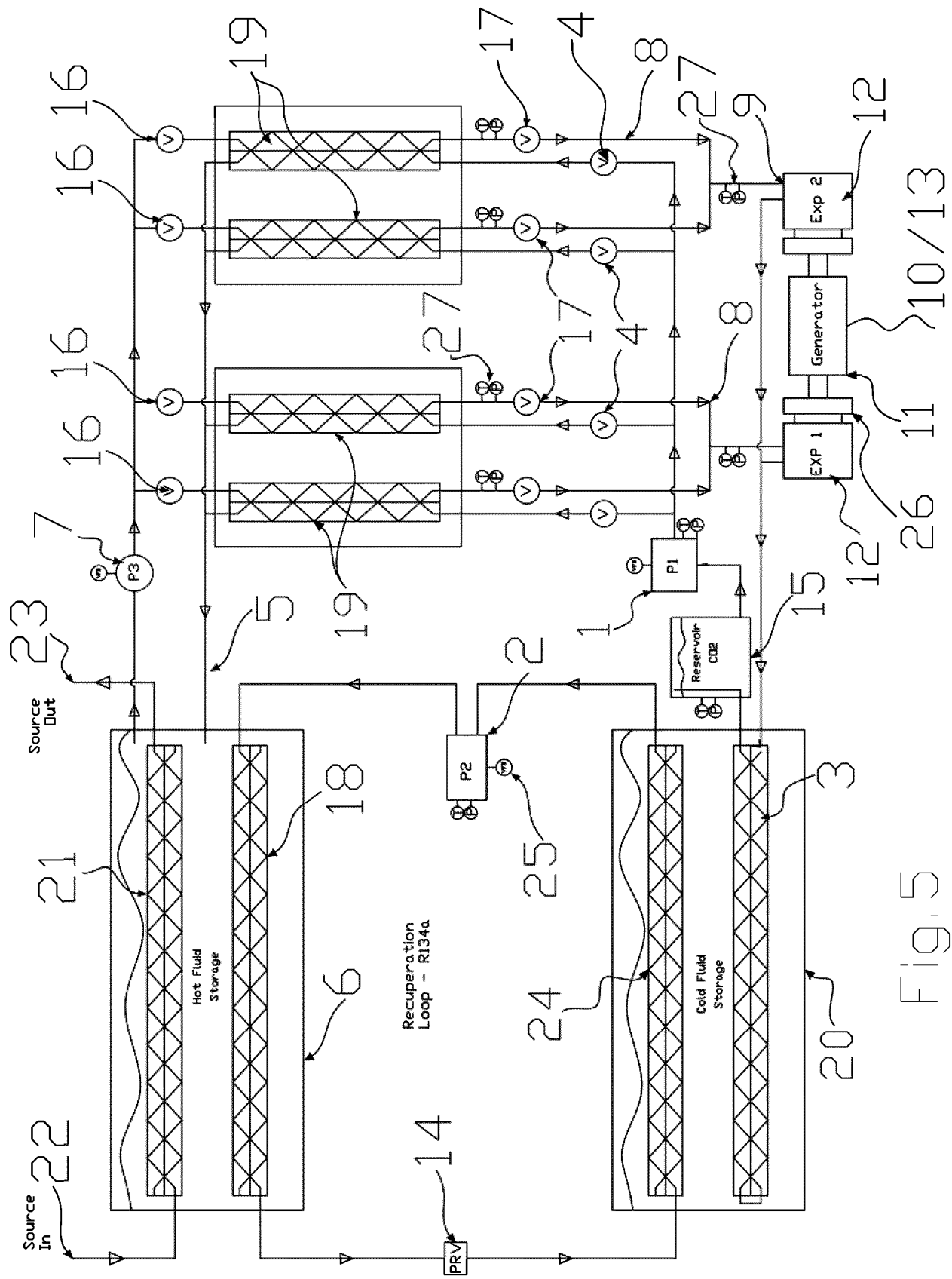


Fig. 4



Super Critical CO2 Working Fluid							
	Temp	Pressure	Density	Volume	Int. Energy	Enthalpy	Quality
	(°F)	(psig)	(lbm/ft ³)	(ft ³ /lbm)	(Btu/lbm)	(Btu/lbm)	
Cycle Location							
HEX Inlet - LP	70	1500	53.3	0.0188	100.07	105.34	Subcooled
Charged HEX - HP	180	6769.2	53.3	0.0188	124.06	147.63	S/Critical
Expander Outlet	61.7	750	21.32	0.0469	125.08	131.72	M-Phase
Compressor Inlet	56.1	750	52.578	0.0190	98.0	100.69	Subcooled
Compressor Outlet	70	1500	53.3	0.0188	100.07	105.34	Subcooled

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2016/051545

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **F01K 27/00** (2006.01), **F02G 1/04** (2006.01), **F03G 4/00** (2006.01), **F03G 6/00** (2006.01),
H02K 7/18 (2006.01)

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)
 IPC: **F01K 27/00** (2006.01), **F02G 1/04** (2006.01), **F03G 4/00** (2006.01), **F03G 6/00** (2006.01),
H02K 7/18 (2006.01), **F22B** (2006.01)
 USPC: 60/641.2, 60/641.7, 60/643, 60/655, 60/659

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

QUESTEL ORBIT

Keywords: heat, exchanger, fluid, pulse, steam, expander, turbine, cyclic+, food, parallel

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2010/0059216 A1 (BRUCKMANN et al.) 11 March 2010 (11-03-2010) see: abstract par. 28 fig. 4	1-19
A	CA 1065841 (POUDEROUX) 6 November 1979 (06-11-1979) see: whole document	1-19

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* "A" "E" "L" "O" "P"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance earlier application or patent but published on or after the international filing date document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	"T" "X" "Y" "&"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art document member of the same patent family
--------------------------------------	--	--------------------------	--

Date of the actual completion of the international search
 29 March 2017 (29-03-2017)

Date of mailing of the international search report
 04 April 2017 (04-04-2017)

Name and mailing address of the ISA/CA
 Canadian Intellectual Property Office
 Place du Portage I, C114 - 1st Floor, Box PCT
 50 Victoria Street
 Gatineau, Quebec K1A 0C9
 Facsimile No.: 819-953-2476

Authorized officer

Julien Daigle (819) 934-4273

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/CA2016/051545

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US2010059216A1	11 March 2010 (11-03-2010)	US2010059216A1 US8708035B2 AU2009289762A1 AU2009289762B2 CN102149999A CN102149999B EP2161525A1 EP2161525B1 EP2161525B8 ES2582657T3 KR20110069804A WO2010025960A2 WO2010025960A3	11 March 2010 (11-03-2010) 29 April 2014 (29-04-2014) 11 March 2010 (11-03-2010) 17 September 2015 (17-09-2015) 10 August 2011 (10-08-2011) 14 November 2012 (14-11-2012) 10 March 2010 (10-03-2010) 20 April 2016 (20-04-2016) 08 June 2016 (08-06-2016) 14 September 2016 (14-09-2016) 23 June 2011 (23-06-2011) 11 March 2010 (11-03-2010) 17 June 2010 (17-06-2010)
CA1065841A	06 November 1979 (06-11-1979)	CA1065841A BR7608446A DE2656426A1 DE2656426C2 ES454362A1 FR2335791A1 FR2335791B1 GB1516796A IT1065670B JPS5276504A JPS5936161B2 NL7613889A NL177954C US4120348A	06 November 1979 (06-11-1979) 13 December 1977 (13-12-1977) 30 June 1977 (30-06-1977) 29 January 1987 (29-01-1987) 16 December 1977 (16-12-1977) 15 July 1977 (15-07-1977) 30 June 1978 (30-06-1978) 05 July 1978 (05-07-1978) 04 March 1985 (04-03-1985) 28 June 1977 (28-06-1977) 01 September 1984 (01-09-1984) 21 June 1977 (21-06-1977) 16 December 1985 (16-12-1985) 17 October 1978 (17-10-1978)