



(51) International Patent Classification:

F01K 21/02 (2006.01) F01K 25/06 (2006.01)

(21) International Application Number:

PCT/IL2023/051160

(22) International Filing Date:

09 November 2023 (09.11.2023)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

FR63/383,136	10 November 2022 (10.11.2022)	US
FR63/530,586	03 August 2023 (03.08.2023)	US
FR63/540,786	27 September 2023 (27.09.2023)	US
63/545,053	20 October 2023 (20.10.2023)	US

(71) Applicant: **TECHNION RESEARCH & DEVELOPMENT FOUNDATION LIMITED** [IL/IL]; Senate House Technion City, 3200004 Haifa (IL).

(72) Inventor: **ROTSCHILD, Carmel**; 10 Hacarmel Street, 5590000 Ganei Tikva (IL).

(74) Agent: **COHN, Lior**; C/O COHN, DE VRIES, STADLER & CO., P.O.B 10278, 6110103 Tel Aviv (IL).

(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, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,

HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, 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, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, 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, ME, 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))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: THERMAL ENERGY STORAGE SYSTEM

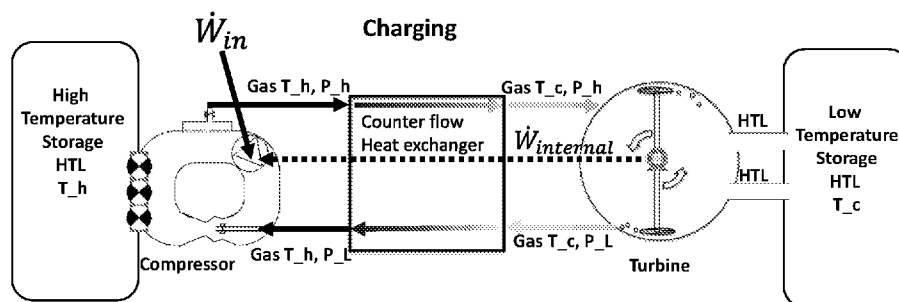


Fig. 5A

(57) Abstract: A system permitting efficient heat pump, storage of thermal energy, and retrieval of this stored thermal energy back to electricity upon demand. The system operates in two operational modes: a charging operational mode, in which thermal energy is pumped in an electrically driven compressor and is transferred into a hot heat transfer liquid reservoir by a heat transfer liquid; and a discharging operational mode, in which thermal energy from the hot reservoir is utilized in a turbine to produce kinetic energy that can be used directly or can be converted into an electric energy to be used when desired.

THERMAL ENERGY STORAGE SYSTEM

TECHNOLOGICAL FIELD

The present disclosure is in the field of thermal-based storage systems, for allowing retrieval of electric energy and controllable use of this energy.

BACKGROUND

5 The prior art for heat engines includes the Carnot Stirling and Ericsson thermodynamic cycle, all reaching the Carnot efficiency limit through isothermal processes when converting heat into work (electricity). Conventionally, heat cycles include a compressor and a turbine based on adiabatic processes, for example in Rankine and Brayton. In the reverse process, heat engines convert work into heat that can be
10 stored. Carnot Battery is a cycle where work, such as electricity, is converted to thermal storage, which is recycled back into electricity. As far as we know all realization of Carnot battery have a limited efficiency. The following are example of the charging-discharging Brayton cycle (see also **Fig. 1**): The system includes high temperature (H-HEX) and cold temperature (C-HEX) heat reservoirs with a heat exchanger, a compressor, and a turbine.
15 The entire system is thermally insulated. In the charging process, electric power operates the compressor that compresses the gas and elevates temperature to high temperature. The heat is stored in the H-HEX. The compressed air cools in the heat exchanger and reaches the turbine for discharging the pressure. The turbine power returns to the compressor. The exit gas is cold and passes through the C-HEX to reduce the temperature
20 of the cold reservoir. The gas continues to the compressor for an additional cycle. The outcome of the charging process is a change in temperature between the two thermal reservoirs. In the discharge process, the low-temperature air from the cold reservoir is compressed and heated and passes through the hot reservoir where its temperature elevates (while the storage is cooled). The hot compressed gas reaches the turbine,
25 producing power that both drives the compressor and generates the output power. The cold gas after the turbine reaches the cold reservoir and returns to the compressor for another cycle until the temperature difference between the two reservoirs results in negative power production. The challenges in the concept are: the thermal energy density is poor leading to a huge size and cost of the device. The heat exchangers are costly. The

- 2 -

expansion and compression are adiabatic which is inefficient due to temperature overshoot with respect to the reservoir's temperature. Also, additional low-grade waste heat is less efficient in boosting the round-trip efficiency due to the high operation temperatures.

5 BACKGROUND ART

References considered to be relevant as background to the presently disclosed subject matter are listed below:

- WO 2022/049573
- WO 2022/234554

10 Acknowledgement of the above references herein is not to be inferred as meaning that these are in any way relevant to the patentability of the presently disclosed subject matter.

GENERAL DESCRIPTION

15 The present disclosure provides a system for allowing an efficient heat pump, storage of thermal energy, and retrieval of this stored thermal energy back to electricity upon demand. Therefore, the system operates in two operational modes: (1) a charging operational mode, in which thermal energy is pumped in an electrically driven compressor and is transferred into a hot heat transfer liquid reservoir (which may be
20 referred to herein, in short also as "hot reservoir") by a heat transfer liquid (HTL); and (2) a discharging operational mode, in which thermal energy from the hot reservoir is utilized in a turbine to produce kinetic energy that can be used directly or can be converted into an electric energy to be used when desired. In addition to its use as a carrier of the thermal energy, the HTL is also an active participant in the compression process within
25 the compressor in the system's charging mode, and in the expansion process occurring within the turbine in the system's discharging mode. The hot reservoir has a temperature that is above ambient temperature, typically considerably higher than the ambient temperature, e.g. by 10°C, 20°C, 30°C, 40°C, 50°C, 60°C, 70°C, 80°C, 90°C, 100°C, 150°C, 200°C or even more above the ambient temperature. The extent of heating of the
30 hot reservoir during charging of energy and the extent of cooling of the hot reservoir

- 3 -

during energy discharge depends, amongst others, on the heat capacity of the hot reservoir.

In some aspects and embodiments of this disclosure also a cold HTL reservoir (which may be referred to herein, in short also as “cold reservoir”) is used and the heat is being pumped from the cold reservoir to the hot reservoir or released from the hot reservoir to the cold reservoir in respective heat storage and heat utilization. The cold reservoir has a temperature that is below ambient temperature, typically considerably lower than the ambient temperature, e.g. by 10°C, 20°C, 30°C, 40°C, 50°C, 60°C, 70°C, 80°C, 90°C, 100°C, 150°C, 200°C or even more below the ambient temperature. The extent of colling of the cold reservoir during storage of energy and the extent of heating of the cold reservoir during energy discharge depends, among others, on the heat capacity of the hot reservoir.

The hot reservoir and the cold reservoir may, by some embodiments of this disclosure, be thermally insulated. Both the compression process and the expansion process involve mixing a working fluid (WF) that flows in the system with the HTL to form a two-phase mixture of WF and HTL (which may be referred to herein as “*HTL/WF mixture*”). In the compressor the WF enters the mixture in its gaseous (the terms “*gas*”, “*gaseous*” etc. are used herein encompass gas and vapor) and is compressed, while in the turbine to cause the WF to enter the mixture as a compressed gas or in its liquid phase, optionally to be further compressed within the mixture. In the HTL/WF mixture, the HTL is typically the more abundant constituent. Upon formation of the HTL/WF mixture or very slightly thereafter, the temperatures of the HTL and the WF are about equal as the HTL either cools or heats the WF, during respective compression or expansion of the WF. It should be noted that the heat capacity of the HTL is much larger than the gaseous WF (the HTL may have a greater heat capacity of about 3 orders of magnitude than that of the gaseous WF). Accordingly, the WF assumes the temperature of the HTL and its expansion in the turbine or its compression in the compressor occurs essentially without a change in temperature. This is referred to herein as “*quasi-isothermal expansion*” and “*quasi-isothermal compression*”, respectively (the term “*quasi*” denotes the fact that if one would measure the temperature very accurately during the process, one could record only small temperature changes, due to the huge heat capacity of the HTL. The temperature at the end of the expansion or compression of the WF during the quasi-

- 4 -

isothermal process is less than 20%, 10%, 5%, 4%, 3%, 2%, or even less than 1% in degrees Kelvin from the initial temperature of the WF.

Therefore, during the compression process, the HTL constantly cools the WF in the HTL/WF mixture, as the heat is transferred from the WF to the HTL, thereby yielding
5 said quasi-isothermal compression of the WF in the HTL/WF mixture. By the end of the compression process, the WF may be in a gas or a liquid phase. At the end of the compression process, the HTL and the WF are separated in a separation zone, for example by means of gravitational separation, centrifugal-based separation or by any other known or suitable separation technique. The compressor used herein is, thus, a two-phase
10 compressor, namely a compressor that operates on a mixture of one material in a liquid phase, namely the HTL, and another in a gas phase, namely the WF.

Similarly, during the expansion process in the turbine, the HTL constantly heats the WF in the HTL/WF mixture, thereby yielding said quasi-isothermal expansion of the WF in the HTL/WF mixture. At the end of the expansion process, the HTL and the WF
15 are separated in a separation zone, for example in one of the separation manners described above. Thus, by the same token of the definition of the compressor and as a two-phase compressor, the turbine of this disclosure is a two-phase turbine.

The HTL and the WF may, by some embodiments, as also further discussed below, be the same substance in different phase, particularly in the compressor. By one
20 embodiment, the compressor has its own HTL that is referred throughout the application as *compressor HTL* that flows in a closed loop in the compressor and the WF that is mixed with the compressor HTL can be the same material but in a different phase. During the compression process in the compressor, the pressure of the compressor HTL drops for a very short period, thereby not allowing the compressor HTL to change its phase to gas
25 while allowing suction of the WF in gaseous phase to be mixed with the compressor HTL. Therefore, the WF and the compressor HTL can be the same material but in different phases during the compression process in the compressor. When the compressor has its own compressor HTL different than the hot HTL, the compressor HTL heats during the compression process and then transfers its heat to the hot HTL reservoir by any suitable
30 thermal coupling.

In some other embodiments, the compressor is fed by HTL from the hot HTL reservoir. Therefore, in these embodiments, the hot HTL is cycled between the hot HTL

- 5 -

reservoir and the compressor, being heated with every cycle and therefore heating the hot HTL reservoir.

In some embodiments of the systems of this disclosure, the flow paths of each of the HTL and the WF may be the same in the two operational modes. In some other
5 embodiments of the systems of this disclosure, the flow paths of each of the HTL and the WF may be the same, albeit in a reverse flow direction. In yet other embodiments of the systems of this disclosure, there are different flow paths for the HTL and the WF in the two operational modes of the systems of this disclosure: (1) in the charging mode, where the HTL is cycled between the hot reservoir and the compressor and the WF is cycled
10 between the compressor and an evaporator; (2) in the discharging mode, where the HTL is cycled between the hot reservoir and the turbine and the WF is cycled between the turbine and a condenser. In some embodiments the same flow paths are used in the two operational modes, albeit in a reverse flow direction.

Three system aspects, described below are provided by this disclosure referred to
15 as “first system aspect”, “second system aspect” and “third system aspect”. While the system of the second system aspect and the third system aspect comprises also a cold reservoir, the system of the first system aspect does not comprise such a reservoir. In the system of the first system aspect, the heat may be exchanged, through the intermediary of the WF, with the environment or an external medium (e.g. body of water) – in the
20 charging operational mode heat is absorbed from the environment or the external medium and *vice versa* in the discharging operational mode. In a system of the second and third system aspects, the heat is pumped, through the intermediary of the WF, between the cold storage and the hot storage in the charging operational mode and *vice versa* in the discharging operational mode.

25 The second and the third system aspects differ in that in the third system aspect the WF is a liquid/vapor phase changing (LVPhC).

The first system aspect provides a system for storing and retrieving electric energy. It comprises a two-phase turbine and a two-phase compressor. The compressor is configured for compressing compressor HTL. The compressor HTL can be the same or
30 different as the hot HTL. The system may also comprise a compressor HTL reservoir that may be configured as an element within the compressor that stores compressor HTL before and/or after the compression process in the compressor or may be an independent

- 6 -

element fluidically coupled to the compressor, for example configured to supplement compressor HTL wasted during the compressor's operation.

The system of the first system aspect, also comprises hot HTL reservoir containing hot HTL. The HTL may be any material (that may be a mixture by itself) that
5 remains in a liquid phase in all range of working temperatures and pressures of the system. As noted above, the HTL may, by some embodiments, be the same material as the WF, yet it remains in the liquid phase due to the short duration of the pressure drop in the compressor. The hot HTL reservoir is configured to receive or discharge hot HTL in the respective charging and discharging operation modes and may comprise substances
10 other than the HTL that can receive and store thermal energy transferred from the HTL, for example stones or gravel. The hot HTL reservoir may be selectively fluidically connectable to a quasi-isothermal, two-phase turbine or a quasi-isothermal or in some embodiments only thermally coupled to the two-phase compressor, thermally insulated two-phase compressor, in respective discharging or charging operational modes, for
15 feeding hot HTL to the respective turbine or compressor or to allow exchange of heat between the compressor HTL and the hot HTL reservoir. In other words, the system is configured to connect the hot HTL reservoir to the compressor in a charging mode and to the turbine in a discharging mode.

The compressor and the turbine are, typically, thermally insulated.

20 In this description reference to an element should be understood to mean that there are at least one of such element. In other words, the term "a", "an" or "the" when referring to an element of the system should be understood as meaning at least one such element. For example, the system may comprise one or more turbines operating in parallel or one or more compressors operating in parallel. Similarly, as another example, a system of this
25 disclosure may comprise one heat exchanger unit or a plurality of such units. The same holds true, for example to the condenser, evaporator, reservoir, and all other noted elements. To simplify the description, reference is made to one such element, e.g. a turbine, a compressor, a heat exchanger, a condenser, an evaporator, a reservoir, etc., with the understanding that it should be read to mean at least one turbine, at least one
30 compressor, at least one heat exchanger, at least one condenser, at least one evaporator, at least one reservoir, etc. Where a system of this disclosure comprises more than one of a defined element, the plurality of such elements may work in series or in parallel, as the case may be.

- 7 -

The system of the first system aspect further comprises a condenser in fluid communication with the turbine for receiving and condensing WF coming from the turbine; namely in the discharging mode of the system the condenser is downstream the turbine in the flow path of the WF.

5 The system of the first system aspect optionally further comprises a working fluid pump (WF pump) in fluid communication with the condenser for pressurizing the condensed WF, that is condensed in the condenser. It is to be noted that the WF pump can be disposed in various positions of the WF flow path, for example it may be disposed in and made to be an integral part of the condenser, can be disposed in the flow path
10 between the condenser and the first heat exchanger or between the first heat exchanger and the turbine.

The system of the first system aspect may, by some embodiments, further comprise an evaporator in fluid communication with the compressor for receiving and evaporating WF coming from the compressor. The evaporator, may be the same or
15 different element than the condenser. Namely, in the system's charging operational mode, the evaporator is downstream the compressor in the WF flow path. In some embodiments, the condenser and the evaporator are the same element. The condenser/evaporator may be configured to allow thermal heat exchange between the WF that flows through them and their surroundings.

20 The discharging mode of the system defines a first flow path of the WF and the charging mode defines a second flow path of the WF. In some embodiments, elements constituting the first WF flow path serve a dual role, being part of also the second WF flow path. This may be so for the conduits (e.g. in the form of pipes) that may be dually used in both the first and the second flow paths (at times at opposite WF flow). This may
25 also be so for other elements, such as the first and second counter flow heat exchangers defined below that may be the same element used in both flow paths, or the condenser that may be configured to serve, in an opposite WF flow path, also as the evaporator.

By some embodiments of the system of the first system aspect, the system comprises a first counterflow heat exchanger, typically a recuperator, that may be
30 disposed in the first flow path between the turbine and the condenser and configured for exchanging heat between WF exiting from the turbine and WF exiting from the condenser.

- 8 -

By some embodiments of the system of the first system aspect, the system comprises a second counterflow heat exchanger of the system, typically a recuperator, which may be the same or different element than the first heat exchanger, that may be disposed in the second flow path between the compressor and the evaporator and
5 configured for exchanging heat between WF exiting from the compressor and WF exiting from the evaporator.

The flow path of the WF in the discharging and the charging operational modes of the first system aspect will now be described.

In the discharging mode, according to one embodiment of the first system aspect
10 of this disclosure, the WF flows in the first flow path to one or more nozzles in the turbine to thereby mix the WF with the HTL to form a HTL/WF mixture; in this flow, the WF may pass through the first heat exchanger. The WF may be an LVPhC WF. The HTL/WF mixture undergoes a quasi-isothermal expansion in the one or more nozzles, namely expansion in which the WF is maintained at about the same temperature due to the heat
15 exchange with the HTL that has much greater heat capacity. In other words, the cooling of the WF in the expansion process has a small effect on the temperature of the HTL/MF mixture. This quasi-isothermal expansion causes acceleration of the HTL/WF mixture and discharge of the mixture through the one or more nozzles. The kinetic energy that is discharged through the nozzles is converted into work through inducing turbine rotation,
20 while reducing temperature of the HTL. This work may be converted into electricity (produced in an electric generator rotationally coupled to the turbine) that may be stored or immediately utilized. The HTL/WF mixture discharged out of the nozzles is received may be received in an optional first separation zone that is configured to separate the WF from the HTL. The separated HTL can be recycled back to said hot reservoir or to the one
25 or more nozzles (these processes typically occur in parallel – a portion of the HTL being recycle back to the hot reservoir while some other hot HTL is propelled out of the reservoir in its place and the other portion continues to cycle back to the one or more nozzles). The separated WF may optionally be directed to flow through the first heat exchanger to reduce its temperature and then received in the condenser to undergo
30 condensation therein. The condensed WF discharged from the condenser flows, this flow may be forced by a pressurizing arrangement configured for pressurizing or propelling the WF, for example such an arrangement comprising a WF pump, configured for pumping the WF in a high pressure back to the turbine, typically through the optional first

- 9 -

heat exchanger where it may be heated by the counter flowing WF flowing from the turbine to the condenser (that is cooled while passing through the heat exchanger, as noted above). Said arrangement may also pressurize the WF to the turbine operation pressure. Said arrangement may be disposed upstream the first heat exchanger and downstream the
5 condenser. In some embodiments, a WF pump is integrated into the condenser. In some embodiments, the pumping arrangement is constituted by the turbine, namely the turbine centrifugal forces causing the WF to be pumped in high pressure back to the turbine.

There turbine may have a plurality of nozzles fixedly coupled to the turbine's axle such that the kinetic energy generated thereby induces rotation of the axle. The nozzles
10 may be disposed on dedicated elements radially extending from the axle or may be disposed on the turbine's rotating blades.

In the charging operational mode, according to one embodiment of the first system aspect of this disclosure, the WF flows in the second flow path and the compressor is configured to receive hot HTL from the hot HTL reservoir and WF vapor, e.g. passing
15 through the second heat exchanger, to form a HTL/WF mixture. The WF in this mixture is quasi-isothermally compressed and optionally condensed (in the case it is an LVPhC) along a compressor flow path, (typically, streaming the WF and the HTL together through a nozzle that is configured to allow quasi-isothermal compression, namely compression in which the WF is maintained at about the same temperature due to the heat exchange
20 with the HTL that has much greater heat capacity. In other words, the heating of the WF in the compression process has a negligible effect on the temperature of the HTL/MF mixture. The HTL/WF mixture may be separated in an optional second separation zone. The separated HTL is cycled back to the hot reservoir or to the compressor (these typically occur in parallel – a portion of the HTL being recycle back to the hot reservoir while some
25 other hot HTL is propelled into the compressor and the other portion continues to cycle within the compressor). The compressed WF is discharged from the compressor and flows, e.g. through the second heat exchanger to reduce its temperature, to the evaporator to undergo evaporation, optionally flash evaporation whereby it cools to a cool temperature below surrounding temperature. The cool temperature is set by the entrance
30 pressure to the compressor. Optionally only part of the WF is evaporated. After evaporation, the vapors may be further heated by the environment to reach a full evaporation at the surrounding temperature. The evaporated WF discharged from the evaporator may be directed to flow through the optional second heat exchanger to be

- 10 -

heated thereby through heat exchange with the counter flowing WF, flowing from the compressor to the evaporator (that is cooled while passing through the heat exchanger, as noted above) and then back to the compressor to undergo another cycle. Optionally, full evaporation is reached only after the recuperator. The compressor may be operated by an
5 electric motor rotationally coupled thereto, to thereby store produced electric energy or access electric energy in the grid for use at a later time, e.g. times of peak grid energy needs.

In some embodiments of the first system aspect, both the discharging operational mode and the charging operational modes are according to the embodiments described
10 above.

The system of the first system aspect is, thus, switchable between two operational modes – a discharging mode and a charging mode. In the discharging mode, the HTL from the hot HTL reservoir is cycled between the reservoir and the turbine, employing the heat stored in the hot HTL reservoir and delivered by the HTL, which is reduced in
15 temperature throughout this process. The WF in the discharging mode flows in a flow path passing through the various elements in the following order (the point of start in the following description is arbitrary as the WF is consciously cycled in the process): received in the turbine; then flows through the first heat exchanger in one flow direction to the condenser; then back from the condenser through the first heat exchanger, in a
20 counterflow direction to that of said one flow direction, back to the turbine; this flow, particularly that from the condenser to the turbine, being driven by the WF pump. In the charging mode, the HTL from the hot HTL reservoir is cycled between the reservoir and the compressor or being in thermal coupling with the compressor HTL, in case that the compressor has its own compressor HTL, increasing its temperature in every cycle. The
25 WF in the charging mode flows in a flow path passing through the following elements in the following order (here again, the point of start in the following description is arbitrary as the WF is consciously cycled in the process): received in the compressor; then flows in one direction through the second heat exchanger, to the evaporator; and then from the evaporator through the second heat exchanger, in a counterflow direction to that of said
30 one flow direction, back to the compressor.

A second system aspect of the present disclosure provides a system for storing heat and retrieving electric energy, that comprises a two-phase turbine and a two-phase compressor. It also comprises a hot HTL reservoir containing hot HTL and a cold HTL

- 11 -

reservoir containing cold HTL, each selectively connectable to a quasi-isothermal, thermally insulated compressor/condenser or a quasi-isothermal, thermally insulated turbine depending on the operational mode of the system.

The two-phase compressor may comprise compressor HTL for its compression
5 operation and compressor HTL reservoir for holding compressor HTL. The compressor HTL can be the same as the hot and cold HTL and the compressor HTL reservoir can be the same as the hot and cold HTL reservoir and then in the charging mode the hot HTL reservoir is fluidically coupled to the compressor for feeding it with hot HTL and in the discharging mode the cold HTL reservoir is fluidically coupled to the compressor for
10 feeding it with cold HTL; or the compressor HTL and the compressor HTL reservoir can be different than the hot HTL and the hot HTL reservoir, respectively, and the compressor HTL flows in a flow path that allows it to thermally exchange heat with the hot HTL reservoir for heating the hot HTL reservoir in the charging mode or cooling the cold HTL reservoir in the discharging mode.

15 The hot HTL is defined by a temperature that is higher than the cold HTL. The hot HTL is usable: (i) in the charging mode in the compression of the WF mixed therein in the compressor while being gradually heated during the quasi-isothermal compression of the WF in the compressor, causing a comparable gradual increase in temperature of the hot reservoir, and (ii) in the discharging mode for operating the turbine, namely for
20 participating in the isothermal expansion of the HTL/working fluid mixture, utilizing the heat stored in the hot reservoir which gradually decreases in this process. The cold HTL is usable: (i) in the discharging mode for condensing and compressing the WF in the compressor, and (ii) in the charging mode for participating in the isothermal expansion of the HTL/WF mixture, heating in this process. Therefore, the minimal temperature of
25 the cold HTL has to be above the boiling temperature of the working fluid in the initial pressure in the turbine. The hot HTL may be the same material or different than the cold HTL.

In the charging operational mode of the system of the second system aspect, heat flows, through the intermediary of the WF, from the cold reservoir to the hot reservoir,
30 with the former cooling and the latter heating in this process, mediated by the input electric energy to the compressor. In the discharging operational mode of the system, the heat flows from the hot reservoir to the cold reservoir, through the intermediary of the

WF, with the former cooling and the latter heating in this process, this energy flow being converted to electric energy by the turbine.

The system of the second system aspect further comprises an intermediary heat exchanger that is disposed in a flow path between the compressor and the turbine.

5 In a charging operational mode of the system of the second system aspect, the compressor/condenser that is powered by external energy, typically by an electric motor receiving energy from an external source, e.g. access electric entry from the grid in times of low electric usage or produced electric energy that cannot be directed to the grid at time of production, is receives hot HTL from the hot HTL reservoir and quasi-
10 isothermally compresses and condense the LVPhC WF mixed with the hot HTL. This compression gradually heats the hot HTL through the charging process. The HTL/WF mixture is separated, with the hot HTL being directed either to the HTL reservoir or recycled for continued use within the compressor (as above, these typically occur in parallel – some portion of the HTL being recycle back to the hot reservoir while some
15 other hot HTL is propelled into the compressor and some other portion continues to cycle within the compressor). The compressed and condensed WF discharged from the compressor/condenser flows in one flow path through the first heat exchanger to reduce its temperature and then, optionally, to be mixed with cold HTL in one or more nozzles of the turbine to be vaporized and undergo isothermal or quasi-isothermal expansion in
20 the one or more nozzles that accelerates the HTL and the vaporized WF mixture to produce kinetic energy, in a manner similar to that describe above. This kinetic energy is convertible to electric energy through an electric generator rotationally coupled to the turbine that may be used to provide auxiliary power to the compressor. Optionally, the cold liquid WF is partially flash evaporated without a turbine and fully evaporated by
25 extracting heat from the environment in an evaporator. The vaporized WF discharged from the turbine, or from the evaporator, is directed towards the first heat exchanger to flow therethrough in a counter flow path to that of said one flow oath, to be, thus, heated (while the compressed and condensed WF is cooled in this process) and then received in the compressor for another cycle.

30 In the discharging operational mode of the system of second system aspect, the compressor (that is powered by a portion of the energy that is produced by the turbine, as noted below) is optionally configured to receive cold HTL from the cold HTL reservoir and quasi-isothermally condense and compress the LVPhC WF mixed in the cold HTL.

- 13 -

This compression gradually heats the cold HTL through the charging process. The HTL/WF mixture is separated, with the hot HTL being directed either to the HTL reservoir or recycled for continued use within the compressor (as above, these typically occur in parallel – some portion of the HTL being recycle back to the hot reservoir while
5 some other hot HTL is propelled into the compressor and some other portion continues to cycle within the compressor). Optionally, the WF is condensed in a condenser condenses the WF. The condensed WF that is discharged from the compressor, or the condenser, flows in a one direction flow path through the first heat exchanger to thereby increase its temperature and then to the turbine be mixed with hot HTL in a nozzle of the
10 turbine to vaporize and undergo quasi-isothermal expansion that accelerates the HTL and WF mixture to produce kinetic energy convertible to electric energy. The WF discharged from the turbine is directed towards the first heat exchanger, to flow in a counter direction flow path to that of said one direction flow path to be cooled (while the condensed WF is heated in this process) and then to be received in the compressor, or condenser, for another
15 cycle.

It is to be noted that in the embodiment that the compressor has its own compressor HTL, the coupling of the compressor to the hot and cold HTL reservoirs is only thermal coupling and the hot HTL and cold HTL do not participate in the compression process in the compressor. In this embodiment, the only HTL that
20 participates in the compression process is the compressor HTL and the flow path of the compressor HTL is designed so as to exchange heat with the hot HTL reservoir and the cold HTL reservoir in the charging mode and discharging mode, respectively.

A system according to a third system aspect is similar in most its elements to that of the second system aspect, with the main difference being that the WF is an LVPhC
25 WF.

The system, of this third system aspects, for storing and retrieving energy in respective charging and discharging operational modes, comprises a two-phase turbine and a two-phase compressor; a hot HTL reservoir containing hot HTL and a cold HTL reservoir containing cold HTL, each selectively connectable to a compressor/condenser
30 or the turbine; an intermediary exchanger disposed in a flow path between the compressor and the turbine. The two-phase compressor may comprise compressor HTL for its compression operation and compressor HTL reservoir for containing the compressor HTL. The compressor HTL can be the same as the hot and cold HTL and the compressor

HTL reservoir can be the same as the hot and cold HTL reservoir and then in the charging mode the hot HTL reservoir is fluidically coupled to the compressor for feeding it with hot HTL and in the discharging mode the cold HTL reservoir is fluidically coupled to the compressor for feeding it with cold HTL, or the compressor HTL and the compressor
5 HTL reservoir can be different than the hot HTL and the cold HTL reservoir, respectively, and the compressor HTL flows in a flow path that allows it to thermally exchange heat with the hot HTL reservoir for heating the hot HTL reservoir in the charging mode or cooling the cold HTL reservoir in the discharging mode.

In the charging mode, the compressor/condenser is made to be fluidically
10 connected to the hot HTL reservoir that is configured to receive hot HTL therefrom and quasi-isothermally compress and condense a WF, which is a liquid/vapor phase changing working fluid (LVPhC) mixed with the hot HTL. The condensed LVPhC flows through the first heat exchanger to reduce its temperature and then to be mixed with cold HTL in one or more nozzles of the turbine to vaporize and undergo isothermal or quasi-isothermal
15 expansion that accelerates the HTL and vaporized LVPhC mixture, to produce kinetic energy convertible to electric energy. The vaporized LVPhC discharged from the turbine is being directed towards the intermediary heat exchanger to be heated for another cycle.

In the discharging mode, the compressor is configured to receive cold HTL from the cold HTL reservoir and quasi-isothermally condense and compress the LVPhC mixed
20 in the cold HTL, such that the condensed LVPhC flows through the intermediary heat exchanger to increase its temperature and then to be mixed with hot HTL in one or more nozzles of the turbine. In the nozzles the mixture vaporizes and undergoes quasi-isothermal expansion that accelerates the HTL and LVPhC mixture to produce kinetic energy, convertible to electric energy. The LVPhC discharged from the turbine is being
25 directed towards the first heat exchanger to be cooled for another cycle.

It is to be noted that in the embodiment that the compressor has its own compressor HTL, the coupling of the compressor to the hot and cold HTL reservoirs is only thermally coupling and the hot HTL and cold HTL do not participate in the compression process in the compressor. In this embodiment, the only HTL that
30 participates in the compression process is the compressor HTL and the flow path of the compressor HTL is designed so as to exchange heat with the hot HTL reservoir and the cold HTL reservoir in the charging mode and discharging mode, respectively.

Some embodiments of this disclosure will now be described. It is to be noted that any combination of the below described embodiments with respect to any system aspect of this present disclosure is applicable. In other words, any system aspect of the present disclosure can be defined by any combination of the described embodiments. The term
5 “system”, unless specifically noted otherwise, will be used below to refer collectively to a system of the first system aspect, the second system aspect and the third system aspect.

In some embodiments of the system, the evaporator and the condenser are the same element. Namely, the evaporator/condenser is an element that is configured to exchange heat with its surrounding and depending on the relation between the WF
10 temperature, pressure, and the surrounding of the evaporator/condenser the result that is obtained is either evaporation of the WF or condensation of the WF. In some embodiments, a partial flash evaporation of the liquid WF is preformed prior to full evaporation in the evaporator.

In some embodiments of the system there is one heat exchanger in the system
15 operating in both the charging and the discharging modes thereof. For example, in the case of the system of the first system aspect, the first counterflow heat exchanger and the second counterflow heat exchanger is the same heat exchanger element. In the case of a system of the first system aspect, having one heat exchanger, the heat exchanger is selectively connectable to the turbine or the compressor, in respective discharging or
20 charging operational mode. However, the use of two different heat exchanger elements, for example one optimally configured for use in the discharging operational mode and the other optimally configured for use in the charging operational mode, is also possible.

In some embodiments, the system further comprises at least one pressure reduction nozzle disposed in the second flow path (and operating in the charging process)
25 between the second heat exchanger and the evaporator to reduce pressure and temperature of the WF that flows from the second heat exchanger to the evaporator, and to thereby achieve a greater temperature difference between the surrounding of the evaporator and the WF in the evaporator to increase heat transfer from the surrounding. It is to be noted that in embodiments in which (1) there is one heat common exchanger, (2) the evaporator
30 is the same element as the condenser, or (3) both (1) and (2), the pressure reduction nozzle is selectively coupled to the second heat exchanger and the evaporator only in the charging mode and is disconnected in the discharging mode.

In some embodiments of the system, the pressure reduction nozzle is an orifice.

In some embodiments the pressure reduction nozzle is a flash evaporation nozzle, which partially evaporate the WF and cools the WF temperature to below the surrounding temperature.

In some embodiments of the system, the WF is a liquid/vapor phase changing
5 (LVPhC) WF, selected to being (i) in a vapor phase when (1) entering the compressor, (2) when in a temperature equilibrium after being mixed with the HTL in the turbine, and (3) when exiting the evaporator, and (ii) in a liquid phase when (4) exiting the condenser and (5) exiting the compressor.

In some embodiments of the system, one or both of the compressor and the turbine
10 is thermally insulated.

In some embodiments, the system further comprises one or more selective valves enabling the selective connections of the hot HTL reservoir to the compressor or the turbine.

In some embodiments, the system further comprises one or more selective valves
15 enabling the selective connections of the hot HTL reservoir to the compressor or the turbine, in respective charging and discharging modes; and the selective connections of the cold HTL reservoir to the compressor or the turbine, in respective discharging and charging modes.

In some embodiments of the system, the HTL is selected from a list consisting of:
20 anti-freezing liquids, water, salty water, thermal oil, molten salt, ethylene glycol and WF in a liquid phase.

In some embodiments of the system, the WF is selected from a list consisting of: air, nitrogen, hydrogen, CO₂, ammonia, propane, ORC phase-changing materials, pentane, cyclopentane, refrigeration phase-changing materials. In some embodiments, the
25 compressor HTL is the same material as the WF. Optionally, the compressor HTL and the WF are the same material when the compressor HTL is different than the hot HTL and it flows in a closed loop in the compressor. In order to heat the hot HTL reservoir, the compressor HTL flows along a flow path that has a portion that allows exchange of heat with the hot HTL reservoir for transferring heat from the compressor HTL to the hot
30 HTL reservoir and therefore to the hot HTL.

In some embodiments, the system further comprises an external thermal source, e.g. from a waste energy source, burning of gas or fossil fuels, to allow controllable heating of the HTL. This may be the case, for example, where the system is intended to

be used as a standard heat engine, and an external heat source may be used to heat the HTL in the process of energy production; for example to heat the evaporator or to apply heat through special heating zones of the HTL flow path. This set up can be used when the thermal energy in the system is depleted.

5 By some embodiments of this disclosure an external heat is used to heat the WF in the evaporator to improve evaporation or raise the evaporated WF to a higher temperature than ambient temperature, optionally last to a higher pressure than ambient pressure, saving compressor power consumption. Optionally, the heat source for heating the evaporator is a waste heat source.

10 In some embodiments of the system, the external thermal source is provided by burning of gas or fossil fuel that heats directly the HTL.

In some embodiments, the system further comprises an external heat source to allow controllable heating of the hot reservoir.

In some embodiments of the system, the condenser and the evaporator are
15 configured to exchange heat with their surroundings for the condensation and the evaporation, respectively.

In some embodiments of the system, the evaporator is configured for heating by an external heat source, such as waste heat, in the charging operational mode. The external heat source may be used to evaporate the working fluid and bring it to a desired
20 temperature, which may increase the efficiency of the system. When the condenser and the evaporator are the same element, the external heat source is only thermally coupled with the condenser/evaporator in the charging mode.

In some embodiments, the system further comprises a thermally insulated enclosure that comprises the condenser and the evaporator, wherein the enclosure
25 typically permits controlled heat exchange with the surrounding. For this it may comprise an inlet for receiving heat from the external heat source, e.g. in the form of exhaust gas, or waste heat, and an outlet for controlled discharge of excess heat and for allowing circulation of incoming heat and outgoing heat from the enclosure.

In some embodiments of the system, the external heat source is waste heat. The
30 waste heat can be at any temperature above the ambient temperature.

In some embodiments of the system, the heat exchangers, including the first and the second counterflow heat exchangers of the first system aspect and the intermediary heat exchangers of the second and third aspects are recuperators.

- 18 -

In some embodiments of the system, the system is configured such that the WF pressure at an inlet of the compressor and pressure of the WF in the evaporator are about the same and lower than the critical pressure in the critical point at a temperature lower than the surrounding temperature, thereby allowing the evaporation of the WF and heat
5 to flow from the surrounding to the WF vapors.

In some embodiments of the system, the first heat exchanger comprises a first thermal pendulum.

In some embodiments of the system, the heat exchanger (including the first or second heat exchanger of the first system aspect and the intermediary heat exchanger of
10 the second and third system aspect) comprises a first heat exchanger section, a second heat exchanger section and a first thermal pendulum section; wherein the flow path of the WF between the first and the second heat exchanger sections is through the thermal pendulum.

In some embodiments of the system, the thermal pendulum is designed to
15 exchange heat only with the WF in the liquid phase that flows in the first heat exchanger.

In some embodiments of the system, the flow path of the WF is such that it flows consecutively, in the different operational modes, either from the first heat exchanger section to the thermal pendulum and then to the second heat exchanger section or from the second heat exchanger section to the thermal pendulum and then to the first heat
20 exchanger section.

Where a system comprises more than one heat exchanger, the thermal pendulum, if existing, and the overall design of the exchangers may be the same or different in all heat exchangers.

In some embodiments of the system, the thermal pendulum has heat capacity
25 value greater than the heat capacity of the WF in its liquid phase and is configured to exchange heat with the WF passing therethrough, namely the working fluid that are discharged from either the first heat exchanger or the second heat exchanger, to compensate for heat exchange inefficiency between the liquid phase of the WF and the gas phase of the WF such that (1) in the charging operational mode the thermal pendulum
30 heats while cooling the liquid before it enters the turbine and (2) in the discharging operational mode the thermal pendulum cools while heating the liquid before it enters the turbine.

In some embodiments of the system, the flow paths of the WF are closed-loop flow paths, namely, the WF flows in a closed system and recycled for each thermodynamic cycle of the system.

In some embodiments of the system, the turbine comprises one or more nozzles
5 and is configured to increase the pressure of the HTL received in it to obtain high-pressure HTL, namely, pressure above ambient or above the pressure of the HTL in the HTL hot reservoir, and to introduce the high-pressure HTL into said one or more nozzles to be mixed there with WF at about the same pressure to form HTL/WF mixture. This permits the quasi-isothermal expansion of the WF within the one or more nozzles that causes
10 acceleration of the HTL/WF mixture towards the nozzles' outlets, kinetic energy of the HTL/WF mixture being that is ejected from the outlets is used to produce energy.

The turbine may be either a reaction turbine or an impulse turbine.

In some embodiments of the system, the turbine comprises an HTL pump configured to pressurize the HTL received in the turbine prior to its introduction into its
15 nozzle.

In some embodiments of the system, the turbine is a reaction turbine.

In some embodiments of the system, the first separation zone comprises a collection unit to collect the ejected HTL separated from the WF and to allow directing it to either the hot HTL reservoir or back to the nozzle of the turbine. For example, a portion
20 of the HTL may be directed to the HTL reservoir and a portion of the HTL may be directed back to the nozzle or the HTL pump.

In some embodiments of the system, said turbine is a reaction turbine and the one or more nozzles are coupled to, mounted on or part of the reaction turbine.

In some embodiments, the collection unit defines a drain in which the separated
25 HTL accumulates, and HTL is suctioned from the drain into the nozzle by the centrifugal force caused by the reaction turbine, acting on the liquid in the nozzle that provides a driving force on the entire HTL column culminating in such suctioning. For an unimpaired suction, some HTL has to be always maintained in the HTL drain. This centrifugal force serves the function of the HTL pump. Such propelling of the HTL from
30 the drain, causes the HTL to enter the nozzle at the nozzle's operational pressure allowing the desired isothermal expansion.

In some embodiments of the system, the first separation zone comprises a curved or circular frame onto which the mixture is ejected, the engagement of the mixture with

the curved or circular frame resulting in a film flow on a surface of the curved or circular frame.

In some embodiments of the system, the compressor comprises a HTL pump configured to increase the HTL pressure, the HTL pump is fluidically coupled to a
5 compressor nozzle that is configured to receive pressurized HTL from the HTL pump and to mix it with WF to obtain HTL/WF mixture within the nozzle, wherein the nozzle is designed to discharge the HTL/WF in a pressure higher than that the pressure of the WF introduced into the compressor.

In some embodiments of the system, the condenser comprises said WF pump.

10 In some embodiments of the system, said compressor HTL is different than the hot HTL and it flows in a closed loop in the compressor and thermally exchanges heat with the hot HTL reservoir in the charging mode. In other words, the compressor has its own compressor HTL that flows in a closed loop. The HTL is heated during the compression cycles and flows, as part of its closed loop flow path, such that it exchanges
15 heat with the hot HTL reservoir to heat the hot HTL reservoir containing the hot HTL that is used by the turbine.

In some embodiments of the system, said compressor HTL is the same as the hot HTL and in the charging mode the hot HTL reservoir is fluidically connectable to the at least one two phase compressor for feeding the hot HTL to the at least one compressor.
20 Namely, the hot HTL reservoir is fluidically connected to the compressor in the charging mode and the hot HTL flows between the compressor and the hot HTL reservoir.

In some embodiments, the system further comprises at least one pressurizing arrangement configured for pressurizing or propelling the WF after being condensed in the at least one condenser.

25 In some embodiments of the system, said pressurizing arrangement comprises a pump.

In some embodiments of the system, said pressurizing arrangement is comprised within the turbine.

In some embodiments of the system, said pressurizing arrangement is constituted
30 by the turbine, namely the rotation of the turbine and its centrifugal forces causing the WF to be pumped into the turbine at the high operation pressure in the turbine before the isothermal expansion.

The following is a description of some exemplary embodiments of the compressor or compressor/condenser of the system of the present disclosure. It is to be noted that any of the following definitions, in any combination can be applied and used in the system of the present disclosure.

5 The compressor elements will be described in reference to the flow of compressed fluid in the downstream direction of flow. The term “proximal” and “distal” will be used to denote respective relative locations that are upstream or downstream with respect to a reference one. In other words, a proximal location is one in which the fluid flows through before reaching a more distal one.

10 The compressor may comprise a compressor pump, configured for pumping HTL in a closed circle filled with HTL, one or more WF introduction orifices and fluid manipulation zone arranged between a proximal suction inlet and a distal outlet. The fluid manipulation section comprises four sections, including a first fluid manipulation zone having a narrowing or converging configuration of its walls between a broad proximal
15 end and a narrower distal end. This has the purpose of accelerating the flow of the HTL and reducing its static pressure to have a lower pressure when entering the second section. This second section is fluid mixing section, having a converging configuration between a narrow proximal end (which is also the distal end of the first section) and a broader distal end.

20 The WF introduction orifice may be one or more dedicated nozzles configured to introduce WF into the second section or orifices defined in the walls of this section configured for introduction of WF into this zone, where it is mixed with the HTL to form the HTL/WF mixture. At this stage the speed of sound drops, and the mixture velocity becomes supersonic.

25 A third section of the fluid manipulation zone has a narrowing configuration between its proximal end and its distal end, configured for decelerating the supersonic flow of the HTL/WF mixture to sonic or subsonic velocity, and for increasing pressure of the two-phase mixture flowing along the third fluid manipulation section. The fourth fluid manipulation section has an expanding configuration between its proximal and distal ends
30 and configured for decelerating and increasing static pressure of the subsonic fluid of the HTL/WF mixture received from the third fluid manipulation section to a pressure in which it exists from the manipulation zone's outlet.

In some embodiments, the WF is vapor, which is condensed along the quasi-isothermal compression, and the fluid mixture discharged from outlet is a liquid mixture with pressurized or condensed WF in the HTL/WF mixture. Namely, the WF may be suctioned into the manipulation zone in a gas phase, and during the flow in various sections the WF changes its phase into liquid and is discharged at the proximal outlet end.

In some embodiments of the manipulation zone, the HTL has pressure value at the distal outlet from the fourth section that is lower than an initial pressure value of the HTL streamed into the proximal inlet of the first section by up to 2 Bar, up to 1 Bar, up to 0.5 Bar, up to 0.3 Bar or up to 0.1 Bar.

10 In some embodiments the initial pressure value is greater than the outlet pressure by up to 30%.

In some embodiments of the manipulation zone, the suction fluid streamed into the first fluid manipulation section has a subsonic velocity.

In some embodiments of the manipulation zone, the manipulation zone inlet is configured to be in fluid communication with a HTL source for receiving the HTL in a pressure greater than ambient pressure.

In some embodiments of the compressor, a separation zone is provided that is configured to receive the fluid mixture discharged from the manipulation zone outlet and separate the HTL and the pressurized WF, wherein the separated pressurized WF is directed to a fluid outlet to be discharged therethrough.

In some embodiments of the compressor, the pressurized HTL/WF mixture is discharged from the proximal fluid outlet at the same flow rate of the HTL introduced in the proximal inlet.

In some embodiments of the compressor, the compressor pump unit is configured to receive the fluid from the separation zone.

In some embodiments of the compressor, the compressor pump is a centrifugal pump, e.g. a vertical fluid pump.

In some embodiments of the compressor, the centrifugal pump has a fluid inlet, e.g. a bottom inlet in the case of a vertical centrifugal pump, configured for enabling flow of a liquid therethrough, wherein the liquid inlet is in fluid communication with a liquid drain of the separation zone storing separated liquid.

In some embodiments of the compressor, the centrifugal pump has at least one arm for supporting fluid flow therealong and fluidly coupled to the at least one nozzle.

- 23 -

In some embodiments of the compressor, the vertical centrifugal pump is rotatable about its vertical axis to thereby enable suction of HTL through the bottom fluid inlet.

In some embodiments of the compressor, the HTL flows in the system in a fluid flow path, wherein the fluid flow path includes at least one closed-loop flow path, namely
5 the separated liquid in the separation zone is pumped back into the manipulation zone, and wherein the pump unit is configured to receive and pressurize the fluid from the separation zone to thereby obtain the pressurized HTL and stream it into the manipulation zone.

In some embodiments of the compressor, the HTL is separated by gravitation from
10 the two-phase mixture in the separation zone.

In some embodiments of the compressor, the separation zone includes a curved or circular frame onto which the two-phase mixture is ejected from the nozzle, the engagement of the mixture with the curved or circular frame results in a film flow on a surface of the curved or circular frame to thereby separate the gas from the liquid.

15 In some embodiments of the compressor, the fluid outlet includes a pressure regulating valve configured to controllably stream the compressed HTL through the fluid outlet upon either (i) a positive pressure difference between the compressed fluid and a fluid tank fluidly coupled to the fluid outlet or (ii) exceeding a pressure threshold of the compressed fluid.

20 The disclosure also provides a system for converting electric energy into heat and for retrieving stored heat into electric energy, comprising (i) a system according the first, second or third system aspects, (ii) at least one electric generator rotationally coupled to the at least one turbine for generation of electricity in the discharging operational mode, and (iii) at least one electric motor rotationally coupled to the at least one compressor for
25 operating the compressor to heat charge the at least one hot reservoir.

EMBODIMENTS

The following numbered paragraphs (written, for convenience in a claim-like format) define some optional embodiments, including a number of independent
30 embodiments and a number of dependent embodiments (namely embodiments that refer to another, e.g. "The system of any one of embodiment 1-33..."), according to aspects of this disclosure. These embodiments may apply be themselves and also in any suitable combinations thereof. These embodiments are intended two add to the above general

- 24 -

description and not limit it in any way. Where a certain dependent embodiment depends from another embodiment (referred to in this paragraph as “reference embodiment”) and includes a certain elements referred to with a “the” qualifier (for example “the second flow path”), it is assumed in connection with such a dependent embodiment (and such a
5 dependent embodiment only), that the qualified element exist in the reference embodiment(s) event if such an element is not defined in the reference embodiment; such element in the reference embodiment being optionally one of such elements recited in other embodiments or in the description above.

1. A system for storing and retrieving energy in respective charging and discharging
10 operational modes, comprising:

at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;

at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL, being the same or different than the hot HTL of the hot reservoir;

15 wherein the at least one hot HTL reservoir is selectively (i) fluidically connectable to the at least one two-phase turbine in discharging operational mode or (ii) fluidically connectable or thermally couplable to the at least one two phase compressor in charging operational mode for (1) feeding hot HTL to the respective turbine in the discharging mode or for (2) in the charging mode, either heat exchanging between the compressor
20 HTL and the hot HTL, when the compressor HTL and the hot HTL are different, or feeding hot HTL to the at least one compressor, when the compressor HTL and the hot HTL are the same (it is to be noted that the hot HTL and the compressor HTL may be different, namely they do not mix with each other, but can be the same material);

at least one condenser in fluid communication with the turbine for receiving and
25 condensing a working fluid (WF) coming from the turbine;

at least one evaporator in fluid communication with the at least one compressor for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;

the discharging mode defining a first flow path of the WF and the charging mode
30 defines a second flow path of the WF; and

wherein in a discharging mode the WF flows in the first flow path from the at least one condenser to one or more nozzles within the at least one turbine, the nozzles being configured to induce rotation of the turbine upon discharge of fluid therefrom, to

- 25 -

- thereby mix the WF with the HTL to form a HTL/WF mixture in said one or more nozzles, in which the WF undergoes a quasi-isothermal expansion, causing acceleration of the HTL/WF mixture and discharge of the mixture through the one or more nozzles while reducing temperature of the HTL, the HTL/WF mixture discharged out of the one or more
- 5 nozzles being received in at least one first separation zone configured to separate the WF from the HTL, the HTL being recycled back to said at least one hot reservoir or to said one or more nozzles and the separated WF flowing into and received in the condenser to undergo condensation therein, the condensed WF discharged from the at least one condenser flows back to the turbine.
- 10 2. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:
- at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;
 - at least one two-phase turbine and at least one two-phase compressor;
 - wherein the at least one hot HTL reservoir is selectively (i) fluidically connectable
 - 15 to the at least one two-phase turbine in discharging operational mode or (ii) fluidically connectable to the at least one two phase compressor in charging operational mode for (1) feeding hot HTL to the respective turbine in the discharging mode or for (2) feeding hot HTL to the compressor in the charging mode;
 - at least one condenser in fluid communication with the turbine for receiving and
 - 20 condensing a working fluid (WF) coming from the turbine;
 - at least one evaporator in fluid communication with the at least one compressor for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;
 - the discharging mode defining a first flow path of the WF and the charging mode
 - 25 defines a second flow path of the WF; and
 - wherein in a discharging mode the WF flows in the first flow path from the at least one condenser to one or more nozzles within the at least one turbine, the nozzles being configured to induce rotation of the turbine upon discharge of fluid therefrom, to thereby mix the WF with the HTL to form a HTL/WF mixture in said one or more nozzles,
 - 30 in which the WF undergoes a quasi-isothermal expansion, causing acceleration of the HTL/WF mixture and discharge of the mixture through the one or more nozzles while reducing temperature of the HTL, the HTL/WF mixture discharged out of the one or more nozzles being received in at least one first separation zone configured to separate the WF

- 26 -

from the HTL, the HTL being recycled back to said at least one hot reservoir or to said one or more nozzles and the separated WF flowing into and received in the condenser to undergo condensation therein, the condensed WF discharged from the at least one condenser flows back to the turbine.

- 5 3. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:

at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;

at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL, being the same or different than the hot HTL of the
10 hot reservoir;

wherein the at least one hot HTL reservoir is selectively (i) fluidically connectable to the at least one two-phase turbine in discharging operational mode or (ii) thermally couplable to the at least one two phase compressor in charging operational mode for (1) feeding hot HTL to the respective turbine in the discharging mode or for (2) heat
15 exchanging between the compressor HTL and the HTL of the hot reservoir in the charging mode;

at least one condenser in fluid communication with the turbine for receiving and condensing a working fluid (WF) coming from the turbine;

at least one evaporator in fluid communication with the at least one compressor
20 for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;

the discharging mode defining a first flow path of the WF and the charging mode defines a second flow path of the WF; and

wherein in a discharging mode the WF flows in the first flow path from the at
25 least one condenser to one or more nozzles within the at least one turbine, the nozzles being configured to induce rotation of the turbine upon discharge of fluid therefrom, to thereby mix the WF with the HTL to form a HTL/WF mixture in said one or more nozzles, in which the WF undergoes a quasi-isothermal expansion, causing acceleration of the HTL/WF mixture and discharge of the mixture through the one or more nozzles while
30 reducing temperature of the HTL, the HTL/WF mixture discharged out of the one or more nozzles being received in at least one first separation zone configured to separate the WF from the HTL, the HTL being recycled back to said at least one hot reservoir or to said one or more nozzles and the separated WF flowing into and received in the condenser to

- 27 -

undergo condensation therein, the condensed WF discharged from the at least one condenser flows back to the turbine.

4. The system of any one of embodiments 1-3, comprising at least one first counterflow heat exchanger disposed in the first flow path between the at least one turbine and the at least one condenser and configured for heat exchange between WF exiting from the at least one turbine and WF exiting from the at least one condenser.

5. The system of embodiment 4, wherein the heat exchanger is configured for reducing the temperature of the WF flowing from the turbine to the condenser.

6. The system of any one of embodiments 1-5, comprising at least one pressurizing arrangement configured for pressurizing or propelling the WF after being condensed in the at least one condenser.

7. The system of embodiment 6, wherein said arrangement comprises a pump.

8. The system of any one of embodiments 1-7, comprising at least one first separation zone disposed in the at least one turbine for separating between the WF and the HTL.

9. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:

at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;

at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL, being the same or different than the hot HTL of the hot reservoir;

wherein the at least one hot HTL reservoir is selectively (i) fluidically connectable to the at least one two-phase turbine in discharging operational mode or (ii) fluidically connectable or thermally couplable to the at least one two phase compressor in charging operational mode for (1) feeding hot HTL to the respective turbine in the discharging mode or for (2) in the charging mode, either heat exchanging between the compressor HTL and the hot HTL, when the compressor HTL and the hot HTL are different, or feeding hot HTL to the at least one compressor, when the compressor HTL and the hot HTL are the same (it is to be noted that the hot HTL and the compressor HTL may be different, namely they do not mix with each other, but can be the same material);

at least one condenser in fluid communication with the turbine for receiving and condensing a working fluid (WF) coming from the turbine;

- 28 -

at least one evaporator in fluid communication with the at least one compressor for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;

the discharging mode defining a first flow path of the WF and the charging mode
5 defines a second flow path of the WF; and

wherein in the charging mode, the WF flows in the second flow path and the at least one compressor is configured to form a compressor HTL/WF mixture and quasi-isothermally compress the WF in the mixture along a compressor flow path to thereby heat the compressor HTL, the compressor HTL exchanges heat with the hot HTL
10 reservoir to thereby heat the hot HTL reservoir and is cycled back to a reservoir, being the same or different than the hot HTL reservoir, or within the least one the compressor, the compressed WF being discharged from the at least one compressor flows to be received in the evaporator to undergo evaporation, the evaporated WF discharged from the at least one evaporator being directed back to the at least one compressor.

15 10. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:

at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;

at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL, being the same or different than the hot HTL of the
20 hot reservoir;

wherein the at least one hot HTL reservoir is selectively (i) fluidically connectable to the at least one two-phase turbine in discharging operational mode or (ii) thermally couplable to the at least one two phase compressor in charging operational mode for (1) feeding hot HTL to the respective turbine in the discharging mode or for (2) heat
25 exchanging between the compressor HTL and the HTL of the hot reservoir in the charging mode;

at least one condenser in fluid communication with the turbine for receiving and condensing a working fluid (WF) coming from the turbine;

at least one evaporator in fluid communication with the at least one compressor
30 for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;

the discharging mode defining a first flow path of the WF and the charging mode defines a second flow path of the WF; and

- 29 -

wherein in the charging mode, the WF flows in the second flow path and the at least one compressor is configured to form a compressor HTL/WF mixture and quasi-isothermally compress the WF in the mixture along a compressor flow path to thereby heat the compressor HTL, the compressor HTL exchanges heat with the hot HTL reservoir to thereby heat the hot HTL reservoir and is cycled back either to a reservoir, being the same or different than the hot HTL reservoir, or within the compressor, the compressed WF being discharged from the at least one compressor flows to be received in the evaporator to undergo evaporation, the evaporated WF discharged from the at least one evaporator being directed back to the at least one compressor.

11. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:

at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;

at least one two-phase turbine and at least one two-phase compressor;

wherein the at least one hot HTL reservoir is selectively (i) fluidically connectable to the at least one two-phase turbine in discharging operational mode or (ii) fluidically connectable to the at least one two phase compressor in charging operational mode for (1) feeding hot HTL to the respective turbine in the discharging mode or for (2) feeding hot HTL to the at least one compressor;

at least one condenser in fluid communication with the turbine for receiving and condensing a working fluid (WF) coming from the turbine;

at least one evaporator in fluid communication with the at least one compressor for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;

the discharging mode defining a first flow path of the WF and the charging mode defines a second flow path of the WF; and

wherein in the charging mode, the WF flows in the second flow path and the at least one compressor is configured to receive the WF and hot HTL to obtain a HTL/WF mixture and quasi-isothermally compress the WF in the mixture along a compressor flow path to thereby heat the hot HTL, the compressor HTL exchanges heat with the hot HTL reservoir to thereby heat the hot HTL reservoir and is cycled back to the hot HTL reservoir or to the compressor, the compressed WF being discharged from the at least one compressor flows to be received in the evaporator to undergo evaporation, the evaporated

- 30 -

WF discharged from the at least one evaporator being directed back to the at least one compressor.

12. The system of any one of embodiments 9-11, comprising at least one second counterflow heat exchanger, disposed in the second flow path between the at least one
5 compressor and the at least one evaporator and configured for heat exchange between WF exiting from the at least one compressor and WF exiting from the at least one evaporator.

13. The system of embodiment 12, wherein the heat exchanger is configured for increasing the temperature of the WF flowing from the compressor to the turbine.

14. The system of any one of embodiments 9-13, comprising at least one second
10 separation zone disposed in the at least one turbine for separating between the HTL and the WF.

15. The system of any one of embodiment 9-14, comprising at least one pressure reduction nozzle disposed in the second flow path between the at least one second heat exchanger and the at least one evaporator to reduce pressure and temperature of the WF
15 that flows from the at least one second heat exchanger to the at least one evaporator.

16. The system of any one of embodiments 1-15, wherein the WF is a liquid/vapor phase changing (LVPhC) WF, selected to being (i) in a vapor phase when (1) entering the at least one compressor, (2) when in a temperature equilibrium after being mixed with the HTL in the at least one turbine, and (3) when exiting the at least one evaporator, and (ii)
20 in a liquid phase when (4) exiting the at least one condenser and (5) exiting the at least one compressor.

17. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:

at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;

25 at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL, being the same or different than the hot HTL of the hot reservoir;

wherein the at least one hot HTL reservoir is selectively (i) fluidically connectable to the at least one two-phase turbine in discharging operational mode or (ii) fluidically
30 connectable or thermally couplable to the at least one two phase compressor in charging operational mode for (1) feeding hot HTL to the respective turbine in the discharging mode or for (2) in the charging mode, either heat exchanging between the compressor HTL and the hot HTL, when the compressor HTL and the hot HTL are different, or

- 31 -

feeding hot HTL to the at least one compressor, when the compressor HTL and the hot HTL are the same (it is to be noted that the hot HTL and the compressor HTL may be different, namely they do not mix with each other, but can be the same material);

at least one condenser in fluid communication with the turbine for receiving and
5 condensing a working fluid (WF) coming from the turbine;

at least one evaporator in fluid communication with the at least one compressor for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;

the discharging mode defining a first flow path of the WF and the charging mode
10 defines a second flow path of the WF; and

wherein in a discharging mode the WF flows in the first flow path from the at least one first condenser to one or more nozzles within the at least one turbine, the nozzles being configured to induce rotation of the turbine upon discharge of fluid therefrom, to thereby mix the WF with the HTL to form a HTL/WF mixture in said one or more nozzles,
15 in which the WF undergoes a quasi-isothermal expansion, causing acceleration of the HTL/WF mixture and discharge of the mixture through the one or more nozzles while reducing temperature of the HTL, the HTL/WF mixture discharged out of the one or more nozzles being received in at least one first separation zone configured to separate the WF from the HTL, the HTL being recycled back to said at least one hot reservoir or to said
20 one or more nozzles and the separated WF flowing into and received in the condenser to undergo condensation therein, the condensed WF discharged from the at least one condenser streamed back to the turbine; and

wherein in the charging mode, the WF flows in the second flow path and the at least one compressor is configured to form a compressor HTL/WF mixture and quasi-
25 isothermally compress the WF in the mixture along a compressor flow path to thereby heat the compressor HTL, the compressor HTL being cycled back to a reservoir, being the same or different than the hot HTL reservoir, or to the at least one compressor and the compressed WF being discharged from the at least one compressor flows to be received in the evaporator to undergo evaporation, the evaporated WF discharged from the at least
30 one evaporator being back to the at least one compressor.

18. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:

at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;

- 32 -

at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL, being the same or different than the hot HTL of the hot reservoir;

wherein the at least one hot HTL reservoir is selectively (i) fluidically connectable
5 to the at least one two-phase turbine in discharging operational mode or (ii) thermally couplable to the at least one two phase compressor in charging operational mode for (1) feeding hot HTL to the respective turbine in the discharging mode or for (2) heat exchanging between the compressor HTL and the hot HTL in the charging mode;

at least one condenser in fluid communication with the turbine for receiving and
10 condensing a working fluid (WF) coming from the turbine;

at least one evaporator in fluid communication with the at least one compressor for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;

the discharging mode defining a first flow path of the WF and the charging mode
15 defines a second flow path of the WF; and

wherein in a discharging mode the WF flows in the first flow path from the at least one first condenser to one or more nozzles within the at least one turbine, the nozzles being configured to induce rotation of the turbine upon discharge of fluid therefrom, to thereby mix the WF with the HTL to form a HTL/WF mixture in said one or more nozzles,
20 in which the WF undergoes a quasi-isothermal expansion, causing acceleration of the HTL/WF mixture and discharge of the mixture through the one or more nozzles while reducing temperature of the HTL, the HTL/WF mixture discharged out of the one or more nozzles being received in at least one first separation zone configured to separate the WF from the HTL, the HTL being recycled back to said at least one hot reservoir or to said
25 one or more nozzles and the separated WF flowing into and received in the condenser to undergo condensation therein, the condensed WF discharged from the at least one condenser streamed back to the turbine; and

wherein in the charging mode, the WF flows in the second flow path and the at least one compressor is configured to form a compressor HTL/WF mixture and quasi-
30 isothermally compress the WF in the mixture along a compressor flow path to thereby heat the compressor HTL, the compressor HTL being cycled back to a reservoir or to the at least one compressor and the compressed WF being discharged from the at least one

- 33 -

compressor flows to be received in the evaporator to undergo evaporation, the evaporated WF discharged from the at least one evaporator being back to the at least one compressor.

19. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:

- 5 at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;
 at least one two-phase turbine and at least one two-phase compressor;
 wherein the at least one hot HTL reservoir is selectively (i) fluidically connectable to the at least one two-phase turbine in discharging operational mode or (ii) fluidically connectable to the at least one two phase compressor in charging operational mode for
10 (1) feeding hot HTL to the respective turbine in the discharging mode or for (2) feeding hot HTL to the at least one compressor;

 at least one condenser in fluid communication with the turbine for receiving and condensing a working fluid (WF) coming from the turbine;

- at least one evaporator in fluid communication with the at least one compressor
15 for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;

 the discharging mode defining a first flow path of the WF and the charging mode defines a second flow path of the WF; and

- wherein in a discharging mode the WF flows in the first flow path from the at
20 least one first condenser to one or more nozzles within the at least one turbine, the nozzles being configured to induce rotation of the turbine upon discharge of fluid therefrom, to thereby mix the WF with the HTL to form a HTL/WF mixture in said one or more nozzles, in which the WF undergoes a quasi-isothermal expansion, causing acceleration of the HTL/WF mixture and discharge of the mixture through the one or more nozzles while
25 reducing temperature of the HTL, the HTL/WF mixture discharged out of the one or more nozzles being received in at least one first separation zone configured to separate the WF from the HTL, the HTL being recycled back to said at least one hot reservoir or to said one or more nozzles and the separated WF flowing into and received in the condenser to undergo condensation therein, the condensed WF discharged from the at least one
30 condenser streamed back to the turbine; and

 wherein in the charging mode, the WF flows in the second flow path and the at least one compressor is configured to receive hot HTL and WF to form a HTL/WF mixture and quasi-isothermally compress the WF in the mixture along a compressor flow

- 34 -

path to thereby heat the hot HTL, the HTL being cycled back to the hot HTL reservoir or to the at least one compressor and the compressed WF being discharged from the at least one compressor flows to be received in the evaporator to undergo evaporation, the evaporated WF discharged from the at least one evaporator being back to the at least one
5 compressor.

20. A system for storing and retrieving energy in respective charging and discharging modes, comprising:

at least one two-phase turbine and at least one two-phase compressor;

at least one hot HTL reservoir containing hot HTL and at least one cold HTL
10 reservoir containing cold HTL, each selectively fluidically connectable to at least one compressor or the at least one turbine;

at least one intermediary heat exchanger disposed in a flow path between the at least one compressor and the at least one turbine;

wherein in the charging mode, the at least one compressor is made to be fluidically
15 connected to the at least one hot HTL reservoir to receive hot HTL therefrom and quasi-isothermally compress a working fluid (WF) mixed with the hot HTL, such that the compressed working fluid flows through the at least one first heat exchanger to reduce its temperature and then to be mixed with cold HTL in one or more nozzles of the turbine to undergo isothermal or quasi-isothermal expansion that accelerates the HTL and working
20 fluid mixture to produce kinetic energy convertible to electric energy, the working fluid discharged from the turbine being directed towards the at least one first heat exchanger to be heated for another cycle;

wherein in the discharging mode, the at least one compressor is configured to receive cold HTL from the cold HTL reservoir and quasi-isothermally compress working
25 fluid mixed in the cold HTL, such that the compressed working fluid flows through the at least one first heat exchanger to increase its temperature and then to be mixed with hot HTL in the one or more nozzles of the turbine to undergo isothermal or quasi-isothermal expansion that accelerates the HTL/WF mixture to produce kinetic energy convertible to electric energy, the working fluid discharged from the at least one turbine being directed
30 towards the at least one first heat exchanger to be cooled for another cycle.

21. A system for storing and retrieving energy in respective charging and discharging modes, comprising:

- 35 -

at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL;

at least one hot HTL reservoir containing hot HTL and at least one cold HTL reservoir containing cold HTL, each selectively connectable to the at least one
5 compressor or the at least one turbine and selectively thermally couplable to the at least one compressor or the at least one turbine;

at least one intermediary heat exchanger disposed in a flow path between the at least one compressor and the at least one turbine;

wherein in the charging mode, the at least one compressor is configured to mix a
10 working fluid (WF) with the compressor HTL to form a compressor HTL/WF mixture and quasi-isothermally compress the compressor HTL/WF mixture to thereby heat the compressor HTL, the compressor is made to be thermally coupled to the at least one hot HTL reservoir to exchange heat between the compressor HTL and the hot HTL reservoir, the compressed WF flows through the at least one first heat exchanger to reduce its
15 temperature and then to be mixed with cold HTL in one or more nozzles of the turbine to undergo isothermal or quasi-isothermal expansion that accelerates the HTL and working fluid mixture to produce kinetic energy convertible to electric energy, the working fluid discharged from the turbine being directed towards the at least one first heat exchanger to be heated for another cycle;

20 wherein in the discharging mode, the at least one compressor is configured to mix the WF with the compressor HTL to form a compressor HTL/WF mixture and quasi-isothermally compress the compressor HTL/WF mixture to thereby heat the compressor HTL, the compressor is made to be thermally coupled to the at least one cold HTL reservoir to exchange heat between the compressor HTL and the cold HTL reservoir, the
25 compressed working fluid flows through the at least one first heat exchanger to increase its temperature and then to be mixed with hot HTL in the one or more nozzles of the turbine to undergo isothermal or quasi-isothermal expansion that accelerates the HTL/WF mixture to produce kinetic energy convertible to electric energy, the working fluid discharged from the at least one turbine being directed towards the at least one first heat
30 exchanger to be cooled for another cycle.

22. A system for storing and retrieving energy in respective charging and discharging modes, comprising:

at least one two-phase turbine and at least one two-phase compressor;

- 36 -

at least one hot HTL reservoir containing hot HTL and at least one cold HTL reservoir containing cold HTL, each selectively connectable to the at least one compressor/condenser or the at least one turbine;

at least one intermediary exchanger is disposed in a flow path between the at least
5 one compressor and the at least one turbine;

wherein in the charging mode, the at least one compressor/condenser is made to be fluidically connected to the at least one hot HTL reservoir to receive hot HTL therefrom and quasi-isothermally compress and condense a working fluid in a liquid/vapor phase changing working fluid (LVPhC) mixed with the hot HTL, such that
10 the condensed LVPhC flows through the at least one first heat exchanger to reduce its temperature and then to be mixed with cold HTL in one or more nozzles of the turbine to vaporize and undergo isothermal or quasi-isothermal expansion that accelerates the HTL and vaporized LVPhC mixture to produce kinetic energy convertible to electric energy, the vaporized LVPhC discharged from the turbine being directed towards the at least first
15 heat exchanger to be heated for another cycle;

wherein in the discharging mode, the at least one compressor is configured to receive cold HTL from the cold HTL reservoir and quasi-isothermally condense and compress LVPhC mixed in the cold HTL, such that the condensed LVPhC flows through the at least one first heat exchanger to increase its temperature and then to be mixed with
20 hot HTL in the one or more nozzles of the turbine to vaporize and undergo isothermal or quasi-isothermal expansion that accelerates the HTL and LVPhC mixture to produce kinetic energy convertible to electric energy, the LVPhC discharged from the at least one turbine being directed towards the at least one first heat exchanger to be cooled for another cycle.

25 23. A system for storing and retrieving energy in respective charging and discharging modes, comprising:

at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL;

at least one hot HTL reservoir containing hot HTL and at least one cold HTL
30 reservoir containing cold HTL, each selectively connectable to the at least one compressor or the at least one turbine and selectively thermally couplable to the at least one compressor or the at least one turbine;

- 37 -

at least one intermediary exchanger is disposed in a flow path between the at least one compressor and the at least one turbine;

wherein in the charging mode, the at least one compressor/condenser is made to be thermally coupled to the at least one hot HTL reservoir to exchange heat with the hot HTL reservoir, the at least one compressor/condenser is configured to mix a liquid/vapor phase changing (LVPhC) working fluid (WF) with the compressor HTL to form a compressor HTL/WF mixture and quasi-isothermally compress and condense the compressor HTL/WF mixture to thereby heat the compressor HTL, the condensed LVPhC flows through the at least one first heat exchanger to reduce its temperature and then to be mixed with cold HTL in one or more nozzles of the turbine to vaporize and undergo isothermal or quasi-isothermal expansion that accelerates the HTL and vaporized LVPhC mixture to produce kinetic energy convertible to electric energy, the vaporized LVPhC discharged from the turbine being directed towards the at least first heat exchanger to be heated for another cycle;

wherein in the discharging mode, the at least one compressor/condenser is made to be thermally coupled to the at least one cold HTL reservoir to exchange heat with the cold HTL reservoir, the at least one compressor/condenser is configured to mix the WF with the compressor HTL to form a compressor HTL/WF mixture and quasi-isothermally compress and condense the compressor HTL/WF mixture, the condensed LVPhC flows through the at least one first heat exchanger to increase its temperature and then to be mixed with hot HTL in the one or more nozzles of the turbine to vaporize and undergo isothermal or quasi-isothermal expansion that accelerates the HTL and LVPhC mixture to produce kinetic energy convertible to electric energy, the LVPhC discharged from the at least one turbine being directed towards the at least one first heat exchanger to be cooled for another cycle.

24. The system of any one of embodiments 1-23, wherein the at least one evaporator and the at least one condenser are the same elements.

25. The system of any one of embodiments 1-24, comprising at least one first counterflow heat exchanger disposed in the first flow path between the at least one turbine and the at least one condenser and configured for heat exchange between WF exiting from the at least one turbine and WF exiting from the at least one condenser.

26. The system of embodiment 25, wherein the heat exchanger is configured for reducing the temperature of the WF flowing from the turbine to the condenser.

- 38 -

27. The system of any one of embodiments 1-26, comprising at least one second counterflow heat exchanger, disposed in the second flow path between the at least one compressor and the at least one evaporator and configured for heat exchange between WF exiting from the at least one compressor and WF exiting from the at least one evaporator.
- 5 28. The system of embodiment 27, wherein the heat exchanger is configured for increasing the temperature of the WF flowing from the compressor to the turbine.
29. The system of embodiment 27 or 28, comprising both said at least one first heat exchanger and said at least one second heat exchanger, wherein the at least one first counterflow heat exchanger and the at least one second counterflow heat exchanger are
- 10 same one or more elements selectively connectable to the at least one turbine or the at least one compressor, in respective discharging mode or charging mode.
30. The system of any one of embodiments 1-29, comprising at least one pressurizing arrangement configured for pressurizing or propelling the WF after being condensed in the at least one condenser.
- 15 31. The system of embodiment 30, wherein said arrangement comprises a pump.
32. The system of any one of embodiments 1-31, comprising at least one first separation zone disposed in the at least one turbine for separating between the WF and the HTL.
33. The system of any one of embodiments 1-32, comprising at least one second
- 20 separation zone disposed in the at least one compressor for separating between the WF and the HTL.
34. The system of any one of embodiment 1-33, comprising at least one pressure reduction nozzle disposed in the second flow path between the at least one second heat exchanger and the at least one evaporator to reduce pressure and temperature of the WF
- 25 that flows from the at least one second heat exchanger to the at least one evaporator.
35. The system of any one of embodiments 1-34, wherein the WF is a liquid/vapor phase changing (LVPhC) WF, selected to being (i) in a vapor phase when (1) entering the at least one compressor, (2) when in a temperature equilibrium after being mixed with the HTL in the at least one turbine, and (3) when exiting the at least one evaporator, and (ii)
- 30 in a liquid phase when (4) exiting the at least one condenser and (5) exiting the at least one compressor.
36. The system of any one of embodiments 1-35, wherein one or both of the at least one compressor and the at least one turbine is thermally insulated.

37. The system of any one of embodiments 1-36, comprising one or more selective valves for allowing the selective connections of the at least one hot HTL reservoir to the at least one compressor and the at least one turbine.
38. The system of any one of embodiments 1-37, wherein the HTL is selected from a list consisting of: anti-freezing liquids, water, salty water, thermal oil, molten salt, ethylene glycol, and the WF in a liquid phase.
39. The system of any one of embodiments 1-38, wherein the WF is selected from a list consisting of: air, nitrogen, hydrogen, CO₂, ammonia, propane, ORC phase-changing materials, pentane, refrigeration phase-changing materials.
40. The system of any one of embodiments 1-39, comprising at least one external thermal source to allow controllable heating of the hot HTL.
41. The system of any one of embodiments 1-40, wherein the at least one condenser and the at least one evaporator are configured to exchange heat with their surroundings for the condensation and the evaporation, respectively.
42. The system of any one of embodiments 1-41, wherein the at least one evaporator is configured for heating by at least one external heat source in the charging operational mode.
43. The system of embodiment 42, comprising a thermally insulated enclosure that comprises the at least one condenser or the at least one evaporator, being configured for heat input from the external heat source and for controlled discharge of excess heat.
44. The system of any one of embodiments 1-43, wherein the at least one first and the at least one second counterflow heat exchangers are recuperators.
45. The system of any one of embodiments 1-44, wherein the at least one intermediary heat exchanger is a recuperator.
46. The system of any one of embodiments 1-45, wherein an inlet compressor pressure of the WF and pressure of the WF in the evaporator are lower than the critical pressure at a temperature lower than the surrounding temperature, thereby allowing the evaporation of the WF and heat to flow from the surrounding to the WF vapors.
47. The system of any one of embodiments 1-46, wherein the at least one first heat exchanger comprises at least one first thermal pendulum.
48. The system of embodiment 47, wherein each of the at least one first heat exchanger comprises a first heat exchanger section, a second heat exchanger section and

- 40 -

a first thermal pendulum section; wherein the flow path of the WF between the first and the second heat exchanger sections is through the thermal pendulum.

49. The system of any one of embodiments 1-48, wherein the second heat exchanger comprises a second thermal pendulum.

5 50. The system of embodiment 49, wherein each of the at least one second heat exchanger comprises a first heat exchanger section, a second heat exchanger section and a second thermal pendulum section; wherein the flow path of the WF between the first and the second heat exchanger sections is through the second thermal pendulum.

51. The system of embodiment any one of embodiments 49 and 50, wherein the
10 second thermal pendulum is the same as the first thermal pendulum.

52. The system of any one of embodiments 1-51, wherein the at least one intermediary heat exchanger comprises at least one intermediary thermal pendulum.

53. The system of embodiment 52, wherein each of the at least one intermediary heat exchanger comprises a first heat exchanger section, a second heat exchanger section and
15 an intermediary thermal pendulum section; wherein the flow path of the WF between the first and the second heat exchanger sections is through the thermal pendulum.

54. The system of any one of embodiments 47-53, wherein
the thermal pendulum has heat capacity value greater than the heat capacity of the WF in its liquid phase and is configured to exchange heat with the WF passing
20 therethrough to compensate for heat exchange inefficiency between the liquid phase of the WF and the gas phase of the WF such that (1) in the charging operational mode the thermal pendulum heats while cooling the liquid before it enters the turbine and (2) in the discharging operational mode the thermal pendulum cools while heating the liquid before it enters the turbine.

25 55. The system of any one of embodiments 1-54, wherein the first flow path and the second flow path are closed-loop flow paths.

56. The system of any one of embodiments 1-55, wherein the at least one turbine is configured to increase the pressure of the HTL to obtain high-pressure HTL and to introduce the high-pressure HTL into said one or more nozzles to be mixed with WF at
30 about the same pressure to form HTL/WF mixture with subsequent quasi-isothermal expansion of the WF within the one or more nozzles accelerating the HTL/WF mixture towards outlets of the one or more nozzles.

- 41 -

57. The system of any one of embodiments 1-56, wherein the at least one compressor comprises a HTL pump for increasing the HTL pressure, the HTL pump being fluidically coupled to a compressor nozzle configured for receiving pressurized HTL from the HTL pump and to mix it with WF to obtain HTL/WF mixture within the nozzle being
5 discharged out of the nozzle at a pressure higher than the pressure of the WF that is introduced into the compressor.

58. The system of any one of embodiments 1-57, wherein the at least one WF pump is comprised within the at least one condenser.

59. The system of any one of embodiments 1-58, wherein the evaporator is
10 maintained at above ambient temperature.

60. The system of any one of embodiments 1-59, wherein said compressor HTL is different than the hot HTL and it flows in a closed loop in the compressor and thermally exchange heat with the hot HTL reservoir in the charging mode.

61. The system of any one of embodiments 1-60, wherein said compressor HTL is the
15 same as the hot HTL and the compressor HTL reservoir is the same as the hot HTL reservoir, and in the charging mode the hot HTL reservoir is fluidically connected to the at least one two phase compressor for feeding the hot HTL to the at least one compressor.

62. A system for converting electric energy into heat and for retrieving stored heat into electric energy, comprising

20 a system according to any one of embodiments 1-61,
at least one electric generator rotationally coupled to the at least one turbine for generation of electricity in the discharging operational mode, and
at least one electric motor rotationally coupled to the at least one compressor for operating the compressor to heat charge the at least one hot reservoir.

25

BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in
30 which:

Fig. 1 is a schematic illustration of a prior art configuration of a thermal energy storage system.

Fig. 2 is a schematic illustration that illustrates the two-phase nozzle mixing compressed gas or vapors and HTL, supporting quasi-isothermal expansion, accelerating the HTL, and generating thrust that is converted to electricity or mechanical work in a turbine, for both reaction and impact turbine configurations.

5 **Fig. 3** is a schematic illustration of a compressor/condenser using HTL in a closed loop to compress and optionally condense working fluid.

Fig. 4 is schematic illustration of a nozzle used in the HTL-based compressor/condenser.

Figs 5A-5B are schematic illustrations of system configurations of a non-limiting
10 embodiment of the system that comprises a high temperature HTL storage and a low HTL storage. **Fig. 5A** exemplifies the charging mode and **Fig. 5B** exemplifies the discharging mode.

Fig. 6 is a schematic illustration of rotating sliced ball valves for allowing
15 exchange of liquids between high-pressure and low-pressure sections without wasting work that can be used in the system.

Figs. 7A-7B are P-V and T-S diagrams of the system for each mode, wherein **Fig. 7A** shows the diagrams of the charging mode and **Fig. 7B** shows the diagrams of the discharging mode in an embodiment where the WF is gas.

Fig. 8 is a P-V diagram of isothermal organic cycle of the system using
20 liquid/vapor phase changing working fluid.

Fig. 9 shows a T-S diagram for the thermodynamic cycle when using the two-phase pentane as a working fluid and Ethylene Glycol as HTL.

Figs 10A-1B are schematic illustrations of system modes of a non-limiting
25 embodiment of the system that comprises a high temperature HTL storage and a low HTL storage, using a liquid/vapor phase changing working fluid. **Fig. 10A** exemplifies the charging mode and **Fig. 10B** exemplifies the discharging mode.

Fig. 11 shows charging and discharging modes T-S diagrams for isothermal phase changing thermodynamic cycle at fixed pressure levels.

Fig. 12 shows charging and discharging T-S diagrams for isothermal phase
30 changing thermodynamic cycle at varying pressure levels.

Figs. 13A-13B are schematic illustrations of a non-limiting embodiment of the system that comprises low and high HTL reservoirs, two recuperators and a thermal

pendulum. **Fig. 13A** exemplifies the charging mode and **Fig. 13B** exemplifies the discharging mode.

Figs. 14A-14B are schematic illustrations of a non-limiting embodiment of the system that comprises only high temperature HTL reservoir, a single recuperator and a compressor and evaporator, which may be the same element. **Fig. 14A** exemplifies the discharging mode that comprises the condenser and **Fig. 14B** exemplifies the charging mode that comprises the evaporator.

Figs. 15A-15B shows the calculation of the efficiency heat and mass balance for the 140°C temperature case. **Fig. 15A** exemplifies the discharging mode and **Fig. 15B** exemplifies the charging mode.

Fig. 16 shows the Pentane T-S diagram exemplifying the enthalpy and entropy relevant for the calculation, including also the case of 140°C exemplified in **Figs 15A-15B**.

Figs. 17A-17B are block diagrams exemplifying non-limiting embodiments of the system of the present disclosure, in which the WF exchanges heat with the surrounding in the condenser / evaporator.

DETAILED DESCRIPTION

The following figures are provided to exemplify embodiments and the realization of the invention of the present disclosure.

In the present disclosure, the solution makes use of isothermal expansion and compression in bubbly media into the Carnot Battery concept. The liquid in the bubbly media increases thermal power density per volume by 1000-fold thereby reducing the size and cost of the system and the bubbles exhibit isothermal expansion and compression that boosts the efficiency compared to the adiabatic process.

A core component in the method and system is a nozzle that mixes compressed gas or vapors with heat transfer liquid (HTL). The HTL maintains liquid in the nozzle. Optionally, the vapors are a result of the vaporization of a phase-changing material that is achieved by mixing it with the HTL in the nozzle. Optionally the vaporization occurs before reaching the nozzle. The vapor or gas mixed with the HTL forms bubbles that expand in the nozzle while keeping nearly the same temperature as the HTL, due to the large heat capacity of the HTL and the excellent heat transfer rate between the vapor

bubbles and the HTL. The thermal energy density is defined by the HTL and is orders of magnitude higher than the heat capacity of vapors per volume. This allows narrow pipes and small systems with high output power. The expansion accelerates the mixture in the nozzle. Both the HTL and the vapors are cooled along with the expansion. This reduction
5 in temperature is less than a few degrees and supports a quasi-isothermal expansion of the gas or vapors. Optionally, the velocity of the mixture becomes supersonic. In the nozzle, the initial pressure and part of the thermal energy of the HTL are converted to kinetic energy under quasi-isothermal conditions. The kinetic energy is used to rotate a turbine, generating electricity, mechanical work, or another form of work. An example of
10 such a nozzle is described in WO 2022/049573, which is incorporated herein by reference in its entirety. For example, molten salt or thermal oil is the HTL that flows in the nozzle. Compressed air, Nitrogen, Ammonia, or other gas is injected into the nozzle, mixed with the HTL, expands quasi-isothermally, accelerates the HTL, and generates thrust that is converted to electricity by a turbine. The power generated by the turbine may be partially
15 used to drive the compressor (through a mechanical shaft or electric connection) that compresses the gas isothermally at cold temperatures. The HTL in the turbine is cooled after a few cycles and needs to be replaced with hot HTL for continuous conversion of heat to work. **Fig. 2** illustrates the two-phase nozzle mixing compressed gas or vapors and HTL, supporting quasi-isothermal expansion, accelerating the HTL, and generating
20 thrust that is converted to electricity or mechanical work in a turbine, for both reaction and impact configurations.

For two-phase flow, a reaction turbine has an advantage over an impulse turbine due to the elimination of cavitation that may damage the impulse turbine. Also, the maximal static pressure at the edges of the reaction turbine is ideal for the injection of the
25 gas phase with minimal head losses. Finally, the non-zero velocity of the exiting jet in a reaction turbine is used to separate the gas/liquid mixture by impinging the jet on a circular frame, inducing a film flow on the walls of the frame, which breaks the bubbles, defining the separation zone.

Another core component is the continuous isothermal compressor and condenser:
30 The term compressor is used to compress gas or vapors that maintains as compressed gas or vapors. The term condenser describes the same device, but the compressed vapors are liquified.

Optionally, the HTL in the compressor/condenser is water, organic liquid such as Ethylene glycol, the same organic material as the organic vapors in a liquid phase, or any other liquid having a liquid phase in the operating temperature. The HTL inlet temperature is between -200 deg Celsius and 1000 deg Celsius or higher. The low-
5 temperature HTL is optionally used to compress or liquefy air, Nitrogen, Hydrogen, CO₂, or any other gases for charging the cold reservoir. The high-temperature HTL is optionally used for charging the high-temperature reservoir. This is achieved by thermally insulating the compressor so that all the invested work is converted to pressure and temperature that is conserved. In such an adiabatic system, the compression is quasi-
10 isothermal due to the large heat capacity of the liquid, which maintains the compressed gas at low temperatures compared to a conventional adiabatic expansion without mixing the gas with the HTL. Also, a moderate temperature difference of 50°C, 100°C, or 200°C is optionally used for hot and cold thermal reservoirs.

An optional method and system for condensing and compressing gases or vapors
15 are described in **Fig. 3**. The system is designed to increase the surface area between the compressing liquid and the compressed gas or vapors, thereby reducing the size and costs of the compressor. A closed-loop flow of HTL is driven by a pump, at a pressure above the pressure of the incoming gas or vapors. A nozzle is designed to reduce the pressure below the incoming gas or vapor pressure. This allows the gas or vapors to be sucked into
20 the HTL flow. The gas or vapors enter from the peripheral envelope or through a designated pipe. The gas or vapors and the HTL are mixed within the nozzle. In the case of vapors, the vapors are optionally liquified due to the temperature of the HTL and its high heat capacity compared to the vapors per volume. After the mixing, the shape of the nozzle is designed to increase the pressure at the outlet of the nozzle above the inlet
25 pressure. Optionally, in the case of vapors, part of the phase change material is left in the vapors phase and compressed as gas. Optionally, most of the vapors liquified after the pressure increased above the critical pressure. Optionally, the gas/HTL or vapor/HTL mixture reduces the speed of sound below the flow velocity of the mixture, leading to a supersonic flow in the nozzle. In this case, a reversed De-laval nozzle is designed as
30 described below. Optionally, the compression is isothermal, or quasi-isothermal, meaning the HTL and the gas or vapors maintain a similar temperature with less than 10% or 20% difference when measured in Kelvin along with the compression. Optionally, after the nozzle, the pressure increases, the flow slows and the mixture is separated by gravity, or

by centrifugal action, or any other separation method. The gas, vapors, or liquid phase of the phase-changing material is collected (in the upper part in case its density is lower than that of the HTL), while the HTL reaches the pump and continues circulating. The HTL is heated along with the compression. Optionally, the hot HTL is replaced with a cooled HTL for the continuous operation of the compressor (not shown in the figure). Optionally, cooling the HTL without replacing it, is done by heat transfer to the surroundings through the surface of the flow. Optionally, the HTL is heated for the storage of thermal energy. Optionally, the compressor pressure at the suction is below ambient pressure. For example, 0.7Bar. This allows the compressor to operate between the maximally compressed pressure and the minimal inlet pressure, 0.7 Bar in this example. At steady-state conditions, the HTL temperature may be sufficiently high for the HTL to evaporate under low pressure at the low-pressure region. In this case, the flow duration in the low-pressure region is much shorter than the heat exchange rate. That is the HTL doesn't have sufficient time to absorb the heat of evaporation from the environment and is maintained as a liquid, which allows the HTL and the vapors to be the same material. For example, compressing vapors of Pentane with liquid pentane as HTL flowing in the compressor. At the low-pressure region, the condition supports the gas phase but as long as the flow in the low region is faster than the heat transfer rate, there is no phase change. Instead, the liquid sucks the vapors of pentane coming from the turbine condensing it and compressing it. The advantage is the elimination of phase separation (bubbles) in the compressing stage, which accelerates the condensing process.

The nozzle of the compressor, exemplified in **Fig. 4**, may include the following sections in order:

1. Converging Inlet section for reducing pressure beyond ambient pressure, composed of HTL only (water as a non-limiting example).
2. Diverging two-phase flow section, where the pressure maintains constant while gas or vapor (air as a non-limiting example) is sucked into the HTL from the ambient through holes or voids in the nozzles envelop. The section marked “-“ is where the suction begins, and the section marked “+” the suction ends. The mixture reduces the velocity of sound below the velocity of the mixture. At the end of the “Diverging two-phase flow section” (marked with a “+”) the flow is supersonic. (See reference for supersonic two-phase flow in “Thrust Enhancement Through Bubble Injection Into an Expanding-Contracting Nozzle With a Throat

Sowmitra Singh”, Tiffany Fourmeau, Jin-Keun Choi, Georges and L. Chahine, DOI: 10.1115/1.4026855)

3. Converging two-phase section, where the pressure of the mixture increases and the Mach number (ratio between the flow and sound velocities) is reduced. At the end of this section, marked with “*”, Mach=1. (See reference for supersonic two-phase flow in “Thrust Enhancement Through Bubble Injection Into an Expanding-Contracting Nozzle With a Throat Sowmitra Singh”, Tiffany Fourmeau, Jin-Keun Choi, Georges and L. Chahine, DOI: 10.1115/1.4026855)
4. Diverging two-phase outlet, where the pressure of the mixture increases and the Mach number reduces. At the end of this section, the mixture reaches its maximal pressure (as a mixture since the HTL itself has higher pressure when it is introduced into the nozzle) (See reference for supersonic two-phase flow in “Thrust Enhancement Through Bubble Injection Into an Expanding-Contracting Nozzle With a Throat Sowmitra Singh”, Tiffany Fourmeau, Jin-Keun Choi, Georges and L. Chahine, DOI: 10.1115/1.4026855).

Referring back to the system, in one configuration of the system, the storage system includes high-temperature and low-temperature HTL reservoirs, a quasi-isothermal thermally insulated compressor, a thermally insulated turbine, a working fluid in the form of gas, a heat exchanger for the gas, and HTL. The gas can be Nitrogen, Air, CO₂, or any other gas, and the HTL can be any liquid that maintains as a liquid in the operating temperature range between the two HTL reservoirs. Optionally, a different HTL is used for the high temperature than the low temperatures reservoirs. This requires filters that block the two HTLs for mixing. Optionally, the same HTL is used in the two reservoirs. In the charging process, electric power input or mechanical power input is used to create a temperature difference between the high temperature, T_h , and cold temperature T_c HTL-reservoirs. During the discharging process, the temperature difference is converted to output electricity.

An example of materials and operational temperatures of the storage system: Using Nitrogen gas as the working fluid (WF) and Ethylene Glycol as the HTL in the temperature range of -40°C and 200°C. Optionally, Ethylene Glycol mixed with water is the HTL.

The charging process is depicted in **Fig. 5A**. Electric power drives the quasi-isothermal thermally insulated compressor. The Nitrogen is compressed from low-

pressure, P_L to high-pressure P_h , and is heated with the HTL to T_h . The compressed Nitrogen and the HTL temperature continue to elevate along with the compressor operation until reaching the maximal value, $T_{h_max}=199^{\circ}\text{C}$ in the case of Ethylene Glycol. Along the compressor operation, the compressed Nitrogen, at any T_h value
5 between T_L and T_{h_max} , exits the compressor reaching the heat exchanger, where the temperature drops to the low temperature, T_c . The compressed cold Nitrogen reaches the turbine and expands quasi-isothermally in the nozzle, accelerating and cooling the HTL, generating thrust that is converted to electricity or mechanical work in the turbine. This electric power or mechanical work supports the compressor operation, reducing the
10 power required from the outside. The HTL at the turbine and the gas cool along with the expansion. The HTL is maintained in the turbine and cools every cycle until reaching the minimal temperature T_{L_min} . The cooled Nitrogen returns to the heat exchanger retrieving the heat and elevating its temperature to T_h . The cycle continues as the gas returns to the compressor. After a few cycles, the temperature difference reaches the
15 maximal values (-40°C and 199°C for Ethylene Glycol). Optionally, hot and cold HTL reservoirs are connected to the compressor and the turbine, for charging the reservoir. The turbine is optionally connected with a circulating pump to the cold HTL reservoir for changing HTL. The compressor is maintained at high pressure. Optionally, the HTL hot reservoir connected to the compressor is also at high pressure.

20 Since it is possible to feed in and extract the same amount of liquid from a compressed tank without performing work (no change in the compressed gas volume), it is possible to maintain the hot reservoir at low pressure while mixing HTL with the compressor. Optionally this is done by inserting and extracting the same amount of liquid from the compressor simultaneously. **Fig. 6** shows an optional mechanism for doing that.
25 A set of ball valves that are blocked for a direct flow are located at the wall between the high-pressure, P_h , and the low-pressure, P_L , sides. HTL fills the empty spaces in the ball valves. Rotating the ball valves exchanges liquids without a significant work investment.

The charging process can be described in P-V T-S diagram depicted in **Fig. 7A**.
30 It operates as a reversed Ericsson thermal cycle. The compressor compresses at high temperatures, by using the hot reservoir. The gas is compressed quasi-isothermal due to the mixing with the HTL. The gas is later cools in the heat exchanger, optionally at

constant pressure, and reaches the turbine connected to the cold reservoir, where it expands quasi-isothermally.

For discharging, the connection of the reservoirs are switched so that the hot reservoir exchange HTL with the turbine and the cold reservoir exchange HTL with the compressor. The discharging mode is depicted in **Fig. 5B**. To ramp up, the compressor maintains the Nitrogen compressed. Optionally a separate chamber of compressed Nitrogen is used to ramp up. Once the valve is open at the compressor or chamber, the compressed Nitrogen at high-pressure P_h and cold temperature T_c passes through the heat exchanger, reaches the turbine at high-temperature T_h , mixes with the hot HTL in the nozzle, expands quasi-isothermally, and generates thrust, which is converted to electricity or mechanical work in the turbine. A portion of the electricity or the mechanical work is transferred to the compressor. The HTL and Nitrogen cool along with the expansion in each cycle. The Nitrogen returns to the heat exchanger at the temperature of the hot HTL, T_h , and low pressure, P_L , and exits the heat exchanger at T_c . Then the Nitrogen reaches the compressor, where it is compressed quasi-isothermally at the cold compressor temperature, T_c . The energy balance is positive because compressing gas at low temperatures and expanding the gas at high temperatures generate work as in heat engines. The cycle continues as long as the temperature difference supports positive energy generation.

The discharging process can be described in P-V T-S diagram depicted in **Fig. 7B**. It operates as an Ericsson thermal cycle. The compressor compresses at low temperatures, by using the cold reservoir. The gas is compressed quasi-isothermal due to the mixing with the HTL. The gas is later heated in the heat exchanger, optionally at constant pressure, and reaches the turbine connected to the hot reservoir, where it expands quasi-isothermally.

The above system is designed to store electric energy by thermal energy and convert it back to electricity. Optionally, if a hot or cold heat source is available, the hot or cold reservoirs exchange heat with the source, reaching the desired temperature without electric power input. In such a case, the 2nd reservoir is at ambient temperature, and the amount of electric power that can be extracted depends on the temperature difference between the heated (or cooled) reservoir and the ambient temperature. Optionally, in addition to the heat source, electricity is used to further increase the temperature difference between the sources to be converted to electricity. Optionally, if

- 50 -

the cold reservoir is at a temperature higher than ambient, air can be used to cool the cold reservoir, leading to more electric power extracted.

In addition, the Nitrogen example can be replaced with organic materials as done in Organic Rankine cycle (ORC). In this case, the electric power used in the compressor
5 condenses the vapors to liquid as in ORC. The liquid vaporizes in the nozzle of the turbine and expands quasi-isothermally in the turbine, where it cools the HTL. Then, the ORC material reaches the heat exchanger and returns to the compressor/condenser for an additional cycle. As an example, ORC materials such as Ethylene glycol as HTL and Propane as the working fluid are used. Any other ORC material can be considered that
10 has a liquid phase at the cold HTL temperature and a gas phase at the hot HTL temperature.

Optionally, the hot reservoir is heated by an external heat source. Optionally, the cold reservoir is cold by an external source such as water flow or air ventilation. Optionally, ventilation or other external work investment is used to slow the cooling rate
15 of the hot reservoir during discharge.

At low temperatures (<200C), a typical Ericsson-based Carnot battery has round-trip efficiency lower than 50% due to the enhanced work of the compressor. The present invention can employ a new thermodynamic cycle based on an isothermal bubbles expansion of organic Liquid/Vapor Phase Change (LVPhC) working fluid in a two-phase
20 nozzle. For Carnot batteries, such a new engine has a great advantage over the Ericsson cycle operating at low temperatures since the phase changing limits the pressure from rising, thereby reducing the compressor load.

The method is optionally described by the thermodynamic cycle stages:

1->2: Liquefied LVPhC is pumped from the condenser and pressured to a pressure
25 P_1 similar or close to the pressure in the mixing chamber in the nozzle.

2->3 The liquefied LVPhC exchanges heat with the vapors going out of the turbine, Increasing its temperature with no phase change (Due to the high latent heat, the liquified LVPhC stays liquid). Optionally, part of the LVPhC vaporizes.

3->4: The compressed liquid (optionally partially vapor) LVPhC is injected into
30 the evaporator, where it is vaporized. Optionally this stage is done in the nozzle.

4->5: The compressed vapor-LVPhC mixes with the HTL in the mixing chamber in the nozzle, where HTL flows. The static pressure and temperature reduction along the flow in the nozzle result in quasi-isothermal expansion, accelerating the LVPhC/HTL

mixture and generating thrust at the nozzle's outlet, which rotates the turbine, generating electricity, mechanical work, or another form of work. Optionally, the velocity of the mixture is supersonic in part of the nozzle.

5->6: The high-temperature vapor-LVPhC vapors exit the nozzle, separated from the HTL, and flow to the heat exchanger where they exchange heat with the liquid-LVPhC going out of the condenser, with no phase change (the vapor stays vapor). Optionally, part of the vapors condenses.

6->1: The vapors are cooled until condensation in a condenser and compressed as a liquid.

10 The P-V diagram for the thermodynamic cycle is shown in **Fig. 8**.

Examples of LVPhC materials are anti-freezing materials such as ORC conventional materials: pentane, isobutane, propane, R134a, R245fa, Fluorocarbons, and toluene.

Fig. 9 and the list below, depicts an example of a controlled volume calculation for the thermodynamic cycle when using the two-phase pentane and Ethylene Glycol as HTL.

Considering 1 Kg of Pentane where the numbers in the T-S diagram are the different thermodynamic states for $P_0=1\text{Bar}$, $P_1=14.5\text{Bar}$, $T_1=155\text{C}$, $T_{\text{HTL_cold}}=35\text{C}$:

6->1: Condensation: 342KJ/Kg.

20 1->2: LVPhC-Liquid pumped isentropic compression to P_1 : 4KJ/Kg.

2->3a: LVPhC-Liquid exchange heat with LVPhC-vapor assuming 30 deg gap: 146KJ/Kg.

3a->3: Additional heat from HTL to reach liquid-vapor equilibrium point at P_1 : 144KJ/Kg.

25 3->4: LVPhC-Liquid vaporization and heating vapor to 155C: 246KJ/Kg.

4->5: LVPhC-vapor expands in the nozzle-isothermal Work: 133KJ/Kg.

5->6: Cooling of the vapors in heat exchange: 146KJ/Kg.

This calculation shows a cycle efficiency of $\eta = \frac{133-4}{133+246+144} = 0.24$.

When assuming an ideal heat exchanger (0°C temperature difference), and an ideal compressor and turbine, the efficiency reaches the Carnot efficiency, which is doubled compared to the conventional ORC efficiency under similar conditions.

We note that superheating is optional for the two-phase nozzle and also supercritical (mixed vapor/liquid phases) is optional due to the bubbly mixture flow in the nozzle. In this option, the line between points 3 and 5 in figure 10 doesn't cross the phase-change bell shape dotted line.

5 Using such an engine typically requires a heat source for evaporating the working fluid, evaporation, and acceleration of the mixture in the nozzle, generating thrust and rotating the turbine. This is followed by using a condenser for cooling and liquifying the vapors for re-heating and recycling in the turbine.

For Carnot Battery, the system includes a compressor/condenser, optionally
10 isothermally compressing/condensing the vapors, an isothermal expansion/evaporation turbine, and the recuperator, a counter-flow heat exchanger between them.

Fig. 10A depicts an optional charging process. The vapor-LVPhC condenses in the compressor/condenser operating on an external power source. The generated heat heats the HTL and the hot reservoir. Then, the hot liquid-LVPhC passes through the
15 recuperator and cools, reaching the turbine where the pressure drops, resulting in evaporation and expansion of the liquid-LVPhC in the nozzle, rotating the turbine, generating power that returns to the compressor. The cold vapor-LVPhC cools the cold reservoir, passes in the recuperator, and returns to the compressor for an additional cycle. This way the work (electricity) invested in the compressor is transformed into hot and
20 cold reservoirs.

In the discharge mode, the turbine HTL is connected to the hot reservoir, while the compressor/condenser is connected to the HTL of the cold reservoir. **Fig. 10B** depicts an optional discharging process. The vapor-LVPhC condenses at the cold reservoir temperature in the compressor/condenser operating. The generated heat heats the HTL
25 and the cold reservoir. Then the liquid-LVPhC passes through the recuperator and is heated, reaching the turbine where the heat and pressure drops result in evaporation and expansion of the liquid-LVPhC in the nozzle, rotating the turbine, generating power that returns to the grid, a portion of the power supports the compressor. The hot vapor-LVPhC cools the hot reservoir, passes in the recuperator, and returns to the compressor for an
30 additional cycle. This way the work (electricity) returned to the grid by using the hot and cold reservoirs.

Optionally, the isothermal compressor/condenser is a compressor that comprises a nozzle as exemplified in **Fig. 4**, which as explained above is a two-phase de Laval

nozzle in "reverse" configuration such that it increases the pressure of a gas, compressing it isothermally by mixing it with the HTL. It is to be noted that the figure is not in scale.

HTL, such as water, low freezing point liquids, Hydrocarbonate liquid, and/or other flow in the nozzle, enters the inlet at a higher pressure than ambient, and exits at the outlet at a higher pressure than ambient. Gas, such as air, Hydrogen, or any other, is sucked into the HTL, compressed, and cooled by the HTL, and emerges at the outlet at a higher pressure than ambient pressure. Though, **Fig. 4** shows an example of water as HTL and air as gas, it is to be noted that the HTL can be selected from any suitable HTL and the gas may be any suitable gas to be compressed. Optionally, the HTL initial pressure and velocity are generated by a pump. Optionally the initial and final pressure values of the HTL are identical within a range of 10%. Optionally the initial and final pressure of the HTL is identical within a range of 20%, or 30%.

Preferably the operation temperature of the HTL is as low as possible. Optionally, below 100°C, 25 °C, 15 °C, or 0 °C. Optionally, for low freezing point HTL, the operation temperature is less than -10 °C, -25 °C, -50 °C. Optionally the HTL temperature is below -195 °C when the HTL is liquid Nitrogen or below 4.2K when the HTL is liquid Helium.

Optionally, such a compressor can be used in a cascaded way to reach higher pressure, thus taking the compressed gas into the gas supply of a second closed loop compressor, for a second stage of pressure. For example, first degree compress air to 15 bars, using water as HTL and a supersonic nozzle. This compressed air flows into the second supersonic nozzle of a second compressor closed loop, which maintains at about 30 bars. At the nozzle, the pressure drops below 15 bars allowing the air to enter the nozzle. At the nozzle's exit the pressure increases to 30 bars, and the air is compressed while cooled by the water.

The system is optionally composed of Pentane as a working fluid or an optional cyclo-pentane for higher temperatures than 180C. The HTL is for example Ethylene glycol for working up to 200C or thermal oil for temperatures up to about 400C, and even molten salts for higher temperatures. Optional working fluids are any fluids that are used in conventional ORC such as pentane, isobutane, propane, R134a, R245fa, Fluorocarbons, and toluene. For high temperatures, water may be used as the working fluid as in the Rankine cycle.

Fig. 11 shows an example of the temperature evolution in the charging and discharging. In this example, fixed low pressure (1bar) and fixed high pressure (14.5) bars

are reached at any cycle regardless of the temperature. The starting reservoir temperatures are for example is optional 90C and 111C. In the figure, the thermodynamic cycle is described by points 5.1-3.1 (compressor/condenser), and 1.1-6.1 (turbine evaporation/expansion).

5 Optionally, the end pressure reached by the turbine and the compressor is set by the saturation pressure. This requires varying pressure according to the temperature profile of this option, where the cold side stays at a fixed temperature while the hot reservoir changes its temperatures of the reservoirs build up. **Fig. 12** depicts this option.

 Optionally, any combination between the fixed pressure and varying pressure can
10 be considered. For example, charging the system at varying pressure (**Fig. 12** left) while discharging at constant pressure (**Fig. 11** right). Optionally, in case the cold reservoir temperature exceeds the ambient temperature, the cold reservoir or the compressor/condenser may be thermally connected with the environment to maintain a lower temperature than what would be achieved if the system is insulated. This will
15 increase the amount of extracted power.

 In addition, due to the inherent higher heat capacity of the working fluid in a liquid phase compared to its vapor phase, in the charging process, the liquid reaches the turbine hotter than the turbine, while in the discharge process the liquid reaches the turbine cooler than the turbine. This reduces the overall round-trip efficiency by screening the
20 temperature difference between the reservoirs. Since the overall net heat transfer to the liquid in a full charging-discharging cycle is zero, optionally a high-value heat capacity body is placed as part of the recuperator heat exchanger, and serves as a heat pendulum that delivers the missing heat energy. While in the recuperator, the liquid phase exchanges heat with the gas phase, at the thermal pendulum only the liquid phase flow, exchanging
25 heat with the thermal mass. **Fig. 13A** shows a divided recuperator (heat exchanger) and a thermal pendulum in the middle in a charging mode, where the temperature is minimally changed. In the charging mode, the thermal pendulum heats while cooling the liquid before it reaches the turbine. **Fig. 13B** shows the discharging mode, where the thermal pendulum cools while heating the liquid before reaching the turbine. The net energy on
30 the pendulum is zero.

 In general, the major advantage of a Carnot battery is its possible transformation into a heat engine configuration. That is, when the thermal storage runs out the discharge configuration becomes a heat engine while the hot reservoir is replaced by burning gas or

- 55 -

hydrogen or any other burning process. This allows the device to supply electricity all year even when the thermal storage ends.

In an optional Carnot battery configuration, one reservoir may be the surrounding. The advantage is the cost reduction with the elimination of one reservoir. In an optional
5 configuration of the system, only a hot reservoir is used while the cold reservoir is the surrounding. In this case, the working fluid is optionally, Pentane, Cyclopentane, water, or any other working fluid used in a two-phase vapor/HTL heat engine. Optionally the HTL is Ethylene Glycol, thermal oil, molten salt, or other non-evaporating liquid at the operation temperature and pressure ranges of the system. Optionally, in the discharge
10 configuration burning gas, hydrogen, or other combustion processes may be used to heat the working fluid and the HTL to generate electricity.

Fig. 17A is a block diagram exemplifying a non-limiting embodiment of the system of the present disclosure, in which the WF exchanges heat with the surrounding in the condenser / evaporator. The system **100** comprises a high temperature HTL storage
15 **102** (throughout the application, the term "high temperature HTL storage" is interchangeable with the term "hot HTL storage" or "hot HTL reservoir") that is selectively connected to the turbine **104** in the discharging mode and to the compressor **106** in the charging mode. When the high temperature HTL storage **102** is fluidically connected to the turbine **104** or the compressor **106** it exchanges HTL with the respective
20 component. In the charging mode, the HTL that is delivered to the compressor **106** has a temperature that is lower than the temperature of the HTL that is received back from the compressor **106**. In the discharging mode, the HTL that is delivered to the turbine **104** has a temperature that is higher than the temperature of the HTL that is received back from the turbine **104**.

25 In each operational mode, the WF flows in a different closed-loop flow path.

In the discharging mode, the WF flows in a first flow path, from the turbine **104**, to the counter flow heat exchanger **108**, to the condenser / evaporator **110** that acts as a condenser, back the counter flow heat exchanger **108** and back to the turbine **104**. In its flow path, after that the WF is condensed and before it enters the nozzle of the turbine
30 **104**, it is pressurized by a WF pump (not shown).

In the charging mode, the WF flows in a second flow path, from the compressor **106** to the counter flow heat exchanger **108**, to the condenser / evaporator **110** that acts as an evaporator, back the counter flow heat exchanger **108** and back to the compressor

106. Typically, between the flow of the WF from the counter flow heat exchanger 108 to the evaporator 110, the pressure of the WF is reduced, e.g. by a dedicated pressure reduction nozzle, in order to reduce the temperature of the WF below the ambient pressure to allow it to receive heat from the surrounding when it passes through the evaporator
5 110.

Fig. 17B is another block diagram exemplifying a different non-limiting embodiment of the system of the present disclosure, in which the WF exchanges heat with the surrounding in the condenser / evaporator. Fig. 17B differs from Fig. 17A by that the compressor 106 comprises its own compressor HTL 107 that flows in a closed loop within
10 the compressor 106 and it does not receive hot HTL from the high temperature HTL storage 102. The compressor 106 further comprises compressor HTL reservoir 109 that stores the compressor HTL 107 before and/or after the compression process in the compressor. The compressor HTL reservoir 109 can be in the form of a chamber or can be a portion of the compressor HTL flow path in the compressor that is different than the
15 manipulation zone, in which the compression occurs. The compressor HTL gradually increases its temperature in each compression cycle of the WF and the compressor is configured to exchange heat with the high temperature HTL storage to heat it. The exchange of heat may be realized by designing that a part of the closed loop flow path of the compressor HTL is thermally coupled with the high temperature HTL storage or with
20 a flow path of the hot HTL, without any exchange of liquids between the compressor 106 and the high temperature HTL storage 102. It is to be noted that the embodiment that the compressor comprises its own HTL and only in thermal coupling with the HTL reservoir may be applied to any aspect of the present disclosure. Therefore, in the aspects that includes also cold HTL reservoir, the compressor may also be in thermal coupling with
25 the cold HTL reservoir without exchanging liquid therewith.

A more specific example of such system configuration is depicted in Figs. 14A-14B, in which during the discharging process (Fig. 14A), the turbine is connected to the hot reservoir and to condenser through a recuperator (the surrounding of the condenser is the cold reservoir). Optionally the working fluid (WF) is Cyclopentane. In this option,
30 liquid WF is pressurized (pumped), heated in the recuperator, and injected into the turbine where it is further heated, evaporated, and expends quasi-isothermally, cooling the hot reservoir. The power generated operates the condenser and delivers the net output power. The vapors continue to the recuperator, cool, and condense in the condenser returning to

the recuperator. The process ends when the temperature difference between the reservoirs is too small. **Fig. 14A** right shows the T-S diagram of such a process. The different thermodynamic stages 3.0-5.0, 3.1-5.1, 3.2-5.2, 5.3-3.3, describe the evaporation and expansion at elevated temperatures of the hot reservoir, as it is discharged (cooled) by the turbine.

In the charging process (**Fig. 14B**), the compressor/condenser is connected to the hot reservoir and is driven by external electric power. WF vapors are compressed and condensed, while heat flows from the WF to the hot reservoir, elevating its temperature. The liquid WF is cooled in the recuperator. Flash evaporation or other pressure reduction means is used to flash evaporate part of the WF, while the WF is cooled below the surrounding temperature. The WF continues to evaporate in the evaporator while heat flows from the surrounding to the WF. In this example, the evaporator is the same device as the condenser. The input vapor pressure in the compressor is the same as the pressure in the evaporator. It is controlled to allow evaporation at a saturation temperature lower than the surrounding temperature. Reducing the pressure reduces the saturation temperature. The high-pressure liquid WF exiting the compressor passes through a pressure reduction nozzle, optionally orifice, that reduces the pressure to the level of the compressor inlet pressure. The result is WF that evaporates while cooling to a temperature lower than the surroundings. This allows heat to flow from the surroundings into the cooled WF supporting further evaporation. The result is WF vapors near the surrounding temperature. The vapor returns to the recuperator heated and again quasi-isothermally compressed in the compressor/condenser, heating the hot reservoir. The process ends when the temperature is sufficiently high.

An example of the system: 250 kW Carnot Battery (CB) that optionally, operates as a peaker gas turbine when the storage runs out.

The CB is evaluated by two parameters: The engine efficiency, and the heat pump efficiency, known as the coefficient of performance (CoP). Ideally, when the charging and discharging are working between the same temperatures, these two parameters cancel each other allowing 100% round trip efficiency. In the present solution, the engine and storage operate at a range of temperatures. At a low temperature ($100\text{C} < 140\text{C}$) the high CoP compensates for the poor efficiency, while at a high temperature ($140\text{C} > 180\text{C}$), the high engine efficiency compensates for the poor CoP. Table 1 symmetrizes the pentane

turbine's practical efficiency calculated by running the heat and mass balance (Setup in **Fig. 13A**) at various temperatures.

Table 1:

Engine efficiency at various temperatures

T (°C)	Efficiency (%)
100	12.5
140	18.75
175	23.1
250	29.9

5

Fig. 15A shows the heat and mass balance for the 140C temperature case, showing 18.75% efficiency.

Fig. 16 depicts the enthalpy and entropy values of pentane at various temperatures. The CoP in the charging process is defined by the heat pump in stages 5-3 at the elevated temperature ranges, where the heat is: $Q = Tds$, the work is $W = Q - dH$, and the $CoP = Q/W$.

As an example, we consider two case studies:

- CB as a stand-alone dispatchable source. In this configuration, at the charging, the pressure in the evaporator is set at 0.38 Bar (saturation temperature at $T=10^{\circ}\text{C}$). This allows the evaporation at ambient temperature. The compressor inlet pressure is 0.38 Bar and the outlet pressure is slightly above the saturation pressure at the reservoir (and the HTL in the compressor) temperature.
- CB plus an additional waste heat source at 75°C heating the evaporator. The waste heat at 75°C allows the Pentane to evaporate at 70°C and 2.8 Bar pressure. Such an initial pressure reduces the work in 5-3 stages while the latent heat extracted to the reservoir is unchanged. Such an external waste heat source boosts the CoP and the CB efficiency, optionally above 100%.

Table 2 summarises the extracted thermodynamic CoP for case 1 (ambient) and case 2 (75°C) for various HTL temperatures. Practically, because the compressor is in the hot section, thermal losses are recycled. For 80% pump efficiency of the compressor and a CoP of 4, the effective efficiency is 85% ($0.8+0.2/4=0.85$). The practical values for 80% pump efficiency are marked in bold in Table 2. As evident, the 75°C waste heat source more than doubles the CoP compared to ambient temperature. The overall round-trip

25

- 59 -

efficiency (electric power out/electric power in) is the multiplication of the CoP and the discharge engine efficiency (Table 1).

Table 2:CoP at various temperatures

T (°C)	Ambient	75°C
100	3.82	11.7
	3.26	9.56
140	2.8	5.3
	2.44	4.44
175	2.18	3.35
	1.95	2.88

5

Table 3 summarizes the return cycle efficiency.

Table 3:Round trip efficiency at various temperatures

	175°C	140°C	100°C
R.T. efficiency (Case-1)	0.58	0.46	0.40
R.T. efficiency (Case-2)	0.86	0.84	1.2

10

As evident, the 75C waste heat source offers an average of > 90% round-trip efficiency. In both cases, when the thermal storage runs out, burning gas or hydrogen drives the engine. Calculating heat and mass balance for pentane at 250C, results in 30% efficiency.

15 To complete the picture, **Fig. 15B** shows the heat and mass balance for the charging of the 250kW turbine at 140C (setup of the system as shown in **Fig. 14B**). The heat and mass balance support round trip efficiency of 84%. In this configuration of the system, the evaporator may be accommodated within an enclosure that receives thereinto the waste heat. The enclosure may have an inlet for receiving the waste heat and an outlet
20 for ventilation when the mass of the waste heat is introduced.

Taking into account that waste heat at 75C is highly common, offering 84% battery efficiency and 30% efficiency as a peaker-turbine, allows storing renewable-based grid overproduction, thereby offering a baseload renewable grid, a major step toward a

- 60 -

complete decarbonization. Another advantage is the decoupling between charging (compressor) and discharging (turbine). Renewable sources such as solar and wind may charge a few hours a day, while the discharge may be nearly continuous. This requires a large compressor and a small turbine.

CLAIMS:

1. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:
 - at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;
 - 5 at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL, being the same or different than the hot HTL of the hot reservoir;
 - wherein the at least one hot HTL reservoir is selectively (i) fluidically connectable to the at least one two-phase turbine in discharging operational mode or (ii) fluidically
 - 10 connectable or thermally couplable to the at least one two phase compressor in charging operational mode for (1) feeding hot HTL to the respective turbine in the discharging mode or for (2) either heat exchanging between the compressor HTL and the HTL of the hot reservoir, the compressor HTL and the hot HTL are different and when the compressor HTL and the hot HTL reservoir are different or feeding hot HTL to the at
 - 15 least one compressor, when the compressor HTL and the hot HTL are the same and the compressor HTL reservoir and the hot HTL reservoir are the same, in the charging mode;
 - at least one condenser in fluid communication with the turbine for receiving and condensing a working fluid (WF) coming from the turbine;
 - at least one evaporator in fluid communication with the at least one compressor
 - 20 for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;
 - the discharging mode defining a first flow path of the WF and the charging mode defines a second flow path of the WF; and
 - wherein in a discharging mode the WF flows in the first flow path from the at
 - 25 least one condenser to one or more nozzles within the at least one turbine, the nozzles being configured to induce rotation of the turbine upon discharge of fluid therefrom, to thereby mix the WF with the HTL to form a HTL/WF mixture in said one or more nozzles, in which the WF undergoes a quasi-isothermal expansion, causing acceleration of the HTL/WF mixture and discharge of the mixture through the one or more nozzles while
 - 30 reducing temperature of the HTL, the HTL/WF mixture discharged out of the one or more nozzles being received in at least one first separation zone configured to separate the WF from the HTL, the HTL being recycled back to said at least one hot reservoir or to said one or more nozzles and the separated WF flowing into and received in the condenser to

- 62 -

undergo condensation therein, the condensed WF discharged from the at least one condenser flows back to the turbine.

2. The system of claim 1, comprising at least one first counterflow heat exchanger disposed in the first flow path between the at least one turbine and the at least one
5 condenser and configured for heat exchange between WF exiting from the at least one turbine and WF exiting from the at least one condenser.

3. The system of claim 2, wherein the heat exchanger is configured for reducing the temperature of the WF flowing from the turbine to the condenser.

4. The system of any one of claims 1-3, comprising at least one pressurizing
10 arrangement configured for pressurizing or propelling the WF after being condensed in the at least one condenser.

5. The system of claim 4, wherein said arrangement comprises a pump.

6. The system of any one of claims 1-5, comprising at least one first separation zone disposed in the at least one turbine for separating between the WF and the HTL.

15 7. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:

at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;

at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL, being the same or different than the HTL of the hot
20 reservoir;

the at least one hot HTL reservoir is selectively (i) fluidically connectable to the at least one two-phase turbine in discharging operational mode or (ii) fluidically connectable or thermally couplable to the at least one two phase compressor in charging operational mode, for (1) feeding hot HTL to the respective turbine in the discharging
25 mode or for (2) either heat exchanging between the compressor HTL and the HTL of the hot HTL reservoir;

at least one condenser in fluid communication with the turbine for receiving and condensing a working fluid (WF) coming from the turbine;

at least one evaporator in fluid communication with the at least one compressor
30 for receiving and evaporating WF coming from the at least one compressor, the at least one evaporator, being same or different element than the at least one condenser;

the discharging mode defining a first flow path of the WF and the charging mode defines a second flow path of the WF; and

- 63 -

wherein in the charging mode, the WF flows in the second flow path and the at least one compressor is configured to form a compressor HTL/WF mixture and quasi-isothermally compress the WF in the mixture along a compressor flow path and to thereby heat the compressor HTL, the compressor HTL exchanges heat with the hot HTL reservoir to thereby heat the hot HTL reservoir and is cycled back to a reservoir, being the same or different than the hot HTL reservoir, or cycled within the least one compressor, the compressed WF being discharged from the at least one compressor to be received in the evaporator to undergo evaporation, the evaporated WF discharged from the at least one evaporator being directed back to the at least one compressor.

8. The system of claim 7, comprising at least one second counterflow heat exchanger, disposed in the second flow path between the at least one compressor and the at least one evaporator and configured for heat exchange between WF exiting from the at least one compressor and WF exiting from the at least one evaporator.

9. The system of claim 8, wherein the heat exchanger is configured for increasing the temperature of the WF flowing from the compressor to the turbine.

10. The system of any one of claims 7-9, comprising at least one second separation zone disposed in the at least one turbine for separating between the HTL and the WF.

11. The system of any one of claim 7-10, comprising at least one pressure reduction nozzle disposed in the second flow path between the at least one second heat exchanger and the at least one evaporator to reduce pressure and temperature of the WF that flows from the at least one second heat exchanger to the at least one evaporator.

12. The system of any one of claims 1-11, wherein the WF is a liquid/vapor phase changing (LVPhC) WF, selected to being (i) in a vapor phase when (1) entering the at least one compressor, (2) when in a temperature equilibrium after being mixed with the HTL in the at least one turbine, and (3) when exiting the at least one evaporator, and (ii) in a liquid phase when (4) exiting the at least one condenser and (5) exiting the at least one compressor.

13. A system for storing and retrieving energy in respective charging and discharging operational modes, comprising:

at least one hot heat transfer liquid (HTL) reservoir containing hot HTL;

at least one two-phase turbine and at least one two-phase compressor configured for compressing compressor HTL being the same or different than the hot HTL;

- 64 -

the at least one hot HTL reservoir is selectively (i) fluidically connectable to the at least one two-phase turbine in discharging operational mode or (ii) fluidically connectable or thermally couplable to the at least one two phase compressor in charging operational mode, for (1) feeding hot HTL to the respective turbine in the discharging
5 mode or for (2) either heat exchanging between the compressor HTL and the hot HTL;

at least one condenser in fluid communication with the turbine for receiving and condensing a working fluid (WF) coming from the turbine;

at least one evaporator in fluid communication with the at least one compressor for receiving and evaporating WF coming from the at least one compressor, the at least
10 one evaporator, being same or different element than the at least one condenser;

the discharging mode defining a first flow path of the WF and the charging mode defines a second flow path of the WF; and

wherein in a discharging mode the WF flows in the first flow path from the at least one first condenser to one or more nozzles within the at least one turbine, the nozzles
15 being configured to induce rotation of the turbine upon discharge of fluid therefrom, to thereby mix the WF with the HTL to form a HTL/WF mixture in said one or more nozzles, in which the WF undergoes a quasi-isothermal expansion, causing acceleration of the HTL/WF mixture and discharge of the mixture through the one or more nozzles while reducing temperature of the HTL, the HTL/WF mixture discharged out of the one or more
20 nozzles being received in at least one first separation zone configured to separate the WF from the HTL, the HTL being recycled back to said at least one hot reservoir or to said one or more nozzles and the separated WF flowing into and received in the condenser to undergo condensation therein, the condensed WF discharged from the at least one condenser streamed back to the turbine; and

25 wherein in the charging mode, the WF flows in the second flow path and the at least one compressor is configured to form a compressor HTL/WF mixture and quasi-isothermally compress the WF in the mixture along a compressor flow path and to thereby heat the compressor HTL, the compressor HTL being cycled back to a reservoir, being the same or different the hot HTL reservoir or to the at least one compressor, the
30 compressed WF being discharged from the at least one compressor flows to be received in the evaporator to undergo evaporation, the evaporated WF discharged from the at least one evaporator being back to the at least one compressor.

- 65 -

14. The system of claim 13, wherein the at least one evaporator and the at least one condenser are the same elements.
15. The system of claim 13 or 14, comprising at least one first counterflow heat exchanger disposed in the first flow path between the at least one turbine and the at least one condenser and configured for heat exchange between WF exiting from the at least one turbine and WF exiting from the at least one condenser.
16. The system of claim 14, wherein the heat exchanger is configured for reducing the temperature of the WF flowing from the turbine to the condenser.
17. The system of any one of claims 13-16, comprising at least one second counterflow heat exchanger, disposed in the second flow path between the at least one compressor and the at least one evaporator and configured for heat exchange between WF exiting from the at least one compressor and WF exiting from the at least one evaporator.
18. The system of claim 17, wherein the heat exchanger is configured for increasing the temperature of the WF flowing from the compressor to the turbine.
19. The system of claim 17 or 18, comprising both said at least one first heat exchanger and said at least one second heat exchanger, wherein the at least one first counterflow heat exchanger and the at least one second counterflow heat exchanger are same one or more elements selectively connectable to the at least one turbine or the at least one compressor, in respective discharging mode or charging mode.
20. The system of any one of claims 13-19, comprising at least one pressurizing arrangement configured for pressurizing or propelling the WF after being condensed in the at least one condenser.
21. The system of claim 20, wherein said arrangement comprises a pump.
22. The system of any one of claims 13-21, comprising at least one first separation zone disposed in the at least one turbine for separating between the WF and the HTL.
23. The system of any one of claims 13-22, comprising at least one second separation zone disposed in the at least one compressor for separating between the WF and the HTL.
24. The system of any one of claim 13-23, comprising at least one pressure reduction nozzle disposed in the second flow path between the at least one second heat exchanger and the at least one evaporator to reduce pressure and temperature of the WF that flows from the at least one second heat exchanger to the at least one evaporator.
25. The system of any one of claims 13-24, wherein the WF is a liquid/vapor phase changing (LVPhC) WF, selected to being (i) in a vapor phase when (1) entering the at

- 66 -

least one compressor, (2) when in a temperature equilibrium after being mixed with the HTL in the at least one turbine, and (3) when exiting the at least one evaporator, and (ii) in a liquid phase when (4) exiting the at least one condenser and (5) exiting the at least one compressor.

5 26. The system of any one of claims 13-25, wherein one or both of the at least one compressor and the at least one turbine is thermally insulated.

27. The system of any one of claims 13-26, comprising one or more selective valves for allowing the selective connections of the at least one hot HTL reservoir to the at least one compressor and the at least one turbine.

10 28. The system of any one of claims 13-27, wherein the HTL is selected from a list consisting of: anti-freezing liquids, water, salty water, thermal oil, molten salt, ethylene glycol, and the WF in a liquid phase.

29. The system of any one of claims 13-28, wherein the WF is selected from a list consisting of: air, nitrogen, hydrogen, CO₂, ammonia, propane, ORC phase-changing materials, pentane, refrigeration phase-changing materials.

30. The system of any one of claims 13-29, comprising at least one external thermal source to allow controllable heating of the HTL.

31. The system of any one of claims 13-30, wherein the at least one condenser and the at least one evaporator are configured to exchange heat with their surroundings for
20 the condensation and the evaporation, respectively.

32. The system of any one of claims 13-31, wherein the at least one evaporator is configured for heating by at least one external heat source in the charging operational mode.

33. The system of claim 32, comprising a thermally insulated enclosure that
25 comprises the at least one condenser or the at least one evaporator, being configured for heat input from the external heat source and for controlled discharge of excess heat.

34. The system of any one of claims 13-33, wherein the at least one first and the at least one second counterflow heat exchangers are recuperators.

35. The system of any one of claims 13-34, wherein an inlet compressor pressure of
30 the WF and pressure of the WF in the evaporator are lower than the critical pressure at a temperature lower than the surrounding temperature, thereby allowing the evaporation of the WF and heat to flow from the surrounding to the WF vapors.

- 67 -

36. The system of any one of claims 13-35, wherein the at least one first heat exchanger comprises at least one first thermal pendulum.

37. The system of claim 36, wherein each of the at least one first heat exchanger comprises a first heat exchanger section, a second heat exchanger section and a first thermal pendulum section; wherein the flow path of the WF between the first and the second heat exchanger sections is through the thermal pendulum.

38. The system of any one of claims 13-37, wherein the second heat exchanger comprises a second thermal pendulum.

39. The system of claim 38, wherein each of the at least one second heat exchanger comprises a first heat exchanger section, a second heat exchanger section and a second thermal pendulum section; wherein the flow path of the WF between the first and the second heat exchanger sections is through the second thermal pendulum.

40. The system of any one of claims 38 and 39, wherein the second thermal pendulum is the same as the first thermal pendulum.

41. The system of any one of claims 13-40, wherein the thermal pendulum has heat capacity value greater than the heat capacity of the WF in its liquid phase and is configured to exchange heat with the WF passing therethrough to compensate for heat exchange inefficiency between the liquid phase of the WF and the gas phase of the WF such that (1) in the charging operational mode the thermal pendulum heats while cooling the liquid before it enters the turbine and (2) in the discharging operational mode the thermal pendulum cools while heating the liquid before it enters the turbine.

42. The system of any one of claims 13-41, wherein the first flow path and the second flow path are closed-loop flow paths.

43. The system of any one of claims 13-42, wherein the at least one turbine is configured to increase the pressure of the HTL to obtain high-pressure HTL and to introduce the high-pressure HTL into said one or more nozzles to be mixed with WF at about the same pressure to form HTL/WF mixture with subsequent quasi-isothermal expansion of the WF within the one or more nozzles accelerating the HTL/WF mixture towards outlets of the one or more nozzles.

44. The system of any one of claims 13-43, wherein the at least one compressor comprises a HTL pump for increasing the HTL pressure, the HTL pump being fluidically coupled to a compressor nozzle configured for receiving pressurized HTL from the HTL

- 68 -

pump and to mix it with WF to obtain HTL/WF mixture within the nozzle being discharged out of the nozzle at a pressure higher than the pressure of the WF that is introduced into the compressor.

45. The system of any one of claims 13-44, wherein the at least one WF pump is
5 comprised within the at least one condenser.

46. The system of any one of claims 1-45, wherein the evaporator is maintained at above ambient temperature.

47. The system of any one of claims 1-46, wherein said compressor HTL is different than the hot HTL and it flows in a closed loop in the compressor and thermally exchange
10 heat with the hot HTL reservoir in the charging mode.

48. The system of any one of claims 1-46, wherein said compressor HTL is the same as the hot HTL and the compressor HTL reservoir is the same as the hot HTL reservoir, and in the charging mode the hot HTL reservoir is fluidically connected to the at least one two phase compressor for feeding the hot HTL to the at least one compressor.

15 49. A system for storing and retrieving energy in respective charging and discharging modes, comprising:

at least one two-phase turbine and at least one two-phase compressor;

at least one hot HTL reservoir containing hot HTL and at least one cold HTL reservoir containing cold HTL, each selectively fluidically connectable to at least one
20 compressor or the at least one turbine; at least one intermediary heat exchanger disposed in a flow path between the at least one compressor and the at least one turbine;

wherein in the charging mode, the at least one compressor is made to be fluidically connected to the at least one hot HTL reservoir to receive hot HTL therefrom and quasi-isothermally compress a working fluid (WF) mixed with the hot HTL, such that the
25 compressed working fluid flows through the at least one first heat exchanger to reduce its temperature and then to be mixed with cold HTL in one or more nozzles of the turbine to undergo isothermal or quasi-isothermal expansion that accelerates the HTL and working fluid mixture to produce kinetic energy convertible to electric energy, the working fluid discharged from the turbine being directed towards the at least one first heat exchanger
30 to be heated for another cycle;

wherein in the discharging mode, the at least one compressor is configured to receive cold HTL from the cold HTL reservoir and quasi-isothermally compress working fluid mixed in the cold HTL, such that the compressed working fluid flows through the

- 69 -

at least one first heat exchanger to increase its temperature and then to be mixed with hot HTL in the one or more nozzles of the turbine to undergo isothermal or quasi-isothermal expansion that accelerates the HTL/WF mixture to produce kinetic energy convertible to electric energy, the working fluid discharged from the at least one turbine being directed
5 towards the at least one first heat exchanger to be cooled for another cycle.

50. A system for storing and retrieving energy in respective charging and discharging modes, comprising:

at least one two-phase turbine and at least one two-phase compressor;

at least one hot HTL reservoir containing hot HTL and at least one cold HTL
10 reservoir containing cold HTL, each selectively connectable to the at least one compressor/condenser or the at least one turbine;

at least one intermediary exchanger is disposed in a flow path between the at least one compressor and the at least one turbine;

wherein in the charging mode, the at least one compressor/condenser is made to
15 be fluidically connected to the at least one hot HTL reservoir to receive hot HTL therefrom and quasi-isothermally compress and condense a working fluid in a liquid/vapor phase changing working fluid (LVPhC) mixed with the hot HTL, such that the condensed LVPhC flows through the at least one first heat exchanger to reduce its temperature and then to be mixed with cold HTL in one or more nozzles of the turbine to
20 vaporize and undergo isothermal or quasi-isothermal expansion that accelerates the HTL and vaporized LVPhC mixture to produce kinetic energy convertible to electric energy, the vaporized LVPhC discharged from the turbine being directed towards the at least first heat exchanger to be heated for another cycle;

wherein in the discharging mode, the at least one compressor is configured to
25 receive cold HTL from the cold HTL reservoir and quasi-isothermally condense and compress LVPhC mixed in the cold HTL, such that the condensed LVPhC flows through the at least one first heat exchanger to increase its temperature and then to be mixed with hot HTL in the one or more nozzles of the turbine to vaporize and undergo isothermal or quasi-isothermal expansion that accelerates the HTL and LVPhC mixture to produce
30 kinetic energy convertible to electric energy, the LVPhC discharged from the at least one turbine being directed towards the at least one first heat exchanger to be cooled for another cycle.

- 70 -

51. A system for converting electric energy into heat and for retrieving stored heat into electric energy, comprising
- a system according to any one of claims 1-50,
 - at least one electric generator rotationally coupled to the at least one turbine for
- 5 generation of electricity in the discharging operational mode, and
- at least one electric motor rotationally coupled to the at least one compressor for operating the compressor to heat charge the at least one hot reservoir.

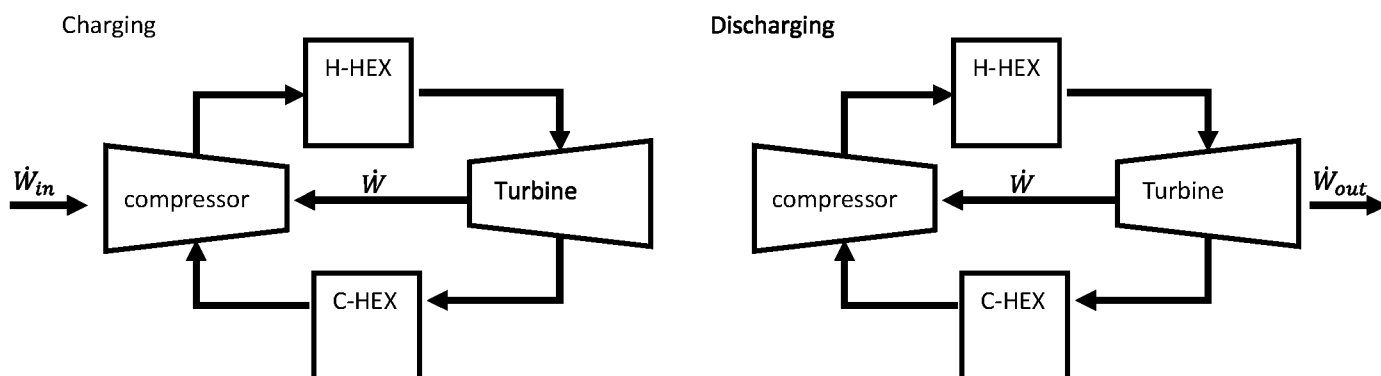


Fig. 1

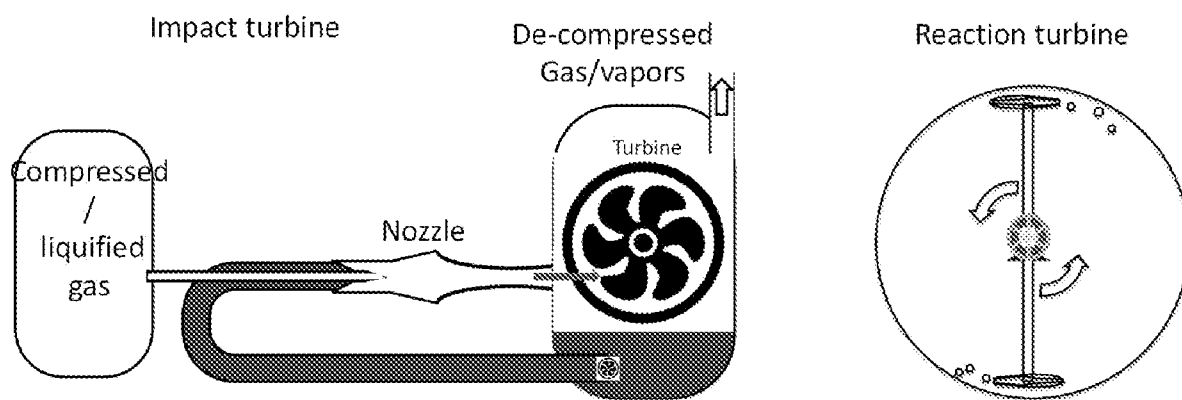


Fig. 2

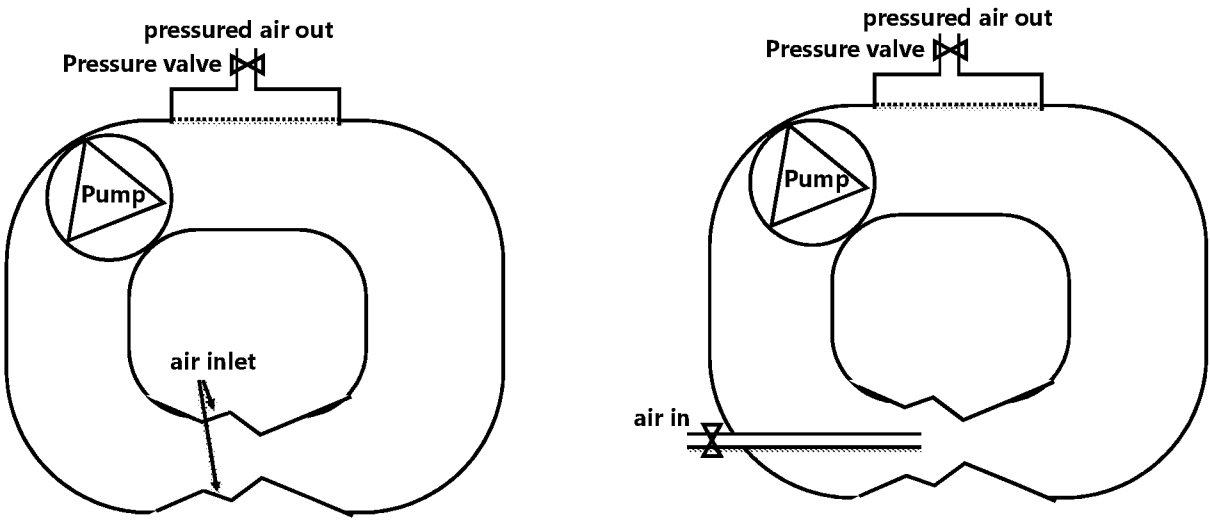


Fig. 3

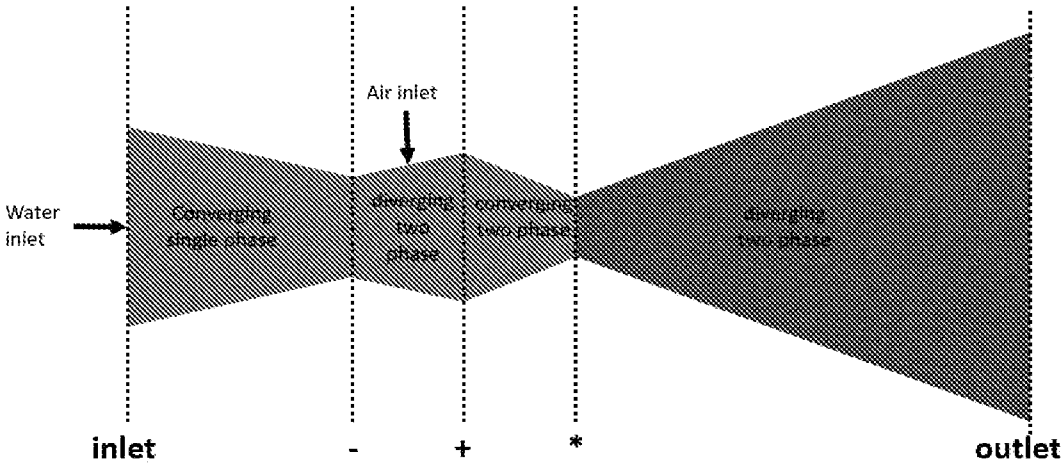


Fig. 4

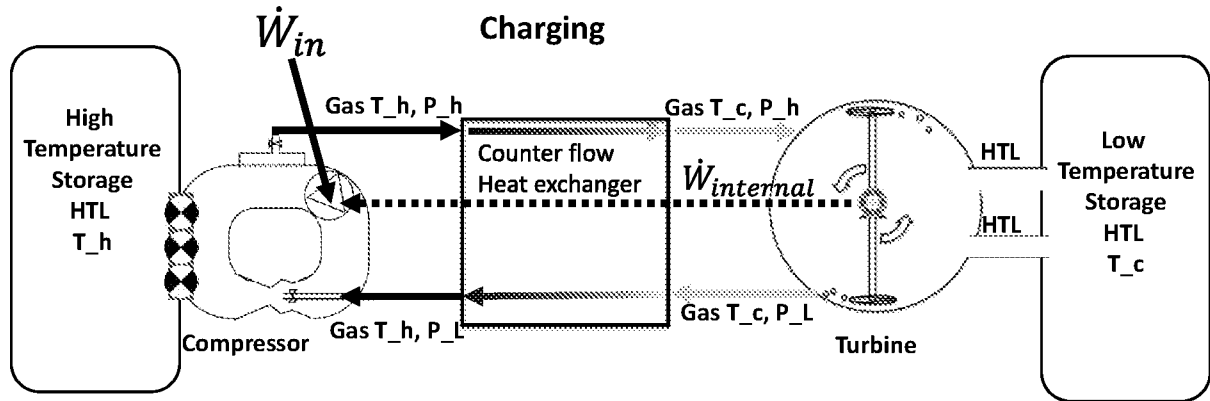


Fig. 5A

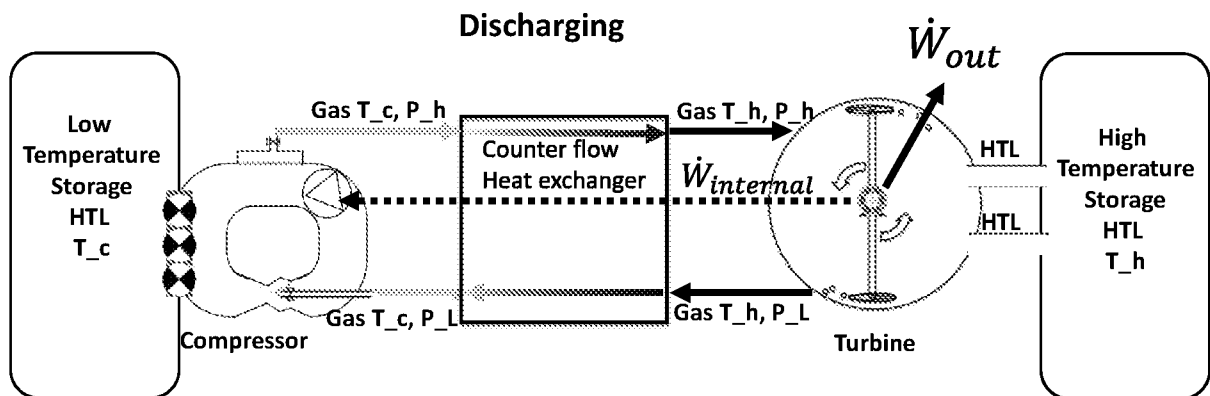


Fig. 5B

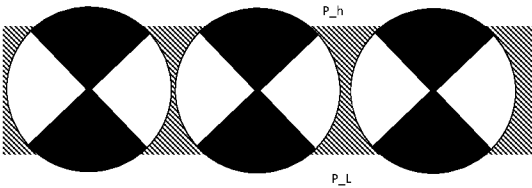


Fig. 6

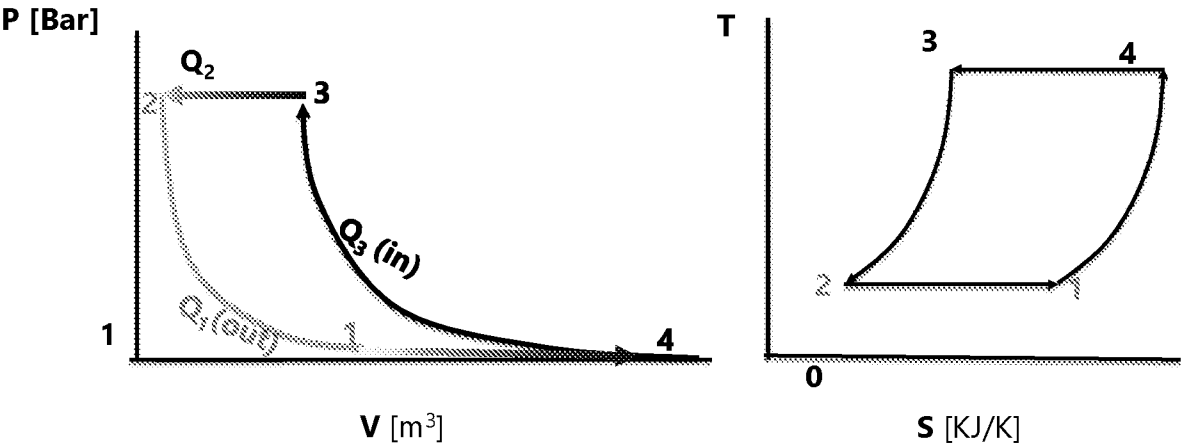


Fig. 7A

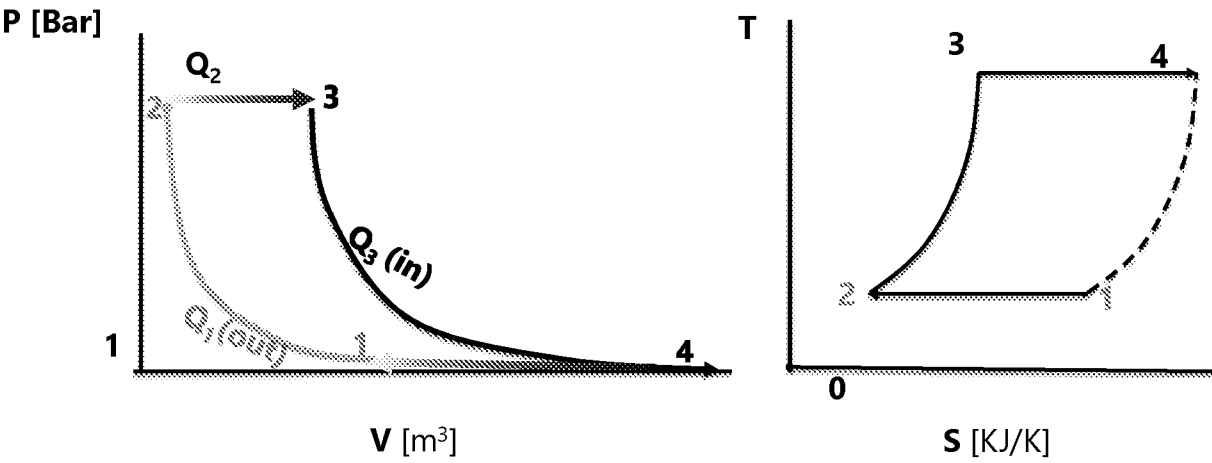


Fig. 7B

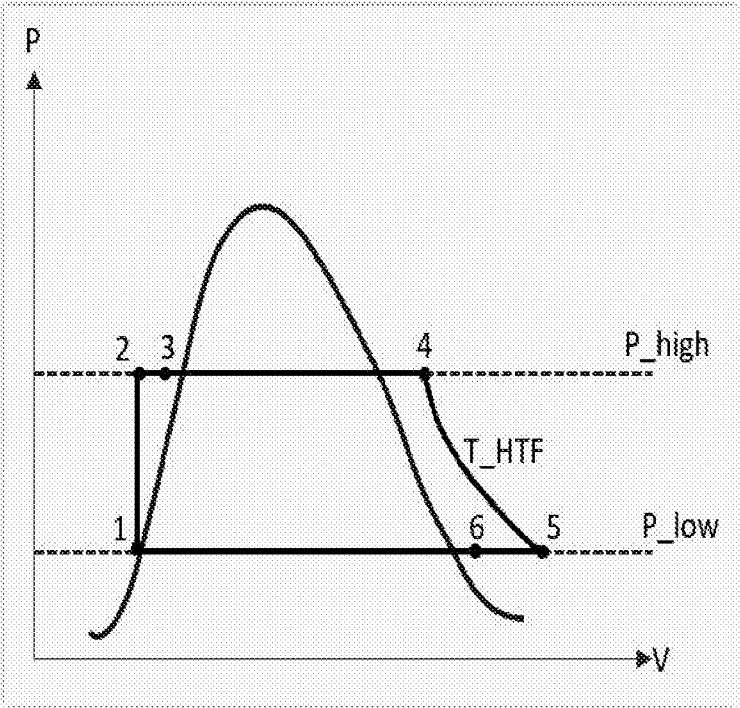


Fig. 8

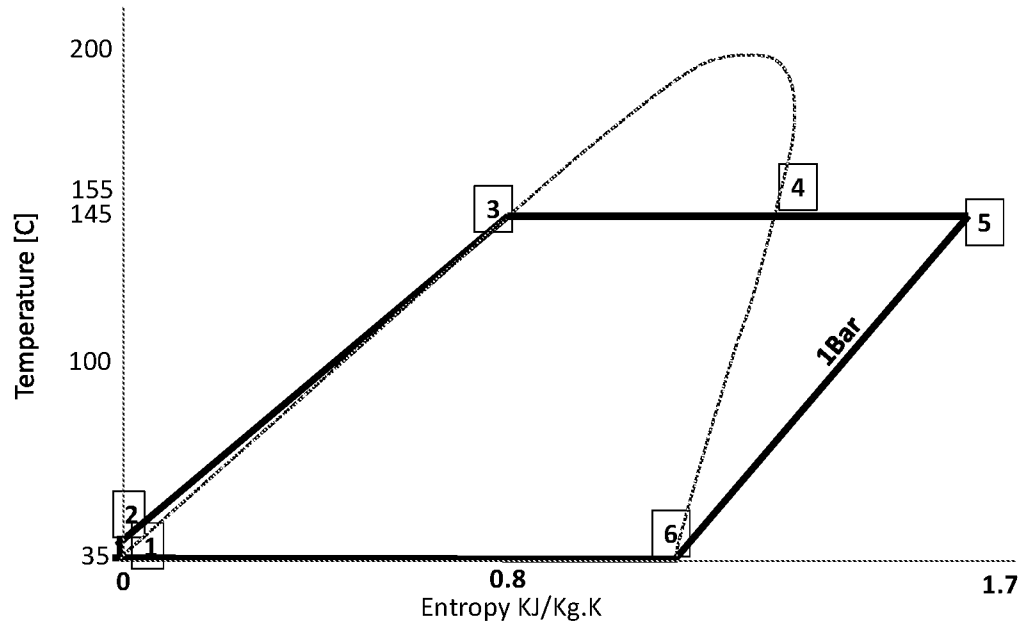


Fig. 9

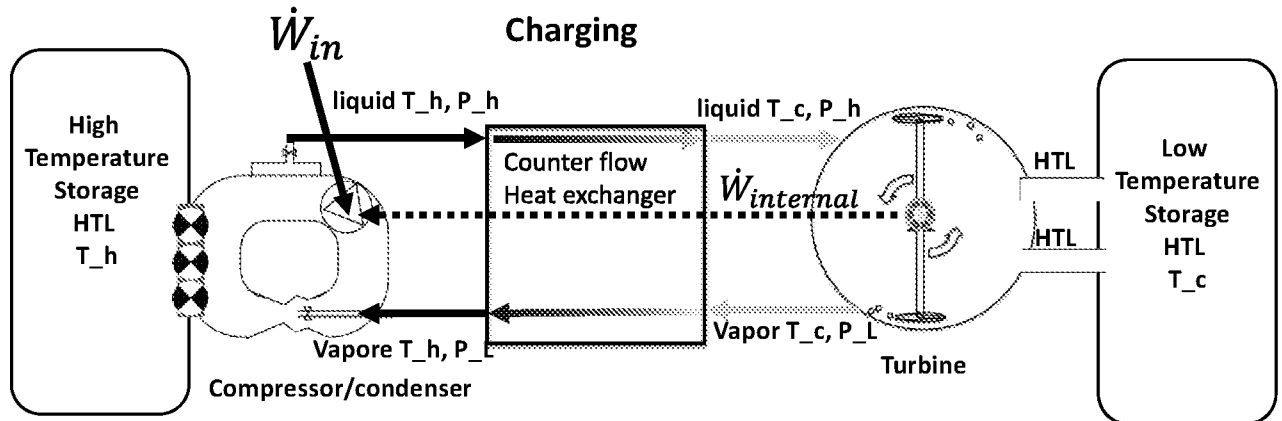


Fig. 10A

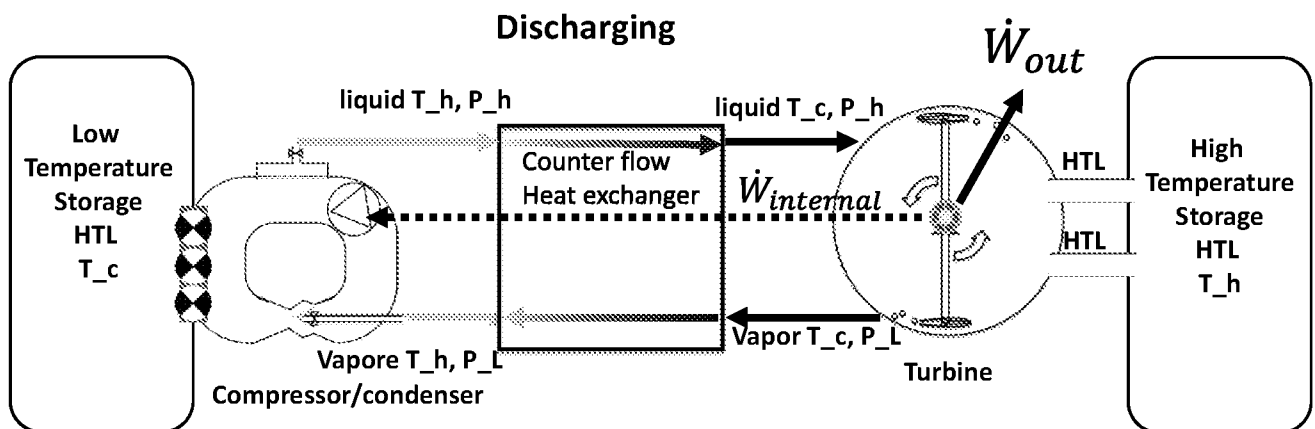


Fig. 10B

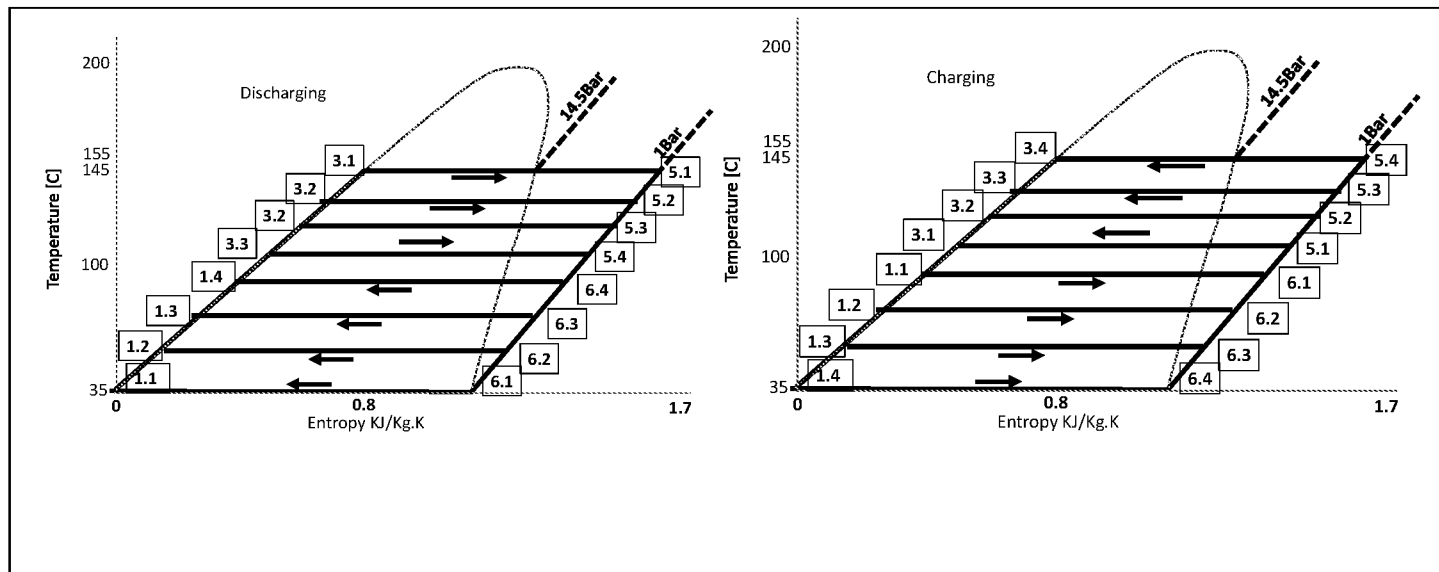


Fig. 11

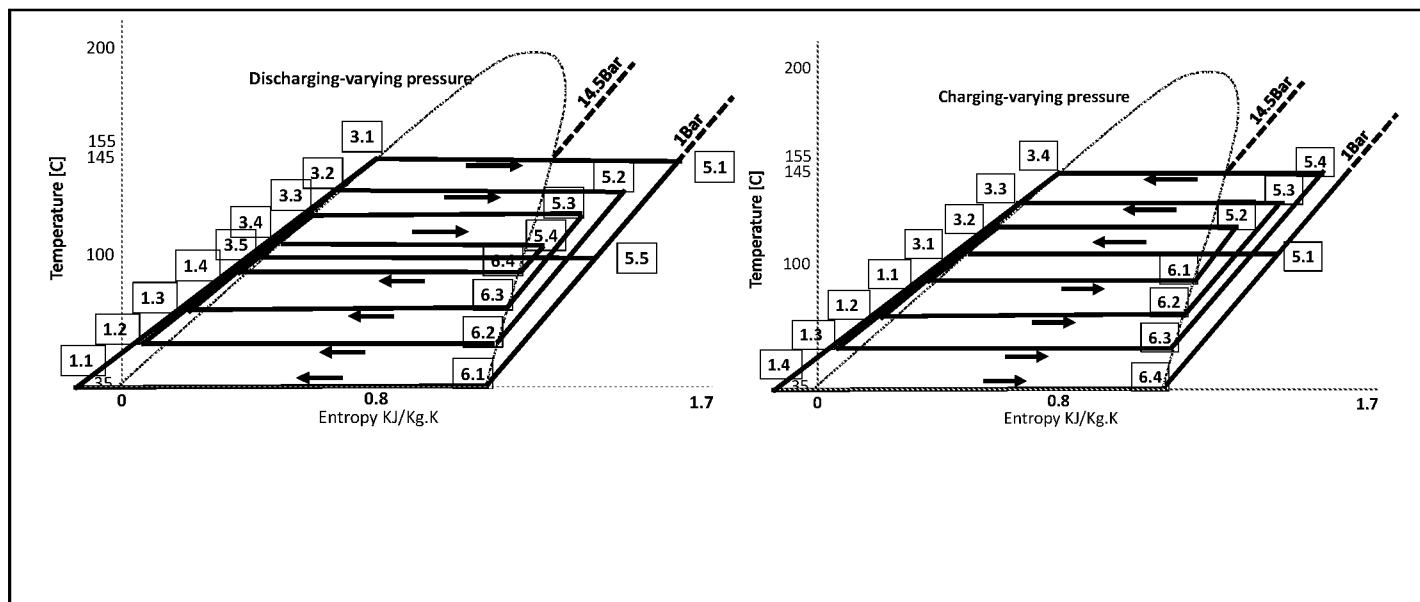


Fig. 12

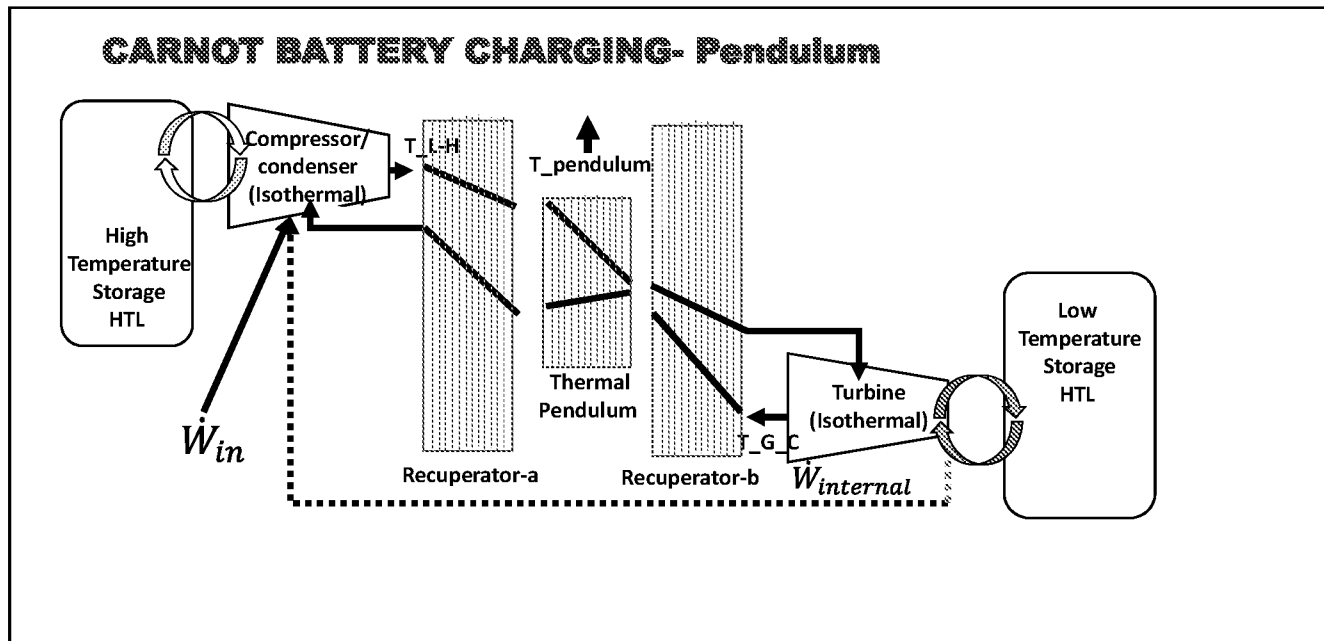


Fig. 13A

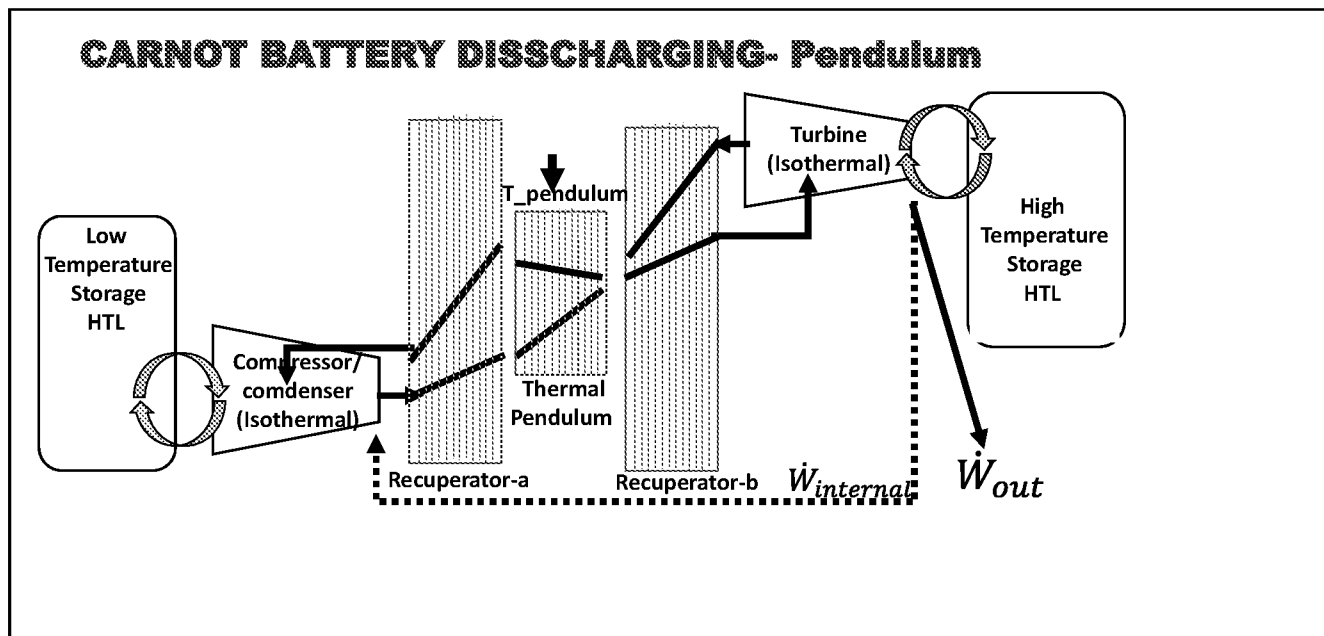


Fig. 13B

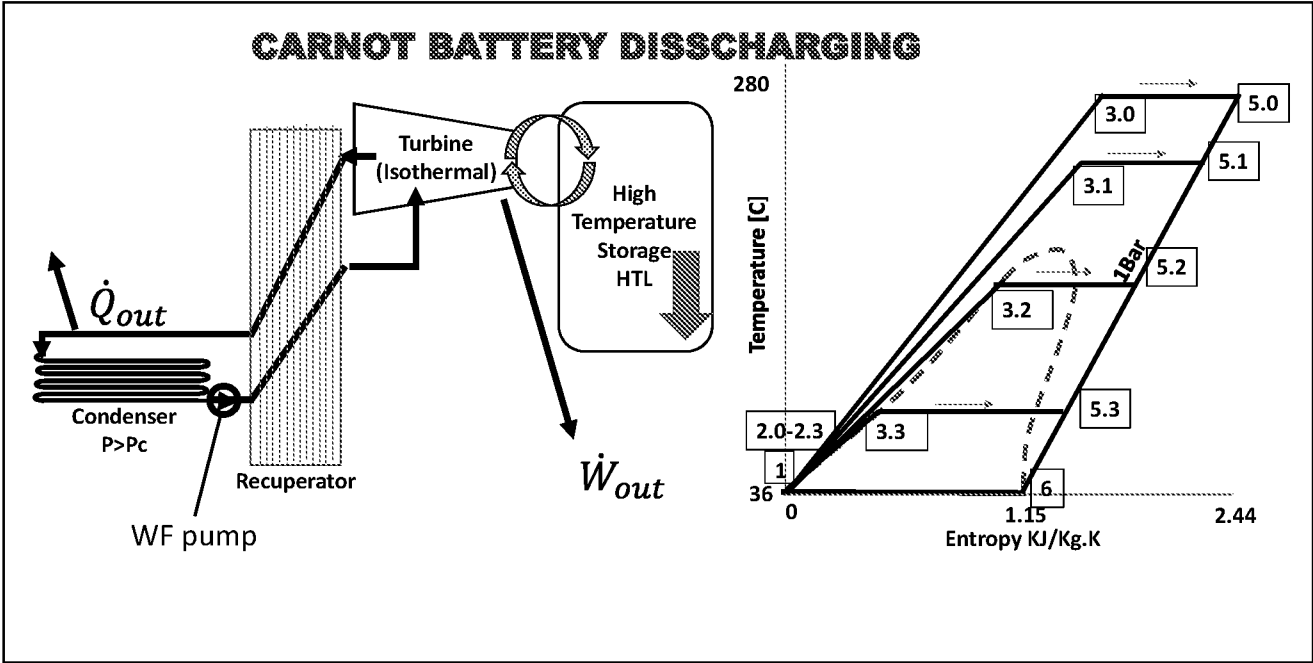


Fig. 14A

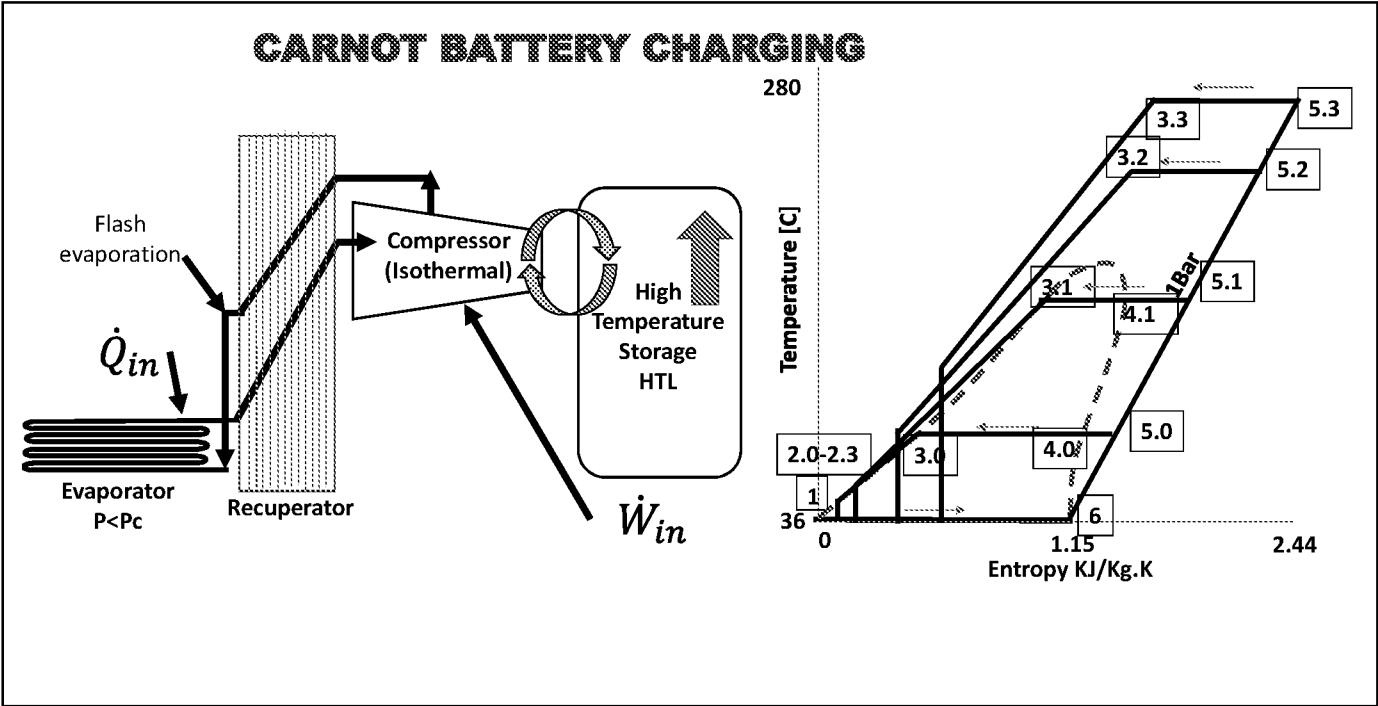


Fig. 14B

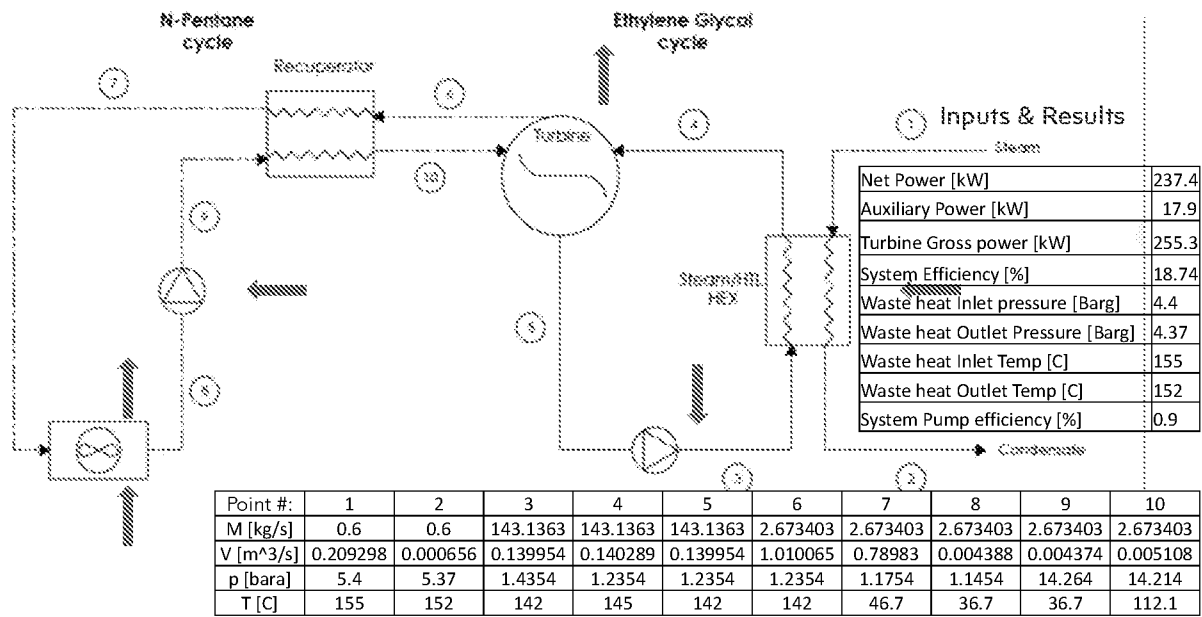


Fig. 15A

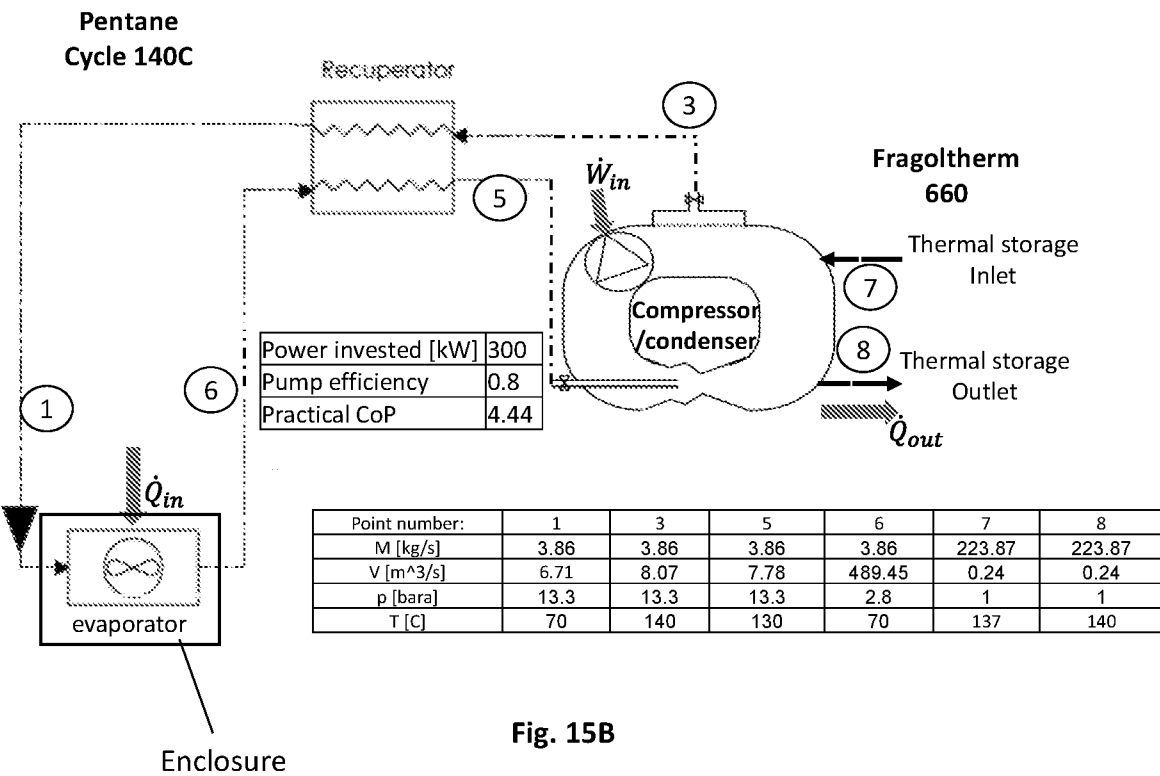


Fig. 15B

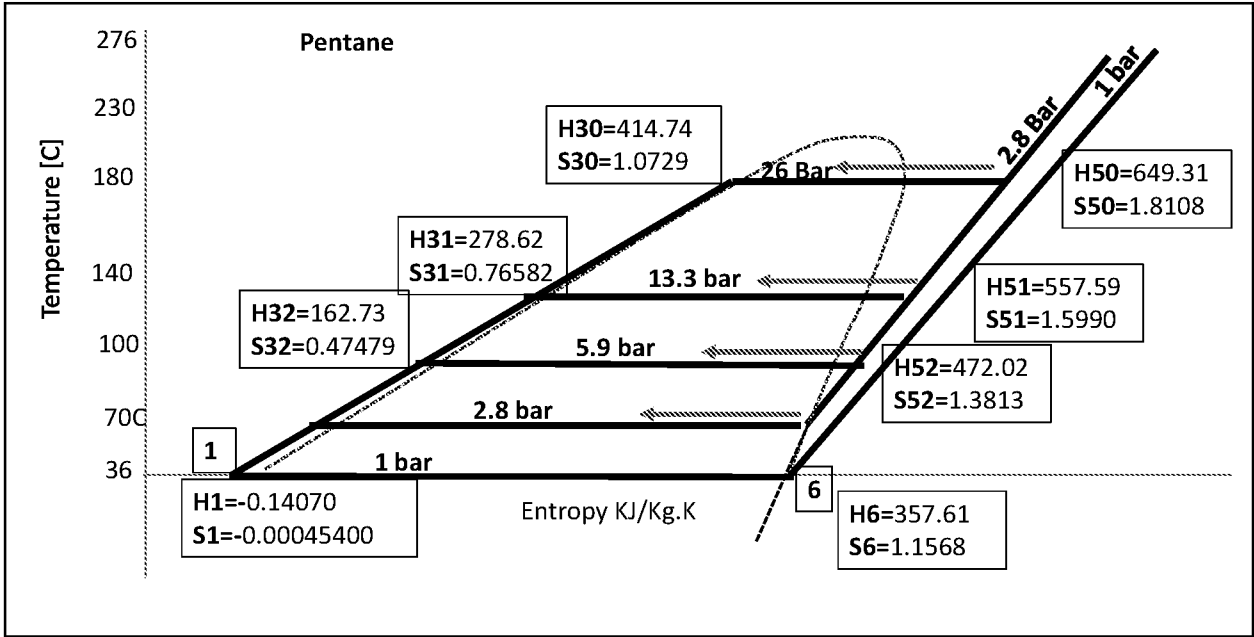


Fig. 16

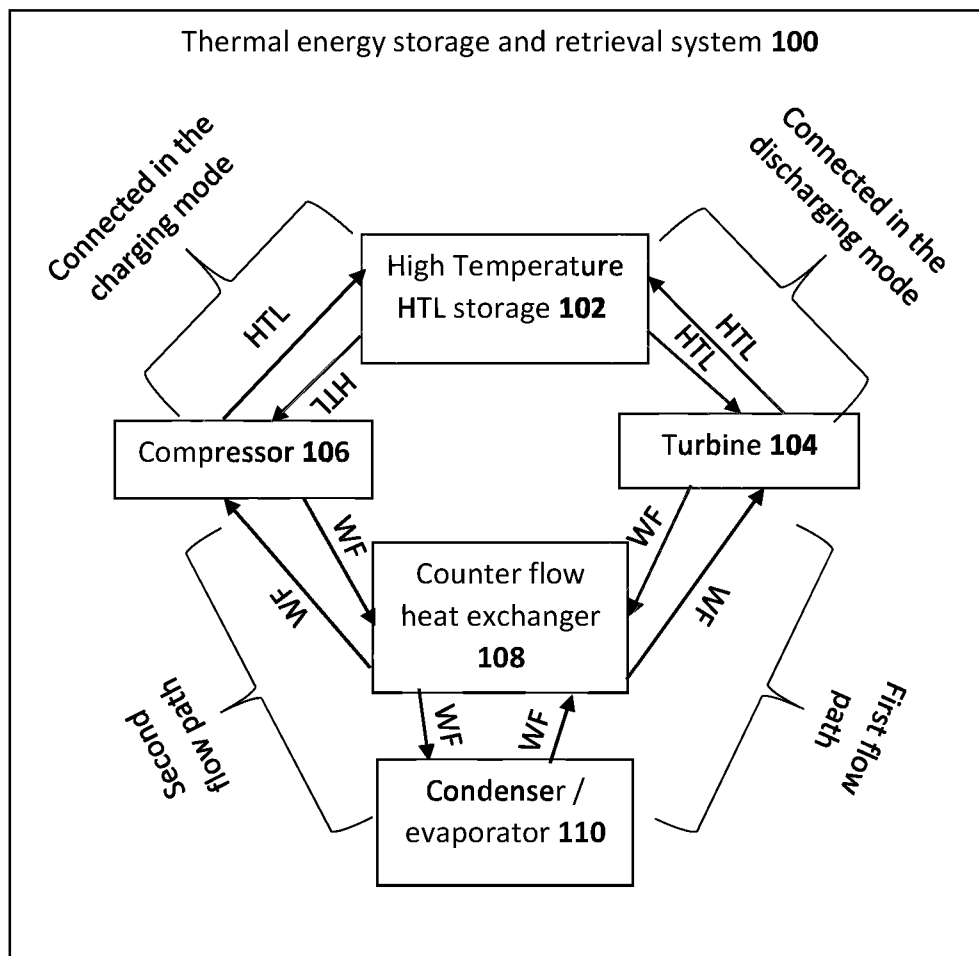


Fig. 17A

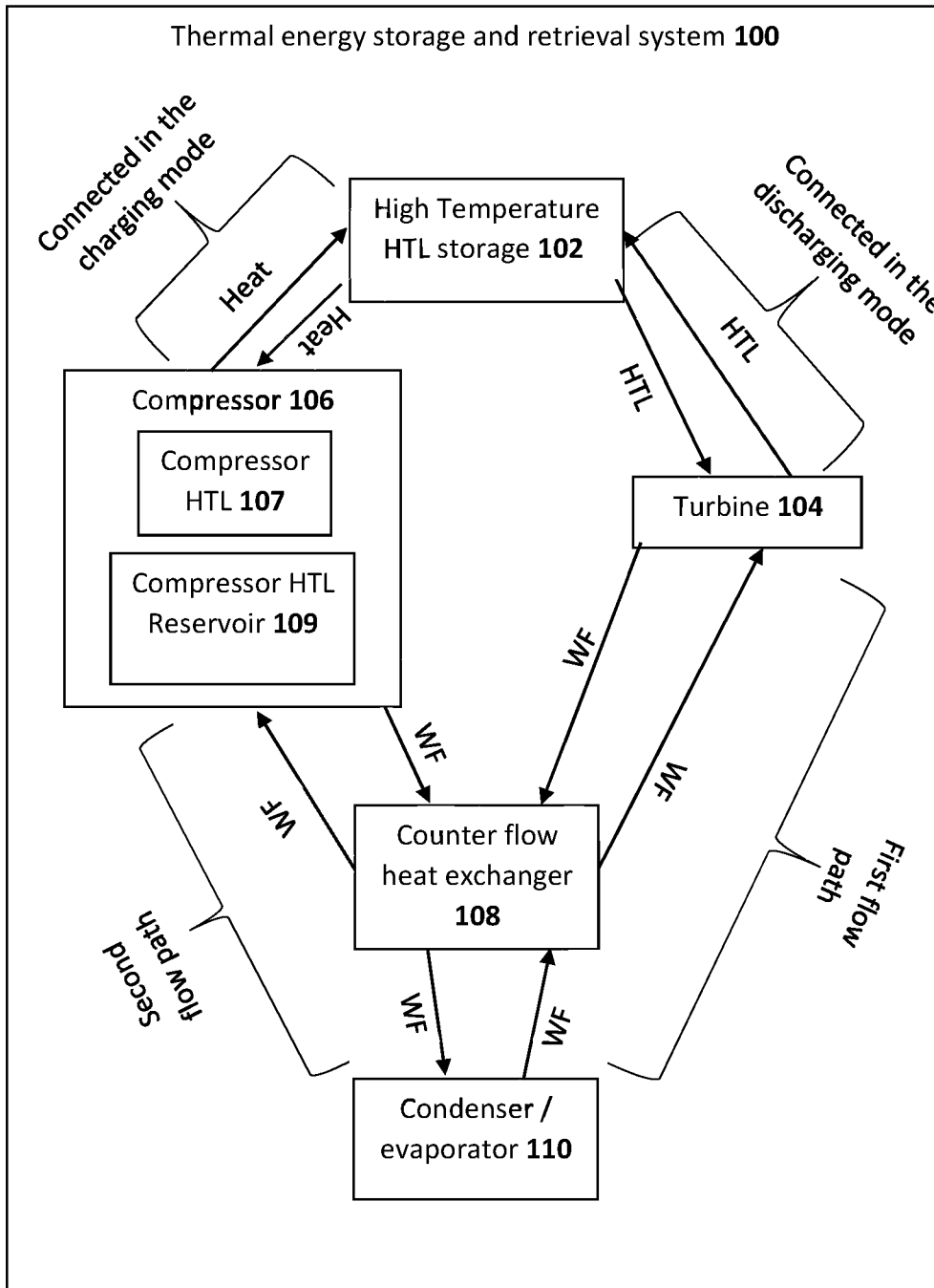


Fig. 17B

INTERNATIONAL SEARCH REPORT

International application No
PCT/IL2023/051160**A. CLASSIFICATION OF SUBJECT MATTER****INV. F01K21/02 F01K25/06**
ADD.

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)

F01K

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

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

EPO-Internal, WPI Data**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/276447 A1 (CHAIX JEAN-EDMOND [FR]) 24 October 2013 (2013-10-24)	1, 4-7, 10, 12-14, 20-23, 25-33, 42-44, 46, 47, 49-51
A	paragraph [0080] - paragraph [0106]; figure 1	2, 3, 8, 9, 11, 15-19, 24, 34-41, 45, 48
A	WO 2015/128049 A1 (BW ENERGIESYSTEME GMBH [DE]) 3 September 2015 (2015-09-03) the whole document	1-51
	----- -/--	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" 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)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" 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

"X" 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

"Y" 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

8 March 2024

Date of mailing of the international search report

20/03/2024

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Röberg, Andreas

INTERNATIONAL SEARCH REPORT

International application No

PCT/IL2023/051160

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 3 492 714 A1 (KOBE STEEL LTD [JP]) 5 June 2019 (2019-06-05) the whole document -----	1-51
A	US 3 972 195 A (HAYS LANCE G ET AL) 3 August 1976 (1976-08-03) the whole document -----	1-51
A	US 2016/298498 A1 (KREUGER STEN [TH]) 13 October 2016 (2016-10-13) the whole document -----	1-51
A	WO 2021/151109 A1 (BENSON MARK CHRISTOPHER [GB]) 29 July 2021 (2021-07-29) the whole document -----	1-51

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IL2023/051160

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013276447 A1	24-10-2013	AU 2011351017 A1 BR 112013016846 A2 CA 2822931 A1 EP 2659098 A2 EP 2952703 A1 JP 6009458 B2 JP 2014501880 A KR 20140089306 A US 2013276447 A1 WO 2012089940 A2	15-08-2013 27-09-2016 05-07-2012 06-11-2013 09-12-2015 19-10-2016 23-01-2014 14-07-2014 24-10-2013 05-07-2012
WO 2015128049 A1	03-09-2015	CN 106062318 A DE 102014002678 A1 EP 3111058 A1 ES 2823808 T3 WO 2015128049 A1	26-10-2016 03-09-2015 04-01-2017 10-05-2021 03-09-2015
EP 3492714 A1	05-06-2019	CN 109869207 A EP 3492714 A1 JP 6763848 B2 JP 2019100263 A KR 20190065940 A	11-06-2019 05-06-2019 30-09-2020 24-06-2019 12-06-2019
US 3972195 A	03-08-1976	NONE	
US 2016298498 A1	13-10-2016	NONE	
WO 2021151109 A1	29-07-2021	NONE	