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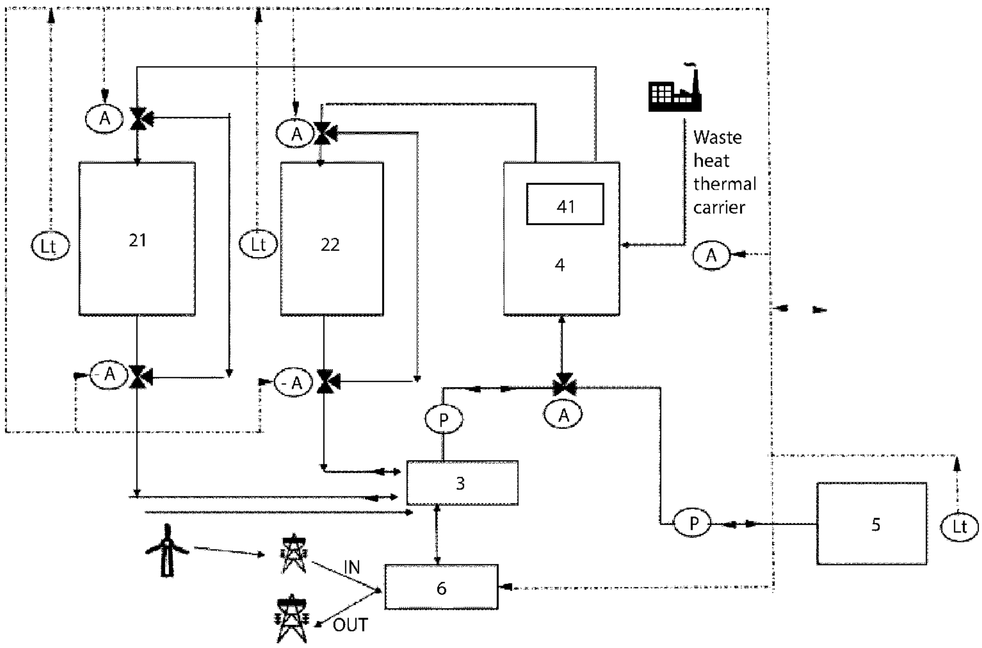

Fig. 1

(57) Abstract: A process of recovering energy from a low enthalpy fluid stream is disclosed. The process comprises a step of exchanging heat between the low enthalpy fluid stream and a regenerative section (4) of a closed loop salinity gradient energy system (1), the closed loop salinity gradient energy system (1) comprising a low concentration saline solution and a high concentration saline solution that feed a salinity gradient energy system (3) configured to produce energy from the difference in salinity concentration between the concentrations of the two saline solutions, an exhausted saline solution being also obtained from the salinity gradient energy system (3), the regenerative section (4) being adapted to separate part of the solvent of the exhausted saline solution and increase salinity of the exhausted saline solution, in order to restore the low concentration saline solution and the high concentration saline solution to be recirculated to the salinity gradient energy system (3). In addition, a system of recovering energy from a low enthalpy fluid stream

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Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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is disclosed.

LOW ENTHALPY RECOVERY

Description

TECHNICAL FIELD

[0001] The present disclosure concerns a process of recovering energy from a low enthalpy fluid stream in a closed loop salinity gradient energy system. Embodiments disclosed herein specifically concern a system capable to convert low enthalpy waste sources into electricity by the closed loop salinity gradient energy system, which is based on differences in salinity between two solutions.

BACKGROUND ART

[0002] All industrial processes use energy and generate waste heat. In particular, large amounts of low-grade thermal energy (temperatures <200°C) are available at many industrial sites. In addition, low-grade thermal energy can also be produced from geothermal and solar-based processes. Generally, the low-grade thermal energy needs additional energy to lower the temperature down to the limits admitted to be dissipated in the environment, such as through cooling fans or cooling water pumps.

[0003] In the past years, solid-state devices based on semiconductor materials have been extensively studied for direct thermal-electric energy conversion, but are expensive and lack the capacity for energy storage.

[0004] Liquid-based thermo-electrochemical systems (TESs) and systems based on salinity gradient energy (SGE) offer potentially less expensive and scalable routes for direct thermal-electric energy conversion that also have the capacity for desirable energy storage. However, these TES and SGE processes have low power densities and energy efficiencies.

[0005] Other solutions available today for waste heat recovery rely on organic Rankine cycle thermodynamic units or thermoelectric technologies that are impractical due to cost and complexity for temperatures between 80-100°C.

[0006] Accordingly, an improved system and process for the recovery of energy from a low enthalpy fluid stream to address the issues of producing low power densities and energy efficiencies of the systems of the current art would be beneficial and would be welcomed in the technology. More in general, it would be desirable to provide methods and systems adapted to more efficiently produce energy for temperature between 80-100°C.

SUMMARY

[0007] In one aspect, the subject matter disclosed herein is directed to a process of recovering energy from a low enthalpy fluid stream, in particular a low temperature fluid stream, by exchanging heat between the low enthalpy fluid stream and a regenerative section of a closed loop salinity gradient energy system. In particular, the closed loop salinity gradient energy system comprises a low concentration saline solution and a high concentration saline solution that feed a salinity gradient energy system configured to produce energy from the difference in salinity concentration between the concentrations of the two saline solutions, together with an exhausted saline solution. The regenerative section increases the salinity of the exhausted saline solution by separating part of the solvent of the exhausted saline solution and, in order to obtain a low concentration saline solution and a high concentration saline solution to be recirculated to the salinity gradient energy system.

[0008] In one aspect, the subject matter disclosed herein concerns a process of recovering energy from a low enthalpy fluid stream by exchanging heat between the low enthalpy fluid stream and a regenerative section of a closed loop salinity gradient energy system wherein energy to the regenerative section of the closed loop salinity gradient energy system is auxiliarily provided by using electric energy from, by way of example and without limitation, an electric grid, an energy storage device, renewable energy sources.

[0009] In another aspect, the subject matter disclosed herein concerns a system of recovering energy from a low enthalpy fluid stream, the system comprising a closed loop salinity gradient energy system comprising two circuits connecting a salinity gradient energy system and a regenerative section, a low concentration saline solution and a high concentrations saline solution each one of the solution flowing in a circuit of the two circuits to feed the salinity gradient energy system to produce energy from the difference in salinity concentration between the concentration of the two saline solutions, together with an exhausted saline solution, the regenerative section separating part of the solvent of the exhausted saline solution and increasing the salinity of the exhausted saline solution, in order to obtain a low concentration saline solution and a high concentration saline solution to be recirculated to the salinity gradient energy system, wherein the system comprises at least one heat exchanger configured to exchange heat between the exhaust saline solution and the low enthalpy fluid stream.

[0010] In another aspect, the subject matter disclosed herein concerns a system of recovering energy from a low enthalpy fluid stream, wherein the low enthalpy fluid stream is, for example, an outlet steam stream from a geothermal power production system and/or a low temperature exhaust gas stream from a thermodynamic power production system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] A more complete appreciation of the disclosed embodiments of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

Fig.1 illustrates a schematic of a system including a closed loop salinity gradient energy system according to a first embodiment; and

Fig.2 illustrates a schematic of a system including a reverse electrodialysis system (RED), according to a second embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

[0012] According to one aspect, the present subject matter is directed to a process of recovering energy from a low enthalpy fluid stream in a closed loop salinity gradient energy system. Specifically, in several embodiments disclosed herein a system is provided that comprises two circuits, with two salt solutions, having the same solvent and salt but with a different salinity concentration and a salinity gradient system adapted to produce energy and a salt solution with a salinity gradient between the values of the two lower than the input. In addition, the system comprises a regenerative section adapted to restore the salinity gradient through the use of the low enthalpy heat as input energy sources.

[0013] Reference now will be made in detail to embodiments of the disclosure, one or more examples of which are illustrated in the drawings. Each example is provided by way of explanation of the disclosure, not limitation of the disclosure. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present disclosure without departing from the scope or spirit of the disclosure. Reference throughout the specification to “one embodiment” or “an embodiment” or “some embodiments” means that the particular feature, structure or characteristic described in connection with an embodiment is included in at least one embodiment of the subject matter disclosed. Thus, the appearance of the phrase “in one embodiment” or “in an embodiment” or “in some embodiments” in various places throughout the specification is not necessarily referring to the same embodiment(s). Further, the particular features, structures or characteristics may be combined in any suitable manner in one or more embodiments.

[0014] When introducing elements of various embodiments the articles “a”, “an”, “the”, and “said” are intended to mean that there are one or more of the elements. The terms “comprising”, “including”, and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0015] Referring now to the drawings, Fig.1 shows a schematic of a system including a closed loop salinity gradient energy system 1. The closed loop salinity gradient energy system 1 can be comprised of two closed circuits, wherein two solutions with a different salinity concentration are adapted to circulate.

[0016] In particular, the closed loop salinity gradient energy system 1 comprises a low concentration solution tank 21 and a high concentration solution tank 22. These two solutions feed a salinity gradient energy system 3. As used herein, the term “salinity gradient energy system” is expressly defined to include any machine or system able to create energy from the difference in salinity concentration between two fluids or solutions. The output of the salinity gradient energy system is a solution with a salinity gradient lower than the input solutions, said solution can be stored in a tank 5. In addition, the closed loop salinity gradient energy system 1 comprises a regenerative section 4 adapted to use a low enthalpy heat as input energy sources. As used herein, the term “regenerative section” is expressly defined to include any machine or system able to produce a regeneration process, that is a thermal method which consists in an endergonic phase transition (e.g. evaporation, crystallization), to separate the solvent of the exhausted solution from the salinity gradient energy system 3 and concentrate the solution for future uses. Furthermore, the regenerative section 4 comprises a heat exchanger 41 configured to exchange heat between the solution flowing in said regenerative section 4 in a cold side of the heat exchanger 41 and the low enthalpy fluid stream flowing in a hot side of the heat exchanger 41.

[0017] In some embodiment the salinity gradient energy system 3 can be an electrochemical device (ECD), a pressure retarded osmosis system (PRO), an accumulator mixing device-capacity mixing device or an accumulator mixing device-battery mixing device.

[0018] In particular, electrochemical device comprises reverse electrodialysis system (RED) or thermally regenerable battery system (TRB). In electrochemical device, in order to increase the efficiency of converting heat to electricity, it is important to choose a salt that raises the boiling point significantly and a solvent with a high latent heat of vaporization. This raises the mixing free energy, which the electrochemical cell uses to generate electricity. Water is often the preferred solvent due to its high latent heat of vaporization. Halides (like Li, Na, Zn) and hydroxides (like Na, K) are good options for soluble salts since they can substantially increase the boiling point, typically by 20-50°C when saturated. A High Concentrated Salt Solution (CSS) can use NaI at 15-17.5% molar fraction, NaCl at 5-8.6% molar fraction, or LiBr at 20-26% molar fraction. Conversely, a Low Concentrated Salt Solution (CSS) can involve NaI at 1.5-2.5% molar fraction, NaCl at 1.5-2.5% molar fraction, or LiBr at 1.5-2.5% molar fraction.

[0019] In particular, in the reverse electrodialysis (RED) the salinity gradient is maintained across the membranes leading to a voltage difference across each membrane that is the driving force behind the migrations of ions from concentrated to dilute solution. Instead, in the thermally regenerable battery (TRB) the faradic reactions on the electrodes lead to diffusion of ions from the concentrated solution to the dilute solution. In ideal solution, the electricity produced by the ECD is equal to the Gibbs free energy of mixing. This energy shall be compared to the specific energy consumption of the regenerative section 4 to calculate the system efficiency.

[0020] In electrochemical device (ECD), between anode and cathode, a voltage is generated as a result of the Donnan potential, with consequent power production. Hence, the ions passage through the membranes will decrease the salinity gradient between the two solutions, so that the salinity gradient at the ECD output is lower than the input.

[0021] Specifically, the electrode in the salinity gradient energy system 3 can be made of carbon fabric (with carbon nanoparticles) with other specific metals added.

[0022] In the accumulator mixing device-capacity mixing device capacitors are charged in a concentrated solution and discharged in a dilute solution so that due to the higher energy released during discharge than the given energy needs for the charge, the system produce power. In addition, in the accumulator mixing device-battery mixing device electrodes are charged in a concentrated solution and discharged in a dilute solution so that faradic reactions during discharge release more energy that required in the charging phase.

[0023] In pressure retarded osmosis system (PRO) it is exploit the osmotic pressure difference developed by a semipermeable membrane to drive the permeation of the solvent from the low-pressure dilute solution to the high-pressure concentrate solution; this results in pressurization of the volume of the solvent which can be used to generate electrical power through a turbine.

[0024] In some embodiment, the regenerative section 4 can be an adsorption desalination system designed to restore the salinity gradient by partially evaporating the water that is adsorbed by the silica gel in the adsorbent beds. For desorption, the silica gel must be heated by releasing water vapor that is condensed producing the distillate stream that dilutes the low-salinity solution. Different adsorption materials and combinations of salts can be used.

[0025] Still, the regenerative section 4 can be a system capable of the Multistage Flash Distillation (MSF) process, which consists of a series of “stages” in which condensed steam is used to preheat the feed solution. The MSF is able to approach the ideal total latent heat recovery by fractionating the overall temperature difference between the hot source and solution into a large number of stages. Each stage operates at a progressively lower pressure to maximize water recovery. In this way, the boiling point can always be reached without supplying additional heat to the outgoing brine.

[0026] In addition, the closed loop salinity gradient energy system 1 comprises at least one energy storage device for storing the energy produced; the energy storage device can be low-cost and without degradation rate.

[0027] Still, the closed loop salinity gradient energy system 1 comprises a digital controller 6 capable of managing the flow from the energy storage device or the salinity gradient energy system 3 according to the operational needs of the plant and financial parameters. In particular, the priority is the control of the electricity demand profile, the plant emissions limits and the OPEX reduction. While the financials parameters to control are the electricity cost, the electricity price and the emissions taxes. Furthermore, the digital controller 6 can be connected to level tank transmitters Lt and actuators A. In addition, the system can be connected to solar or wind power sources. The digital controller 6 can be a computer or programmable logic controller (PLC).

[0028] Referring to Fig. 2, both the salinity gradient energy system 3 and the regenerative section 4 are embodied by a reverse electrodialysis system (RED), which is particularly convenient in case of low-cost electricity (night/weekend) or renewable surplus. In this case, the waste heat can be reintroduced, totally or partially, into the reverse electrodialysis system to increase efficiency and thus power.

[0029] In some embodiment, both the salinity gradient energy system 3 and the regenerative section 4 are embodied by a thermally regenerable battery system (TRB). This is particularly convenient in case of low-cost electricity (night/weekend) or renewable surplus. In this case, the waste heat can be reintroduced, totally or partially, into the thermally regenerable battery system (TRB) to increase efficiency and thus power.

[0030] While the aspects of the invention have been described in terms of various specific embodiments, it will be apparent to those of ordinary skill in the art that many modifications, changes, and omissions are possible without departing form the spirt and scope of the claims. In addition, unless specified otherwise herein, the order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments.

Low Enthalpy Recovery

CLAIMS

1. A process of recovering energy from a low enthalpy fluid stream, in particular a low temperature fluid stream, the process comprising a step of exchanging heat between the low enthalpy fluid stream and a regenerative section (4) of a closed loop salinity gradient energy system (1), the closed loop salinity gradient energy system (1) comprising a low concentration saline solution and a high concentration saline solution that feed a salinity gradient energy system (3) configured to produce energy from the difference in salinity concentration between the concentrations of the two saline solutions, an exhausted saline solution being also obtained from the salinity gradient energy system (3), the regenerative section (4) being adapted to separate part of the solvent of the exhausted saline solution and increase salinity of the exhausted saline solution, in order to restore the low concentration saline solution and the high concentration saline solution to be recirculated to the salinity gradient energy system (3).

2. The process of claim 1, wherein the low enthalpy fluid stream is an outlet stream from a power production system.

3. The process of claim 2, wherein the low enthalpy fluid stream is a low temperature exhaust gas stream from a thermodynamic power production system.

4. The process of claim 2, wherein the low enthalpy fluid stream is an outlet steam stream from a geothermal power production system.

5. The process of one or more of the preceding claims, wherein the temperature of the low enthalpy fluid stream is lower than 200°C and higher than 80°C.

6. The process of one or more of claims 1-5, wherein the process also comprises a step of providing a thermally regenerable battery system (TRB) as salinity gradient energy system (3) and/or regenerative section (4).

7. The process of one or more of claims 1-6, wherein the process also comprises a step of providing a reverse electro dialysis system (RED) as salinity gradient energy system (3) and/or regenerative section (4).

8. The process of claim 6 or 7, wherein the process also comprises a step of flowing at least part of the low enthalpy fluid stream to provide heat to the thermally regenerable battery system (TRB) and/or to the reverse electro dialysis system (RED).

9. The process of claim 7 or 8, wherein the process also comprises a step of providing electric energy from an electric grid or produced by an electric grid to the reverse electro dialysis system (RED) and/or the thermally regenerable battery system (TRB).

10. The process of one or more of claims 7- 9, wherein the process also comprises a step of using at least part of the electric energy stored in an energy storage device to provide energy to the reverse electro dialysis system (RED) and/or thermally regenerable battery system (TRB).

11. The process of one or more of the preceding claims, wherein the process also comprises a step of using at least part of the electric energy produced by the salinity gradient energy system (3) to provide energy to an energy storage device.

12. A system of recovering energy from a low enthalpy fluid stream, in particular a low temperature fluid stream, the system comprising a closed loop salinity gradient energy system (1) comprising two circuits connecting a salinity gradient energy system (3) and a regenerative section (4) , a low concentration saline solution and a high concentrations saline solution, each solution flowing in a respective circuit of the two circuits to feed the salinity gradient energy system (3) to produce energy from the difference in salinity concentration between the concentration of the two saline solutions, and to obtain an exhausted saline solution, the regenerative section (4) being adapted to separate part of the solvent of the exhausted saline solution and increase salinity of the exhausted saline solution, in order to restore the low concentration saline solution and the high concentration saline solution to be recirculated to the salinity gradient energy system (3) wherein the system comprises at least one heat exchanger (41) configured to exchange heat between the exhaust saline solution flowing in said regenerative section (4) in a cold side of the heat exchanger (41) and the low enthalpy fluid stream flowing in a hot side of the heat exchanger (41).

13. The system of claim 12, wherein the hot side of the heat exchanger

(41) is connected to a low temperature exhaust gas outlet line of a power production system.

14. The system of claim 13, wherein the power production system is a thermodynamic power production system.

15. The system of claim 13, wherein the power production system is a geothermal power production system.

16. The system of claims 12-15, wherein the regenerative section (4) and/or the salinity gradient energy system (3) comprises a reverse electro dialysis system (RED).

17. The system of claim 16, wherein the system is coupled with an electric grid to provide energy to the reverse electro dialysis system (RED).

18. The system of one or more of claims 16 and 17, wherein the reverse electro dialysis system (RED) is connected to renewable energy power production system.

19. The system of one or more of claims 16 to 18, wherein the system also comprises an energy storage device adapted to provide energy to the reverse electro dialysis system (RED).

20. The system of one or more of claims 12-19, wherein the regenerative section (4) and/or the salinity gradient energy system (3) comprises a thermally regenerable battery system (TRB).

21. The system of one or more of claims 16- 20, wherein the system is coupled with at least part of the low enthalpy fluid stream to provide heat to the thermally regenerable battery system (TRB) and/or to the reverse electro dialysis system (RED).

22. The system of one or more of claims 12 to 21, wherein the system also comprises means for using at least part of the electric energy produced by the salinity gradient energy system to provide energy to an energy storage device.

23. The system of one or more of claims 12 to 22, wherein the regenerative section (4) is chosen from: an adsorption desalination system or a system capable for the multistage flash distillation (MSF) process.

24. The system of one or more of claims 12 to 23, wherein the system also comprises a digital controller (6) adapted to control the salinity gradient energy system (3).

25. The system of one or more of claims 12 to 24, wherein the electrode in the salinity gradient energy system (3) is made of carbon fabric, with carbon nanoparticles.

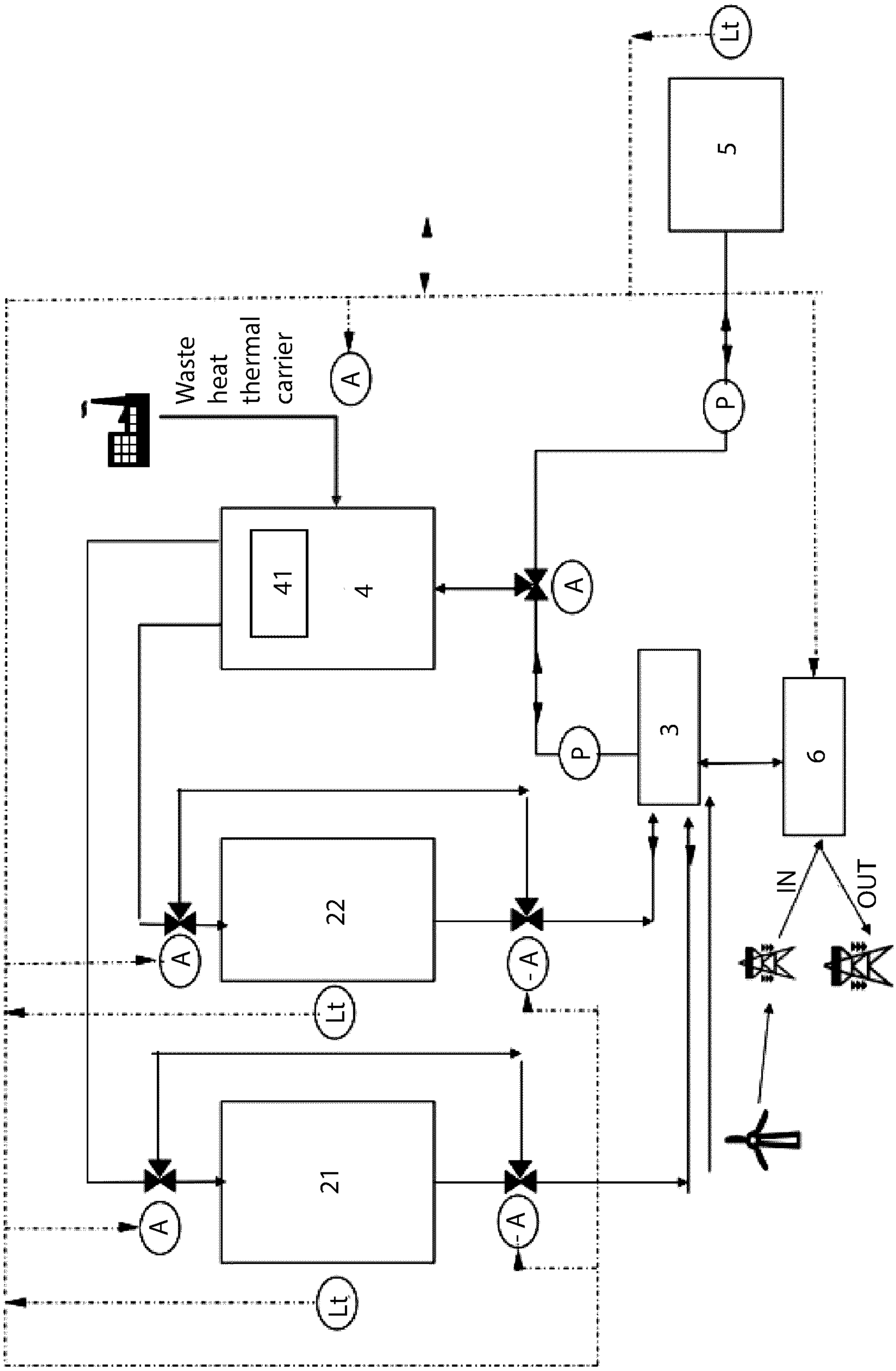
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Fig. 1

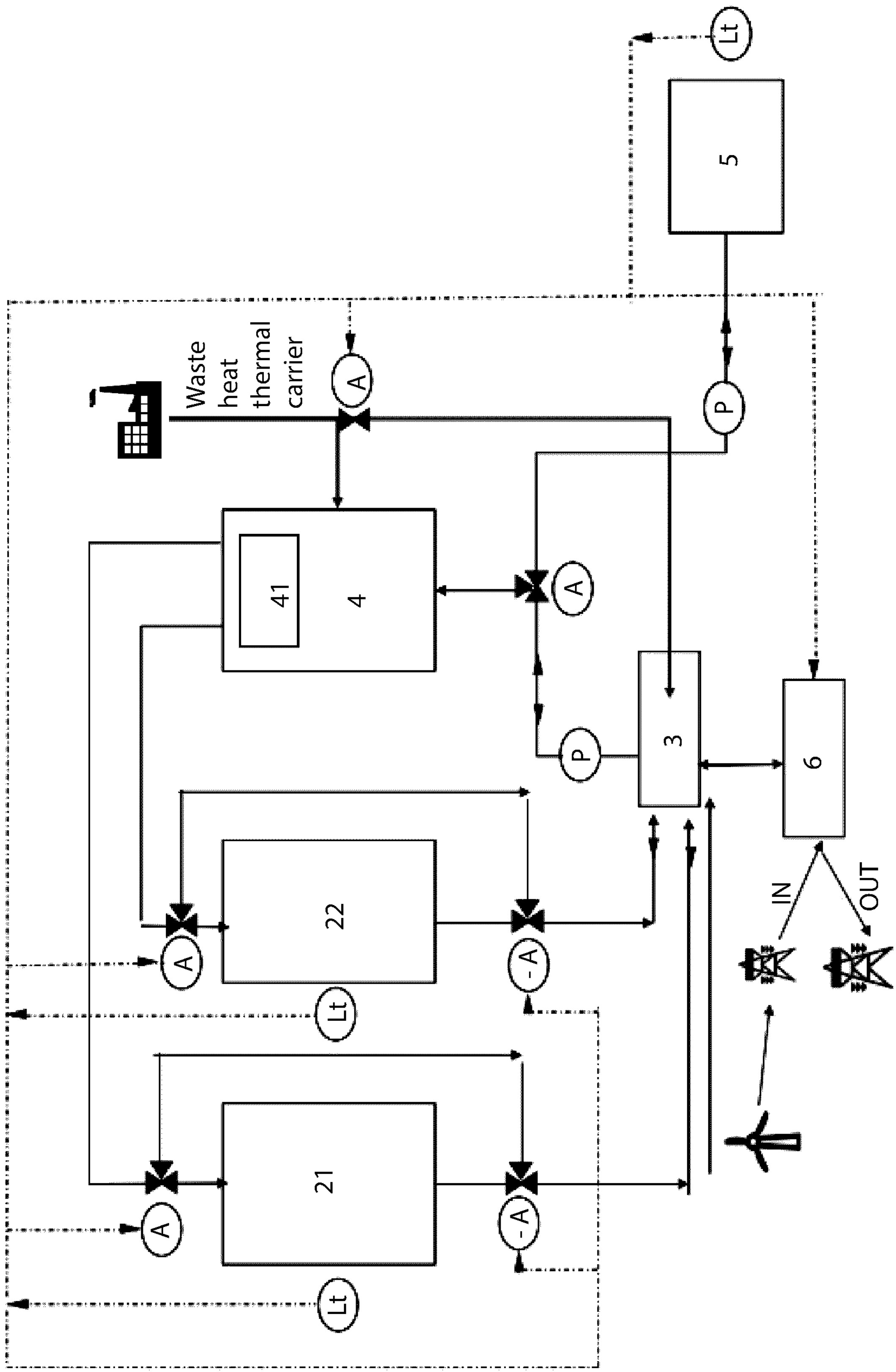
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Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/025327

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03G7/00 B01D61/00
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)
F03G B01D

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2023/219996 A1 (NANA RAHUL S [US]; FERIA RAFAEL A [US]) 16 November 2023 (2023-11-16) paragraph [0102] - paragraph [0106]; figure 8	1-25
X	US 10 690 122 B2 (UNIV KING ABDULLAH SCI & TECH [SA]; UNIV NANYANG TECH [SG]) 23 June 2020 (2020-06-23) column 8, line 31 - column 11, line 7	1-25

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

☒ See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 January 2025	07/02/2025

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/025327

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2023219996 A1	16-11-2023	NONE	
US 10690122 B2	23-06-2020	US 2019003465 A1	03-01-2019
		WO 2017125877 A1	27-07-2017