(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 933 175 A1

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
05.01.2022 Bulletin 2022/01

(51) Int Cl.:
F01K 3/18 *(2006.01)*

(21) Application number: **20183435.5**

(22) Date of filing: **01.07.2020**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(71) Applicant: **Siemens Gamesa Renewable Energy GmbH & Co. KG**
20097 Hamburg (DE)

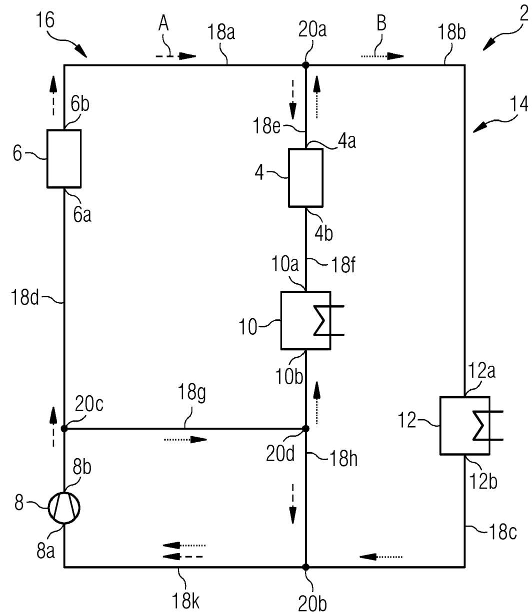
(72) Inventors:
- **Zaczek, Alexander**
  22765 Hamburg (DE)
- **Künzel, Florian**
  20099 Hamburg (DE)

(74) Representative: **Aspacher, Karl-Georg**
Siemens Gamesa Renewable Energy GmbH & Co. KG
Otto-Hahn-Ring 6
81739 München (DE)

(54) ## THERMAL ENERGY STORAGE SYSTEM

(57) A thermal energy storage system (2) is provided. The thermal energy storage system comprises an energy storage device (4) configured to store thermal energy; a charging flow path (16) configured to provide thermal energy from a heat source (6) to the energy storage device (4) via a heat transfer medium, wherein the thermal energy storage system (2) is operable in a charging mode in which the heat transfer medium is transported along the charging flow path (16); and a discharging flow path (14) configured to provide thermal energy from the energy storage device (4) to a first heat consumer (12) via the heat transfer medium and to return the heat transfer medium at least partially to the energy storage device (4). The thermal energy storage system (2) is operable in a discharging mode in which the heat transfer medium is transported along the discharging flow path (14). The thermal energy storage system (2) further includes a second heat consumer (10) arranged in the charging flow path (16) and in the discharging flow path (14) such that the heat transfer medium passes through the second heat consumer (10) both during operation in the charging mode and during operation in the discharging mode.

FIG 1



EP 3 933 175 A1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a thermal energy storage system and a method for operating such an thermal energy storage system.

BACKGROUND

[0002] Thermal energy storage systems with an energy storage device are well known in the prior art. These systems are used for storing thermal energy in an energy storage device (charging mode) by transferring thermal energy from a heat source to the energy storage device with a heat transfer medium. During discharging, these systems transfer thermal energy stored in the energy storage device to a heat consumer by means of a heat transfer medium. Common energy storage devices used in these thermal energy storage systems include a first and a second port coupled to a storage chamber and a heat storage material. Possible energy storage devices for the thermal energy storage systems are for example described in detail in the document EP 3 102 796 A1.

[0003] However, the use of such thermal energy storage system is limited because the energy storage device within the energy storage system can only be operated efficiently at high temperatures, for example between 700 and 900° C. Consequently, the heat transfer medium flowing through the energy storage device is also heated up to such a high temperature. The heat transfer medium at such high temperature is then used for specific applications, for example for generating high temperature and high pressure steam (e.g. 565°C at 180 bar) for a steam turbine which is used to reconvert the stored thermal energy to electrical energy. For such applications, the heat supply that is provided only intermittently (i.e. only during the discharging phase) is not problematic.

[0004] It would however be desirable to increase the possible applications of such thermal energy storage system and to make the system available also for heat consumers that require a constant supply with heat. It is also desirable to use such energy system more efficiently.

SUMMARY

[0005] Accordingly, there is a need to mitigate at least some of the drawbacks mentioned above and to provide a thermal energy storage system that is more versatile. There is further a need to use such thermal energy storage system more efficiently.

[0006] This need is met by the features of the independent claims. The dependent claims describe embodiments of the invention.

[0007] According to an embodiment of the invention, a thermal energy storage system is provided. The thermal energy storage system comprises an energy storage device configured to store thermal energy and a charging flow path configured to provide thermal energy from a heat source to the energy storage device via a heat transfer medium. The thermal energy storage system is operable in a charging mode in which the heat transfer medium is transported along the charging flow path. The thermal energy storage system further includes a discharging flow path configured to provide thermal energy from the energy storage device to a first heat consumer via the heat transfer medium, and configured to return the heat transfer medium at least partially to the energy storage device. The thermal energy storage system is operable in a discharging mode in which the heat transfer medium is transported along the discharging flow path. The charging and discharging flow paths are configured such that the heat transfer medium is at least partly transported along same passage through the energy storage device. The thermal energy storage system further includes a second heat consumer arranged in the charging flow path and in the discharging flow path such that the heat transfer medium passes through the second heat consumer both during operation in the charging mode and during operation in the discharging mode.

[0008] As the heat transfer medium that is flowing through the second heat consumer has either passed the energy storage device (charging mode) or the first heat consumer (discharging mode), considerable amounts of thermal energy have already been withdrawn from the heat transfer medium, so that the temperature of the medium is significantly lower compared to medium directly leaving the heater or from the storage device. Furthermore, heat transfer medium that still includes a considerable amount of residual thermal energy flows through the second heat consumer both in the charging mode and the discharging mode. The second heat consumer thus continuously receives a substantial amount of thermal energy. With the thermal energy storage system, it therefore becomes possible to supply a plurality of different applications with heat that require only lower temperatures and/or that require a constant heat supply. Examples are district heating, feedwater heaters for steam turbines and the like. The versatility of the system is thus significantly improved. By such arrangement of the second heat consumer, the temperature of the heat transfer medium received by the second heat consumer does also not fall below a threshold temperature (e.g. 150°C or 200° C) during charging as well as during discharging mode, so that sufficient heat can continuously be provided to the second heat consumer.

[0009] The location of the second heat consumer in the discharging flow path has also the advantage that the temperature of the heat transfer medium entering the energy storage device during the discharging mode is further reduced by the heat transfer in the second heat consumer. This leads to a higher temperature difference between the heat transfer medium entering the energy storage device during discharging and the temperature of the heat storage material. Thus, a 'deeper' discharge is possible and thus more thermal energy can be extracted from the energy storage device.at A higher amount of extractable energy may thus be stored, or the energy storage device can be built smaller for storing the same amount of extractable energy.

[0010] In general 'energy storage device' means a system that is configured to store thermal energy. Thereby, the energy storage device is not restricted to a single energy storage chamber. The energy storage device may comprise 1, 2, 3 or more energy storage chambers which are connected parallel or in series.

[0011] The charging flow path and the discharging flow path may be provided by any kind of e. g. pipes or conduits, in particular thermally insulated pipes, which are used in the thermal energy storage system for routing the heat transfer medium through the charging and discharging flow paths. The 'charging mode' corresponds to a mode in which the heat transfer medium passes along the charging flow path and the 'discharging mode' corresponds to a mode in which the heat transfer medium passes along the discharging flow path.

[0012] The first heat consumer may be a steam generator (in particular a heat recovery steam generator, HRSG) that generates steam during the discharging mode, in particular steam that is suitable for powering a steam turbine configured to convert stored thermal energy into electrical energy. The steam generator may also be termed main steam generator and may be configured to generate steam having a temperature of higher than 400°C at a pressure of more than 100 bar. The first heat consumer may only be operable during the discharging mode.

[0013] In an embodiment, the heat transfer medium is a gaseous medium, in particular air or nitrogen. Air is cost efficient and readily available, and the medium may thus be replenished from the environment. Also, sealing of the storage device and of the flow paths is not a major concern when using air.

[0014] The charging flow path may implement a closed cycle that is configured to return the heat transfer medium leaving the energy storage device, via the second heat consumer, back to the heat source in order to increase the amount of thermal energy stored in the heat transfer medium. In the charging mode, the heat transfer medium is cycled in the charging flow path through the heat source and the energy storage device for continuously transferring thermal energy to the energy storage device. Such closed cycle is more energy efficient.

[0015] The discharging flow path may implement a closed cycle that is configured to return the heat transfer medium that has provided thermal energy to the first and second heat consumer back to the energy storage device to take up thermal energy stored in the energy storage device. In discharging mode, the heat transfer medium is cycled in the discharging flow path through the energy storage device, the first and the second heat consumer. By such closed discharging cycle, the energy efficiency is further improved compared to an open cycle.

[0016] In an embodiment, the thermal energy storage system comprises a conduit that provides a (direct) flow connection between the energy storage device and the second heat consumer. The thermal energy storage system is configured such that in the charging mode, heat transfer medium leaving the energy storage device is passed by the conduit to the second heat consumer and in the discharging mode, heat transfer medium leaving the second heat consumer is passed by the conduit to the energy storage device. The conduit may be any kind of pipe or conduit, in particular an insulated pipe, for routing the heat transfer medium in the charging and discharging mode. The second heat consumer may thus be connected at a position in the system at which it receives the heat transfer medium directly from the energy storage device in the charging mode, and at which the flow through the second heat consumer corresponds to the flow through the energy storage device. Such position may be favorable with respect to the temperature of the medium flowing through the second heat consumer in both modes.

[0017] The thermal energy storage system may be configured to supply in the discharging mode the heat transfer medium at a temperature between 500 and 1000°C to the first heat consumer. The heat transfer medium may have a temperature between 500 and 1000°C or 600 and 900°C, preferably between 600 and 800°C when leaving the energy storage device. Preferably, the thermal energy storage system supplies in the discharging mode the heat transfer medium at a temperature of 500°C to 900°C (e.g. 700°C to 800°C) to the first heat consumer.

[0018] The thermal energy storage system may be configured to supply in the charging mode and in the discharging mode the heat transfer medium at a temperature between 100 and 400°C to the second heat consumer. The heat transfer medium at the second heat consumer may have the same or substantially the same temperature in the charging and discharging mode. The heat transfer medium supplied to the second heat consumer may in particular have a temperature between 150 and 350°C, or 200 and 350°C.

[0019] In an embodiment, the second heat consumer is a steam generator configured to transfer the thermal energy of the heat transfer medium to a working medium of a steam cycle (water/steam). For example, the second heat consumer may be configured to generate steam for the steam cycle. The second consumer may be a heat exchanger or steam boiler.

[0020] Alternatively, the second heat consumer may be a heat exchanger configured to transfer thermal energy of the heat transfer medium to water of a water cycle, in particular to generate hot (heated) water in the water cycle, or to a thermal oil of a thermal oil cycle.

[0021] The second heat consumer may thus generate steam/hot water having a 'lower quality' than steam generated by the first heat consumer. The generated steam or hot water may have a (low) temperature between 120°C and 190°C and a (low) pressure between 5 and

20 bar, e.g. about 10 bar.

[0022] In an embodiment, the thermal energy storage system is configured to provide a continuous heat supply to the second heat consumer via the heat transfer medium when operating the thermal energy storage system alternatingly in the charging mode and the discharging mode. The continuous heat supply leads to greater application possibilities because there are some heat consumers, e.g. district heating that require a permanent heat supply.

[0023] The thermal energy storage system may further comprise at least one blower configured to convey (i.e. to transport) the heat transfer medium along the charging flow path in the charging mode and to convey the heat transfer medium along the discharging flow path in the discharging mode.

[0024] Along the charging flow path, the heat transfer medium is in particular circulated from the blower through the heat source, the energy storage device, the second heat consumer and back to the blower. Thereby, the heat transfer medium provides thermal energy to the energy storage device and to the second heat consumer. Along the discharging flow path, the heat transfer medium is circulated from the blower through the second heat consumer, the energy storage device, the first heat consumer and back to the blower. Thereby, thermal energy is transferred from the energy storage device to the heat transfer medium and the heat transfer medium may provide heat to the first and second heat consumers.

[0025] The output of the at least one blower may have the same flow direction in the charging and discharging mode. At least one control valve may be provided downstream of the at least one blower to separate the flow paths into the charging and the discharging flow paths. Further control valves, e. g. three way valves or on/off valves, may be provided upstream of the at least one blower. The thermal energy storage system may include a control unit configured to control the control valves such that in charging mode, the heat transfer medium flows along the charging flow path and in discharging mode, the heat transfer medium flows along the discharging flow path.

[0026] In other configurations, at least one blower may be used for the charging flow path and at least one blower for the discharging flow path. Further blowers may be provided, e.g. for redundancy, for boosting or if the pressure drop is too large along the charging/discharging flow path. Preferably, the at least one blower is arranged in the charging flow path downstream of the second heat consumer and upstream of the heat source with regard to the flow direction in the charging flow path, and is arranged in the discharging flow path downstream of the first heat consumer and upstream of the second heat consumer with regard to the flow direction in the discharging flow path. Thereby, the same blower may be used for transporting the medium in the charging and discharging flow paths. This is efficient and reduces costs for further blowers.

[0027] In an embodiment, the charging flow path is configured to guide the heat transfer medium through the energy storage device in a first flow direction to increase the amount of thermal energy stored in the energy storage device and the discharging flow path is configured to guide the heat transfer medium through the energy storage device in a second flow direction that is opposite to the first flow direction. The second heat consumer is arranged in the charging flow path downstream of the energy storage device and upstream of the heat source with regard to the first flow direction and is arranged in the discharging flow path downstream of the first heat consumer and upstream of the energy storage device with regard to the second flow direction.

[0028] 'Downstream' means 'in flow direction behind'. In the charging flow path, 'downstream' of the energy storage device means that the heat transfer medium first passes the energy storage device and then the second heat consumer and 'upstream' of the heat source means that the heat transfer medium passes the second heat consumer prior to being returned to the heat source.

[0029] In the discharging flow path, 'downstream' of the first heat consumer means that the heat transfer medium first passes the first heat consumer and then the second heat consumer and 'upstream' of the energy storage device means that the heat transfer medium passes the second heat consumer prior to being returned to the energy storage device.

[0030] In an embodiment, the energy storage device comprises a storage chamber. The storage chamber may comprise at least one first port operated as an inlet for the heat transfer medium in the charging mode and as an outlet for the heat transfer medium in the discharging mode and at least one second port operated as an outlet for the heat transfer medium in the charging mode and as an inlet for the heat transfer medium in the discharging mode. The energy storage device may further comprise a heat storage material disposed in the storage chamber. The heat storage material may have open pores and/or may provide flow channels through which the heat transfer medium may flow and exchange thermal energy with the heat storage material.

[0031] The thermal energy storage system may be configured to store thermal energy in the energy storage device at a temperature between 300 °C and 1000 °C, preferably between 500 °C and 1000 °C, more preferably between 600°C and 900°C when the thermal energy storage device is in a charged state. For example, the temperature in the charged energy storage device may be kept between 650 and 800°C.

[0032] Flow channels (or heat exchange channels) can be built into the heat storage material, or such channels may form due to the structure of the material, e.g. by interspaces or gaps in the heat storage material, e.g. between rocks/stones. Preferably, the heat storage material comprises a mesh of heat exchange channels through which the heat transfer medium passes, both along the charging and the discharging flow path.

[0033] For example, the heat storage material may comprise or consist of rocks, bricks, stone, lava stone, granite, basalt and/or ceramics provided as bulk material (which may be configured as pebble bed). Preferably, the heat storage material comprises or consists of sand and/or stones, in particular gravel, rubble and/or grit. The stones can be natural stones or artificial stones (e.g. containers filled with material, such as clinkers or ceramics). The heat storage device can thus be provided cost efficiently while being capable of storing large amounts of thermal energy.

[0034] The energy storage device may be a horizontal storage device wherein a main flow direction of the heat transfer medium through the storage device is in horizontal direction (i.e. substantially parallel to the earth's surface). A horizontally oriented direction of the heat exchange flow may be achieved by providing the first and second ports laterally, e.g. in side walls/boundaries of the storage chamber. In other embodiments, the energy storage device may be a vertical storage device wherein a main flow direction of the heat transfer medium through the storage device is in vertical direction (i.e. substantially perpendicular to the earth's surface). The inlet/outlet ports may then be provided in upper/lower walls/boundaries of the storage chamber, or one port may be provided in an upper part and the other in a lower part of side walls/boundaries of the storage chamber. In some implementations, the energy storage device may comprise a diffuser section for evenly distributing the heat transfer medium into the storage and for reducing the flow speed of the medium. The diffuser may be provided at either port of the energy storage device. The diffuser may comprise a convection reducing structure, for example by providing a vertical layer of convection reducing elements within the diffuser of the respective port.

[0035] The storage chamber may be a space, a cavity, an excavation or a housing in which the heat storage material is located. The energy storage device may further comprise a nozzle section provided between the storage chamber and the respective port. The nozzle section may for example include a tapered portion leading from the storage chamber to the respective port. Flow speed and pressure of the heat transfer medium entering/leaving the energy storage device through the respective port may be adjusted by providing such nozzle section.

[0036] In an embodiment, the thermal energy storage system is configured to alternatingly operate in the charging mode and the discharging mode. Accordingly, the system may cause alternating flows in opposite direction or in the same direction through the energy storage device to charge/discharge the energy storage device.

[0037] In the charging mode, heat transfer medium that has been heated by the heat source passing through the energy storage device and thereby heats the heat storage material, a cooler medium being exhausted from the energy storage device. After the charging is completed, the storage device may be left in a standstill period of hours or even days until the stored thermal energy is needed. In the discharging mode, the flow direction may be the same as in the charging mode or may be reversed, so that colder heat transfer medium (e.g. air) is introduced into the port that acted as outlet in the charging mode. The heat storage material transfers heat to the heat transfer medium, which leaves the energy storage device at the other (hot) end through the port that acted as inlet in the previous charging mode. The storage device may thus have a hot port (inlet for charging and outlet for discharging) and a cold port (inlet for discharging and outlet for charging). For a modified distribution of the medium within the storage, the energy storage device may include a plurality of hot ports and/or a plurality of cold ports.

[0038] The heat storage material may be separated into a layered thermal energy storage structure by dividing elements, such as steel plates or metal sheets. The sheets or plates may comprise any suitable heat resistant material, such as metal, synthetic fabric or the like, that are substantially impermeable for the working fluid. The dividing elements may prevent a change in the temperature distribution within the thermal energy storage structure due to natural convection during the standstill period, i.e. prevent that hot fluid surrounding heat storage material in the lower part of the chamber flows to the upper part of the chamber.

[0039] In some configurations, the energy storage device may include several storage chambers placed in series and/or parallel with valves and piping in between, including bypass-lines. This may allow an adaptation of the size of the active storage chamber to the present needs. For example, during charging, the flow of the heat transfer medium and thus the heating may be stopped for one chamber if the specific chamber has been fully charged. This allows the maintaining of a desired temperature gradient within each of the storage chambers.

[0040] In particular, the thermal energy storage system may be configured such that during the charging cycle of a storage chamber, a temperature front travels through the heat storage material from the hot end to the cold end of the chamber. The temperature front is a zone of strong temperature gradient in the heat storage material, which separates the hot and the cold zones in the chamber. The charging of the respective storage chamber will preferably be stopped when the temperature at the cold end begins to rise above a predetermined temperature threshold. By using a plurality of chambers interconnected in series via valves and bypass-lines, during idling operations, i.e. between charging and discharging phases, the chambers can be disconnected from each other to prevent a mass flow between them initiated by natural convection. A valve may thus be provided for isolating a charged storage chamber from its neighboring storage chamber(s). Thus, mass flow caused by convection inside a heat storage chamber, which contains the temperature gradient, is limited to this single storage chamber.

[0041] In an embodiment, the heat source is configured to receive energy from a renewable energy source, in particular from a wind and/or solar and/or water energy source. The use of renewable energy sources is environmentally friendly. However, the heat source may also be provided with energy from nonrenewable energy sources like coal, oil, nuclear and/or natural gas.

[0042] The heat source may for example comprise a heater, in particular an electrical heater that converts electrical energy into thermal energy. It may additionally or alternatively comprise a heat exchanger that for example provides heat exchange between a working fluid (e.g. of a solar plant, of an industrial process, or the like, such as an exhaust gas or waste heat) and the heat transfer medium. The heat source may additionally or alternatively comprise a heat pump.

[0043] The second heat consumer may implement at least one of a feedwater heater configured to heat feedwater of a steam turbine, a district heating system heater configured to heat a medium of a district heating system, or a steam turbine standby heater configured to supply steam to a steam turbine to maintain the steam turbine or components of the steam turbine at a predetermined temperature. By transferring the thermal energy of the heat transfer medium to the medium of the feedwater heater, of the steam turbine standby heater or of the district heating system heater, steam or hot water may efficiently be generated in the respective system.

[0044] If the second heat consumer is implemented as a feedwater heater of a steam turbine, it is not necessary to extract steam from an intermediate stage of the steam turbine of the steam cycle for feedwater heating. Therefore, the steam that is conventionally extracted from the steam turbine to be used in the feedwater heater can be transformed to work by expansion in the steam turbine and thus, the efficiency of the system is increased.

[0045] In some embodiments, the second heat consumer may also be implemented as one, two or more heat exchangers, which may for example directly heat feedwater, e.g. it may be implemented as an LP feedwater heater and an HP feedwater heater providing respective LP/HP feedwater heating.

[0046] The steam or hot water generated in the district heating system heater may be distributed through a system of insulated pipes and may be provided for residential and commercial heating requirements, such as space heating or water heating.

[0047] When implementing the second heat consumer as a steam turbine standby heater, components of the main steam cycle can be maintained at a predetermined temperature, which reduces the ramp-up time of the main steam cycle. Thus, the efficiency of the steam turbine can be increased.

[0048] The thermal energy storage system may comprise a respective steam turbine, and the steam turbine may be provided with steam for operation from the first heat consumer. The steam turbine may further be configured to drive an electrical generator to convert stored thermal energy into electrical energy.

[0049] A further embodiment of the invention provides a method of operating a thermal energy storage system. The method comprises operating the thermal energy storage system in a charging mode in which a heat transfer medium is transported along a charging flow path from a heat source to an energy storage device to thereby provide thermal energy from the heat source to the energy storage device; and operating the thermal energy storage system in a discharging mode in which the heat transfer medium is transported along a discharging flow path from the energy storage device to a first heat consumer to thereby provide thermal energy from the energy storage device to the first heat consumer. In the charging mode and the discharging mode, the heat transfer medium is at least partly transported along same passage through the energy storage device. The method further comprises providing thermal energy from the heat transfer medium to a second heat consumer that is arranged in the charging flow path and in the discharging flow path such that the heat transfer medium passes through the second heat consumer both during operation in the charging mode and during operation in the discharging mode. By such method, advantages similar to the ones outlined further above may be achieved.

[0050] It should be clear that the method may be performed by a thermal energy storage system having any of the configurations described herein.

[0051] It is to be understood that the features mentioned above and those yet to be explained below can be used not only in the respective combinations indicated, but also in other combinations or in isolation, without leaving the scope of the present invention. In particular, the features of the different aspects and embodiments of the invention can be combined with each other unless noted to the contrary.

BRIEF DESCRIPTION OF THE DRAWINGS

[0052] The forgoing and other features and advantages of the invention will become further apparent from the following detailed description read in conjunction with the accompanying drawings. In the drawings, like reference numerals refer to like elements.

Fig. 1 is a schematic drawing showing a thermal energy storage system according to an embodiment of the invention.

Fig. 2 is a schematic drawing showing a thermal energy storage system according to an embodiment of the invention.

Fig. 3 is a schematic drawing showing a steam turbine including a feedwater heater supplied with thermal energy by the second heat consumer of a thermal energy storage system according to an embodiment of the invention.

Fig. 4 is a schematic drawing showing an energy storage device according to an embodiment of the invention.

DETAILED DESCRIPTION

[0053] In the following, embodiments of the invention will be described in detail with reference to the accompanying drawings. It is to be understood that the following description of the embodiments is given only for the purpose of illustration and is not to be taken in a limiting sense. It should be noted that the drawings are to be regarded as being schematic representations only, and elements in the drawings are not necessarily to scale with each other. Rather, the representation of the various elements is chosen such that their function and general purpose become apparent to a person skilled in the art. As used herein, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted.

[0054] Fig. 1 is a schematic drawing showing a thermal energy storage system according to an embodiment of the invention. The thermal energy storage system 2 includes an energy storage device 4, a heat source 6, a blower 8, a first and second heat consumer 12, 10 and a heat transfer medium flowing and transferring thermal energy within the thermal energy storage system. The heat transfer medium may be a gaseous medium, e. g. air.

[0055] Starting at the blower 8, an outlet of the blower 8b is connected to the inlet of the heat source 6a by conduit 18d. The heat transfer medium exiting the heat source 6 through an outlet of the heat source 6b is transported to junction 20a by conduit 18a. At junction 20a, conduit 18b is connected to an inlet 12a of the first heat consumer 12. From the first heat consumer 12, the heat transfer medium is guided to an inlet of the blower 8a by conduits 18c and 18k. Further, the thermal energy storage system 2 includes a conduit 18e from the junction 20a to a first port 4a of the energy storage device 4. The heat transfer medium exits the energy storage device 4 through a second port 4b and is guided to a first port 10a of the second heat consumer 10. The heat transfer medium exits the second heat consumer 10 through a second port 10b and flows through a conduit 18h which is connected to conduit 18k at junction 20b. Another conduit 18g is provided in the thermal energy storage system 2 which connects junction 20c of conduit 18d and junction 20d of conduit 18h. The junctions 20a-d may include a component configured to control through which of the conduits connected to the junction the heat transfer medium flows. Such control may occur in dependence on the operating mode of the thermal energy storage system 2. Some of the junctions 20a-d may be controlled by at least one control valve, such as one or a combination of a three way valve, an on/off valve, a directional valves and the like. The control valves can be controlled such that the heat transfer medium flows along a discharging and a charging flow path, which do not form separate circuits and therefore share the same heat transfer medium.

[0056] The thermal energy storage system 2 can be operated in two operation modes, a charging and a discharging mode:

In the charging mode, the heat transfer medium is transported in a first flow direction A along a charging flow path 16 that includes the blower 8, the heat source 6, the energy storage device 4, and the second heat consumer 10. Starting from the blower 8 the heat transfer medium is transported to the heat source 6 through conduit 18d. The heat source 6 may be, e. g., an electrical heater which converts electrical energy to thermal energy by heating an electrical resistor, or it may be a heat exchanger that is supplied with heat from a different source via a working fluid, such as a working fluid of a solar power plant or an exhaust gas from an industrial process, in particular waste heat. However, the heat source 6 may be any other kind of heat source which supplies thermal energy and can be used for heating the heat transfer medium. The thermal energy of the heat source 6 is transferred to the heat transfer medium while the heat transfer medium is passing the heat source 6. The heat transfer medium may be heated up to a temperature between 600 and 1000° C at the heat source 6. The 'heated' heat transfer medium is further transported to the energy storage device 4 through conduits 18a and 18e.

[0057] In charging mode, the flow connection at junction 20a between conduit 18a and conduit 18e may by established by controlling a respective control valve. At the energy storage device 4, the thermal energy of the heat transfer medium is transferred to the energy storage device, in particular to a heat storage material 24 (see Fig. 4) disposed in the energy storage device 4. Thereby, the amount of thermal energy stored in the energy storage device 4 is increased and available for later use. The heat transfer medium exits the energy storage device 4 at lower temperature (compared to the temperature at which it exits the heat source 6), flows through conduit 18f in the first flow direction A and enters the second heat consumer 10. When exiting the energy storage device 4 the heat transfer medium may have a temperature between 100°C and 500°C, preferably 180°C and 350°C. The second heat consumer 10 may be a heat exchanger or a steam generator for generating steam or hot water with relatively low temperatures, e. g. about 100-350°C. Thus, the heat transfer medium exiting the energy storage device 4 may be used for operating the second heat consumer 10, in particular for transferring heat to a second medium of the second heat consumer 10 and generating e. g. steam or hot water. The heat transfer medium exiting the second heat consumer 10 is guided back to the blower 8 through conduits 18h and 18k, which are in flow communication at junction 20b. When the heat transfer medium enters the blower 8, the charging cycle is completed. The system 2 may be operated in the charging mode (i.e. cycle the heat transfer medium along the charging flow path) until the energy storage is fully charged.

[0058] In the discharging mode, the heat transfer medium is transported in a second flow direction B along a discharging flow path 14 that includes the blower 8, the second heat consumer 10, the energy storage device 4, and the first heat consumer 12. Starting from the blower 8, the heat transfer medium is transported to the second heat consumer 10 through conduits 18d, 18g and 18h. At junction 20c, the discharging flow path 14 branches off from the charging flow path 16, e.g. controlled by a control valve, such a three way valve or two on/off valves. Conduit 18g is brought into flow communication with conduit 18h at junction 20d, by e.g. a control valve, such that the heat transfer medium is flowing in conduit 18h in the second flow direction B towards the second heat consumer 10, flow direction B being opposite to the first flow direction A in conduit 18h. When exiting the second heat consumer 10, the heat transfer medium is guided by conduit 18f to the energy storage device 4 in which thermal energy is transferred from the heat storage material 24 (see Fig. 3) to the heat transfer medium while passing the energy storage device 4. The heat transfer medium may be heated up to a temperature between 600 and 1000° C in the energy storage device 4.

[0059] When exiting the energy storage device 4, the 'heated' heat transfer medium (compared to the heat transfer medium entering the energy storage device 4) flows, via conduits 18e and 18b and junction 20a into the first heat consumer 12. The second flow direction B of the heat transfer medium in the discharging mode through the second heat consumer 10 and the energy storage device 4 is opposite to the first flow direction A through these components in the charging mode.

[0060] At the first heat consumer 12, the heat transfer medium transfers the thermal energy to a second medium. The first heat consumer may be a steam generator that generates steam from the second medium with high temperature and pressure (e.g. 565° C at 180 bar). The heat transfer medium exiting the first heat consumer 12 and being guided back to the blower 8 through conduits 18c and 18k has a temperature of, e.g., between 150 and 450°C. When the heat transfer medium enters the blower 8, the discharging cycle is completed. The system 2 may operate in the discharging mode in which the heat transfer medium is cycled along the discharging flow path until the energy storage device is fully discharged or no further heat demand is present. When the energy storage device is fully discharged or no heat demand exists, the thermal energy storage system may be operated in the charging mode again until the energy storage device is re-charged.

[0061] The heat transfer medium in discharging mode may still have a temperature in the range of e. g. 150 and 350 °C when entering the second heat consumer 10, which is sufficient to operate said heat consumer 10 in the same way as in the charging mode. Thus, the second heat consumer 10 may be operated in the charging mode as well as in the discharging mode at a temperature of the heat transfer medium in the range of, e.g., 150 to 450° C. Thereby, it is also possible to provide a continuous heat supply to the second heat consumer 10 via the heat transfer medium when operating the thermal energy storage system 2 alternatingly in the charging mode and the discharging mode.

[0062] The output of the blower 8 has the same flow direction in the charging and discharging mode. At least one control valve may be provided downstream of the blower 8 to separate the flow paths into the charging and the discharging flow paths 14, 16. Further control valves, e. g. three way valves, may be provided upstream of the blower 8. The thermal energy storage system 2 may include a control unit configured to control the control valves such that in charging mode, the heat transfer medium flows along the charging flow path 16 (dashed arrows) and in discharging mode, the heat transfer medium flows along the discharging flow path 14 (dotted arrows). It should be clear that there may be arranged more than one blower 8 in the thermal energy storage system 2. Further blowers could be used e.g. for boosting the pressure of the heat transfer medium or for the purpose of redundancy.

[0063] A respective control unit configured to control such control valves may include a microprocessor and memory, which stores control instructions which are executed by the processor and which alternatingly operate the system 2 in the charging mode and the discharging mode and possibly in an idle mode. Such processor may for example be a digital signal processor, an application specific integrated circuit (ASIC), a microprocessor or the like. The memory may include flash-memory, a hard disk drive, RAM, ROM, and other types of volatile and non-volatile memory. Such control unit may furthermore include input and output interfaces for controlling the control valves and for receiving sensor signals. As a non-limiting example, the temperature in the energy storage device 4 may be monitored to determine when operation in the charging mode is necessary or when the maximum amount of energy is stored. Likewise, it may determine the heat demand of heat consumer 12 and operate the system 2 accordingly in the discharging mode to supply the respective thermal energy.

[0064] Fig. 2 is a schematic drawing showing a thermal energy storage system according to an embodiment of the invention. The thermal energy storage system 2a includes the same components as the thermal energy storage system 2 shown in Fig. 1. The structure of the two systems is substantially the same, therefore only the differences of system 2a compared to system 2 of Fig. 1 are described in the following. The explanations given above with respect to system 2 of Fig. 1 are therefore also valid for the thermal energy storage system 2a of Fig. 2.

[0065] The main difference of system 2a is the position of the second heat consumer 10. The second heat consumer 10 is arranged downstream of the energy storage device 4 and upstream of the blower 8 with regard to the charging mode and the first flow direction. With regard to the discharging mode and the second flow direction, the second heat consumer 10 is arranged downstream of the first heat consumer 12 and upstream of the blower 8. The second heat consumer 10 is arranged in the charging mode as well as in the discharging mode upstream of the blower 8. As shown in Fig. 2, the second heat consumer 10 is arranged between junction 20b and blower 8. Conduit 18c which is connected at the one end to the outlet of the first heat consumer 12b is connected at the other end to junction 20b which is connected to the inlet of the second heat consumer 10a through conduit 18j. The outlet of the second heat consumer 10b is connected to the inlet of the blower 8a through conduit 18i. In Fig. 2, conduit 18h is connected at the one end to the second port of the energy storage device 4b and at the other end to conduit 18c at junction 20b. Due to the position of the second heat consumer 10 and in contrast to the thermal energy storage system 2 of Fig. 1, the flow direction through the second heat consumer 10 of the thermal energy storage system 2a of Fig. 2 is the same in the charging mode and the discharging mode.

[0066] Fig. 3 is a schematic drawing showing a steam turbine including feedwater heaters of a steam power plant according to an embodiment of the invention. In the following, the function of the steam power plant 45 and its components is first briefly described and then reference is made to the specific application of the thermal energy storage system 2, 2a of Figs. 1 and 2 in the steam power plant 45.

[0067] In the steam power plant 45, a boiler 56 is heated up by e.g. burning fuel and air which is supplied into the boiler through an inlet 42. The boiler 56 may also be heated up by the output of a heat storage or a heater which is supplied into the boiler through the inlet 42. As the combustion end product, gas is discharged from the boiler 56 via the outlet 44. The boiler 56 further includes an economizer 46, a reheater 48, a drum 50, and a superheater 52 through which a working medium of the steam cycle flows. The working medium exiting the superheater 52 and thus the boiler 56 as superheated steam is fed to a high-pressure (HP) turbine 34. The HP turbine 34 is coupled to a low-pressure (LP) turbine 32 and both turbines are further coupled to a generator 30 for generating electrical energy. The HP turbine 34 is driven by expanding the superheated steam. The steam exiting the HP turbine 34 is reheated in a reheater 48 in the boiler 56 and then transported to the LP turbine 32 in which the reheated steam is expanded and the LP turbine 32 is driven. Both turbines 34, 32 drive the generator 30, which generates electricity. The steam exiting the turbine 32 is fed to a condenser 36 in which the steam is condensed to water. The water is further fed to a LP feedwater heater 38.

[0068] A feedwater heater in general is used in a steam power plant to pre-heat water (feedwater) that is transported to the boiler 56 by transferring heat from steam to the feedwater flowing through the feedwater heater. As shown in Fig. 3, the feedwater of LP feedwater heater 38 is heated by the energy derived from steam extracted between the stages of the LP turbine 32. The steam is then returned into the cycle via condenser 36. The heated feedwater exiting the LP feedwater heater 38 is pressurized by a pump 54 and fed to a HP feedwater heater 40. Part of the steam exiting the HP turbine 34 may be used for heating the feedwater flowing through the HP feedwater heater 40.

[0069] The feedwater flowing through the HP feedwater heater 40 is heated by transferring heat from the steam of the HP turbine 34 to the feedwater, and it is thereafter fed to the economizer 46. The economizer 46 is used for heating the water up to but not normally beyond the boiling point of the water. The heated feedwater is further fed to the steam drum 50. In the steam drum 50, the saturated steam is drawn off the top of the drum and is further guided through the superheater in which the superheated steam is generated by transferring heat resulting from the combustion process of e.g. fluid and air. After that, the steam cycle repeats as described above. Superheated steam is a dry gas which is used to drive turbines, since water droplets can severely damage the turbines.

[0070] As described above, the second heat consumer 10 of the thermal energy storage systems 2, 2a is supplied with heat transfer medium at a temperature between 100 and 500° C in the charging mode and in the discharging mode. With regard to the steam power plant mentioned above, the feed water heaters 38, 40 may be operated with the steam provided by the second heat consumer 10 for heating the feedwater that is circulated in the steam power plant. Alternatively, the second heat consumer 10 may implement one or both of the feedwater heaters 38, 40, i.e. may directly heat the feedwater. By such solutions, the feedwater heaters 38, 40 do no longer need to be supplied with steam extracted from an intermediate stage of the steam turbines 32, 34 of the steam power plant. This is an advantage since the steam that was previously extracted from the steam turbines 32, 34 to be used in the feedwater heaters can now be transformed to work by expanding the steam in the turbine. Thus, the efficiency of the steam power plant is increased.

[0071] It should be clear that the second heat consumer 10 of the thermal energy storage system 2, 2a may be used for any kind of steam power plant which may have a different structure than the steam power plant 45 of Fig. 4 including at least one feedwater heater for heating the feedwater flowing through the feedwater heater. The steam turbine may form part of the thermal energy storage system, it may for example be employed to convert stored thermal energy back into electrical energy. The boiler may then not operate with combustible fuel, but may be provided with thermal energy by the first heat consumer 12.

[0072] Fig. 4 is a schematic drawing showing an energy storage device 4 according to an embodiment of the invention. The energy storage device 4 includes at least one first and at least one second port 4a, 4b which provide a flow connection into a storage chamber 22.

[0073] In the charging mode, the at least one first port 4a is operated as an inlet and the at least one second port 4b as an outlet for the heat transfer medium while the heat transfer medium flows in a first flow direction A.

[0074] In the discharging mode, the at least one first port 4a is operated as an outlet and the at least one second port 4b as an inlet for the heat transfer medium while the heat transfer medium flows in a second flow direction B which is opposite to the first flow direction A of the charging mode.

[0075] The energy storage device 4 further includes a heat storage material 24 that is disposed in the storage chamber 22. The heat storage material may have open pores and/or provides flow channels through which the heat transfer medium can flow and exchange thermal energy with the heat storage material 24. As outlined above, the heat storage material 24 may be e.g. sand or rocks/gravel. The energy storage device 4 may have any of the above-described configurations.

[0076] While specific embodiments are disclosed herein, various changes and modifications can be made without departing from the scope of the invention. The present embodiments are to be considered in all respects as illustrative and non-restrictive, and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.

Claims

1. A thermal energy storage system (2), comprising:

    an energy storage device (4) configured to store thermal energy;
    a charging flow path (16) configured to provide thermal energy from a heat source (6) to the energy storage device (4) via a heat transfer medium, wherein the thermal energy storage system (2) is operable in a charging mode in which the heat transfer medium is transported along the charging flow path (16);
    a discharging flow path (14) configured to provide thermal energy from the energy storage device (4) to a first heat consumer (12) via the heat transfer medium and to return the heat transfer medium at least partially to the energy storage device (4), wherein the thermal energy storage system (2) is operable in a discharging mode in which the heat transfer medium is transported along the discharging flow path (14),
    wherein the charging and discharging flow paths (16, 14) are configured such that the heat transfer medium is at least partly transported along same passage through the energy storage device (4); and
    a second heat consumer (10) arranged in the charging flow path (16) and in the discharging flow path such that the heat transfer medium passes through the second heat consumer (10) both during operation in the charging mode and during operation in the discharging mode.

2. The thermal energy storage system according to claim 1, wherein the heat transfer medium is a gaseous medium, in particular air.

3. The thermal energy storage system according to claim 1 or 2, wherein the charging flow path (16) implements a closed cycle that is configured to return the heat transfer medium leaving the energy storage device (4) back to the heat source (6) so as to increase the amount of thermal energy stored in the heat transfer medium.

4. The thermal energy storage system according to any of the preceding claims, wherein the discharging flow path (14) implements a closed cycle that is configured to return the heat transfer medium that has provided thermal energy to the first and/or second heat consumer (12, 10) back to the energy storage device (4) to take up thermal energy stored in the energy storage device (4).

5. The thermal energy storage system according to any of the preceding claims, wherein the thermal energy storage system (2) comprises a conduit (18f) that provides a flow connection between the energy storage device (4) and the second heat consumer (10), wherein the thermal energy storage system (2) is configured such that in the charging mode, heat transfer medium leaving the energy storage device (4) is passed by the conduit (18f) to the second heat consumer (10) and in the discharging mode, heat transfer medium leaving the second heat consumer (10) is passed by the conduit (18f) to the to the energy storage device (4).

6. The thermal energy storage system according to any of the preceding claims, wherein the thermal energy storage system (2) is configured to supply in the discharging mode the heat transfer medium at a temperature between 600 and 1000° C to the first heat consumer (12).

7. The thermal energy storage system according to any of the preceding claims, wherein the thermal energy storage system (2) is configured to supply in the charging mode and in the discharging mode the heat transfer medium at a temperature between 100 and 400°C, preferably between 150 and 300°C to the

second heat consumer (10).

8. The thermal energy storage system according to any of the preceding claims, wherein the second heat consumer (10) is a steam generator configured to transfer the thermal energy of the heat transfer medium to a working medium of a steam cycle.

9. The thermal energy storage system according to any of claims 1-7, wherein the second heat consumer (10) is a heat exchanger configured to transfer thermal energy of the heat transfer medium to water of a water cycle.

10. The thermal energy storage system according to any of the preceding claims, wherein the thermal energy storage system (2) is configured to provide a continuous heat supply to the second heat consumer (10) via the heat transfer medium when operating the thermal energy storage system (2) alternatingly in the charging mode and the discharging mode.

11. The thermal energy storage system according to any of the preceding claims, wherein the thermal energy storage system (2) further comprises at least one blower (8) configured to convey the heat transfer medium along the charging flow path (16) in the charging mode and to convey the heat transfer medium along the discharging flow path (14) in the discharging mode.

12. The thermal energy storage system according to any of the preceding claims, wherein the charging flow path is configured to guide the heat transfer medium through the energy storage device (4) in a first flow direction (A) to increase the amount of thermal energy stored in the energy storage device (4), and wherein the discharging flow path (14) is configured to guide the heat transfer medium through the energy storage device (4) in a second flow direction (B) that is opposite to the first flow direction (A), wherein the second heat consumer (10) is arranged in the charging flow path (16) downstream of the energy storage device (4) and upstream of the heat source (6) with regard to the first flow direction (A) and is arranged in the discharging flow path (14) downstream of the first heat consumer (12) and upstream of the energy storage device (4) with regard to the second flow direction (B).

13. The thermal energy storage system according to any of the preceding claims, wherein the energy storage device (4) comprises
a storage chamber (22), wherein the storage chamber (22) comprises at least one first port (4a) operated as an inlet for the heat transfer medium in the charging mode and as an outlet for the heat transfer medium in the discharging mode and at least one second port (4b) operated as an outlet for the heat transfer medium in the charging mode and as an inlet for the heat transfer medium in the discharging mode, and
a heat storage material (24) disposed in the storage chamber (22), wherein the heat storage material (24) has open pores and/or provides flow channels through which the heat transfer medium can flow and exchange thermal energy with the heat storage material (24).

14. The thermal energy storage system according to any of the preceding claims, wherein the second heat consumer (10) implements at least one of a feedwater heater (38, 40) configured to heat feedwater of a steam turbine (32 34), a district heating system heater configured to heat a working medium of a district heating system, or a steam turbine standby heater configured to supply steam to a steam turbine to maintain the steam turbine or components of the steam turbine at a predetermined temperature.

15. A method for operating an thermal energy storage system, comprising:

- operating the thermal energy storage system (2) in a charging mode in which a heat transfer medium is transported along a charging flow path (16) from a heat source (6) to an energy storage device (4) to thereby provide thermal energy from the heat source (6) to the energy storage device (4);
- operating the thermal energy storage system (2) in a discharging mode in which the heat transfer medium is transported along a discharging flow path (14) from the energy storage device (4) to a first heat consumer (12) to thereby provide thermal energy from the energy storage device (4) to the first heat consumer (12), wherein the heat transfer medium is in the charging mode and in the discharging mode at least partly transported along same passage through the energy storage device (4); and
- providing in the charging mode and in the discharging mode thermal energy from the heat transfer medium to a second heat consumer (10) that is arranged in the charging flow path (16) and in the discharging flow path such that the heat transfer medium passes through the second heat consumer (10) both during operation in the charging mode and during operation in the discharging mode.

FIG 1

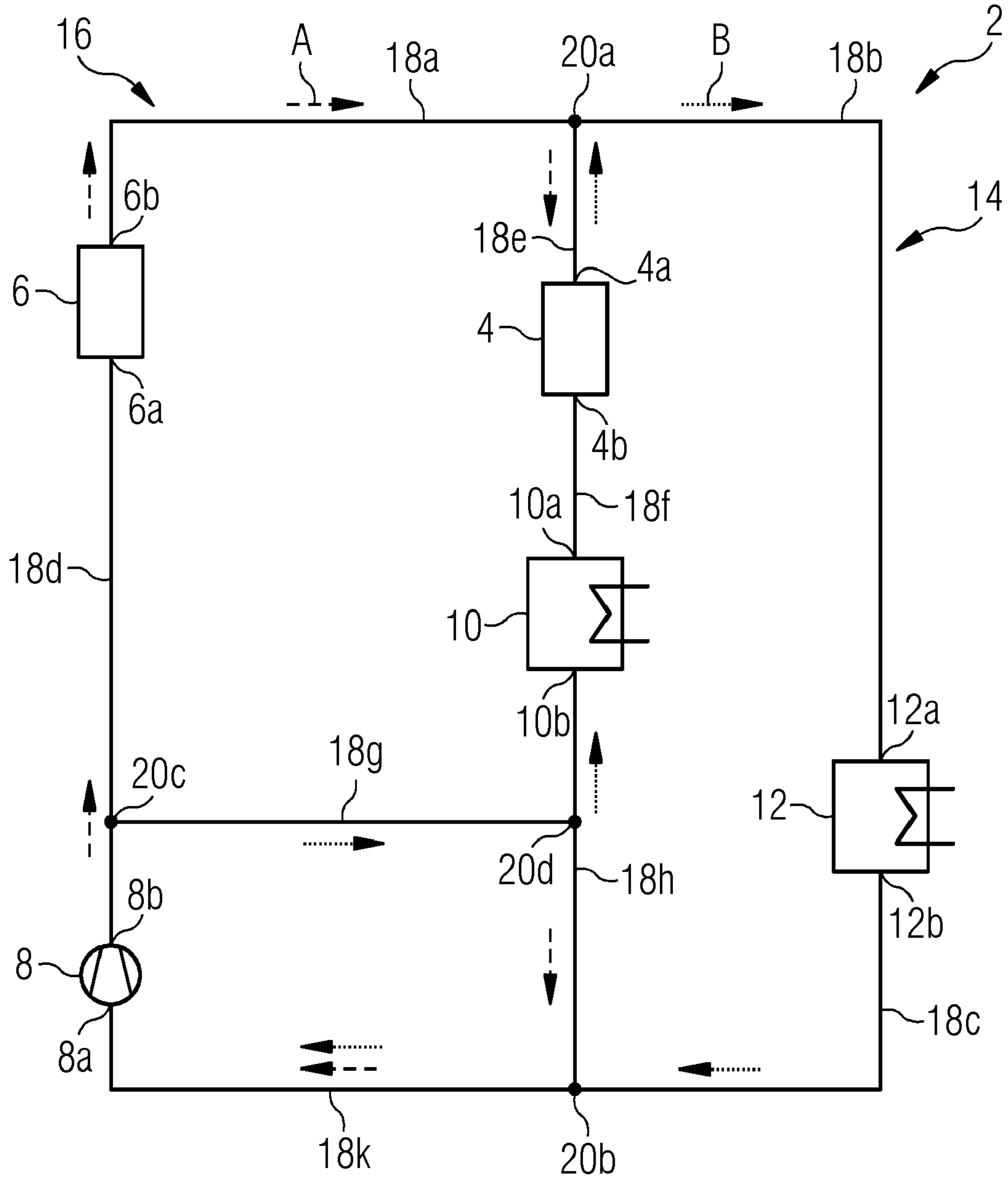

16
A
18a
20a
B
18b
2
6b
18e
4a
14
6
4
6a
4b
10a
18f
18d
10
10b
12a
18g
20c
12
20d
18h
8b
12b
8
18c
8a
18k
20b

FIG 2

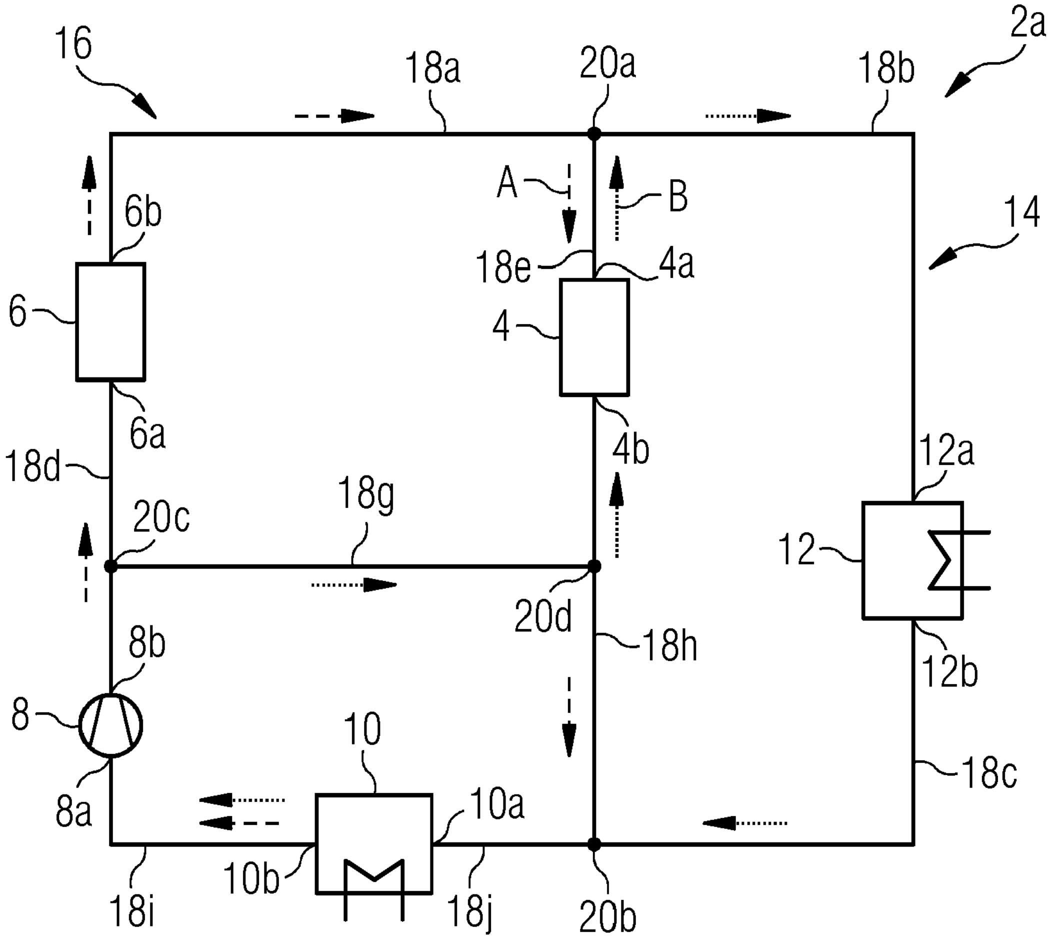

16
18a
20a
18b
2a
A
B
6b
18e
4a
14
6
4
6a
4b
12a
18d
18g
20c
12
20d
18h
12b
8b
8
10
18c
10a
8a
10b
18i
18j
20b

FIG 3

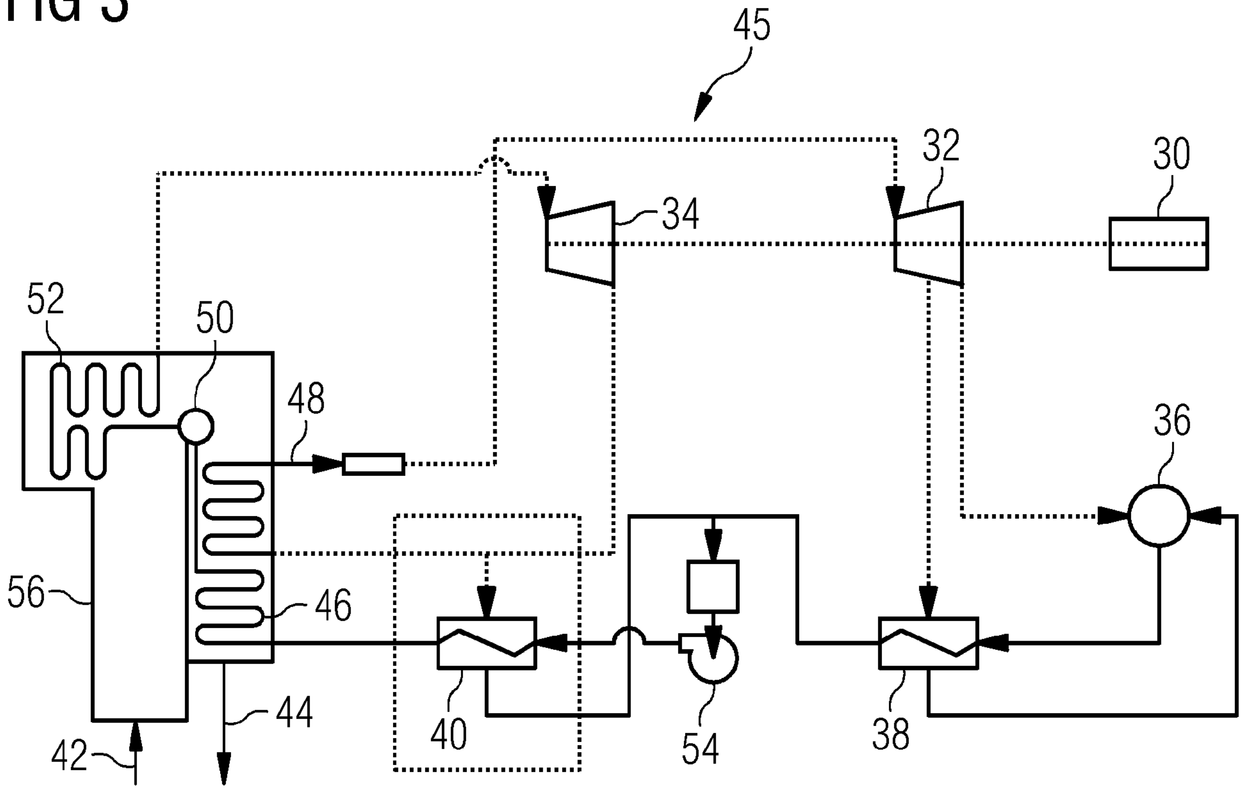
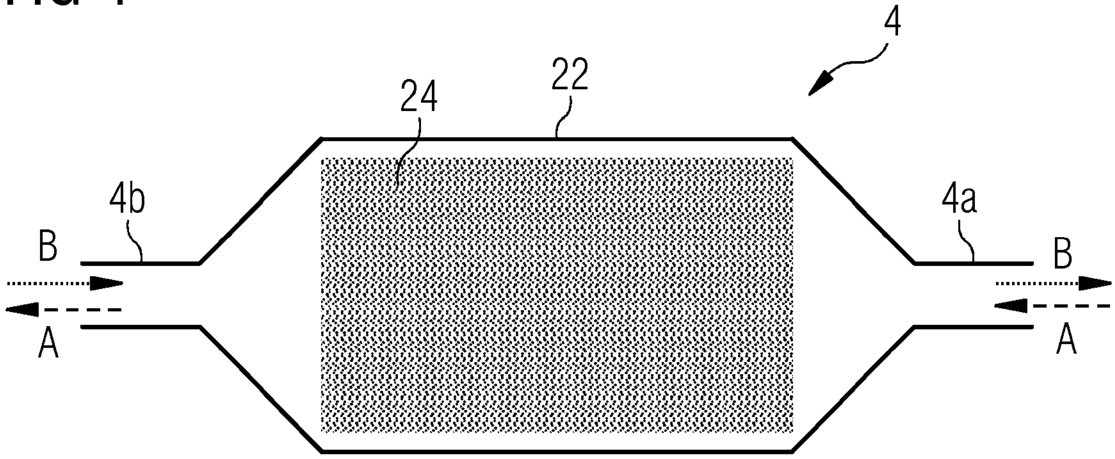


FIG 4



Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 20 18 3435

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 4 094 148 A (NELSON HAZEN E) 13 June 1978 (1978-06-13) * column 2, line 54 - column 9, line 28; figure 1 *	1-15	INV. F01K3/18
A	US 2014/020383 A1 (YOSHIDA TAKUYA [JP] ET AL) 23 January 2014 (2014-01-23) * paragraph [0036]; figure 2 *	1-15	
A	US 2010/251711 A1 (HOWES JONATHAN SEBASTIAN [GB] ET AL) 7 October 2010 (2010-10-07) * lines 118-160; figure 4 *	1-15	
A	GB 2 537 126 A (ISENTROPIC LTD [GB]) 12 October 2016 (2016-10-12) * page 40, line 5 - page 44, line 15; figure 11bi *	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

F01K

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	25 November 2020	Röberg, Andreas

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 20 18 3435

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

25-11-2020

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4094148 A	13-06-1978	CA 1080984 A	08-07-1980
		DE 2809527 A1	21-09-1978
		IT 1092556 B	12-07-1985
		JP S6211166 B2	11-03-1987
		JP S53115432 A	07-10-1978
		US 4094148 A	13-06-1978
US 2014020383 A1	23-01-2014	EP 2685101 A1	15-01-2014
		JP 5537730 B2	02-07-2014
		JP WO2012120556 A1	07-07-2014
		US 2014020383 A1	23-01-2014
		WO 2012120556 A1	13-09-2012
US 2010251711 A1	07-10-2010	BR PI0817513 A2	16-05-2017
		CA 2701526 A1	09-04-2009
		CN 101883913 A	10-11-2010
		CN 103104302 A	15-05-2013
		DK 2220343 T3	05-08-2013
		EP 2220343 A2	25-08-2010
		ES 2416727 T3	02-08-2013
		JP 5272009 B2	28-08-2013
		JP 5558542 B2	23-07-2014
		JP 2010540831 A	24-12-2010
		JP 2013032847 A	14-02-2013
		PL 2220343 T3	29-11-2013
		PT 2220343 E	22-08-2013
		US 2010251711 A1	07-10-2010
		US 2010257862 A1	14-10-2010
		WO 2009044139 A2	09-04-2009
GB 2537126 A	12-10-2016	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- EP 3102796 A1 **[0002]**