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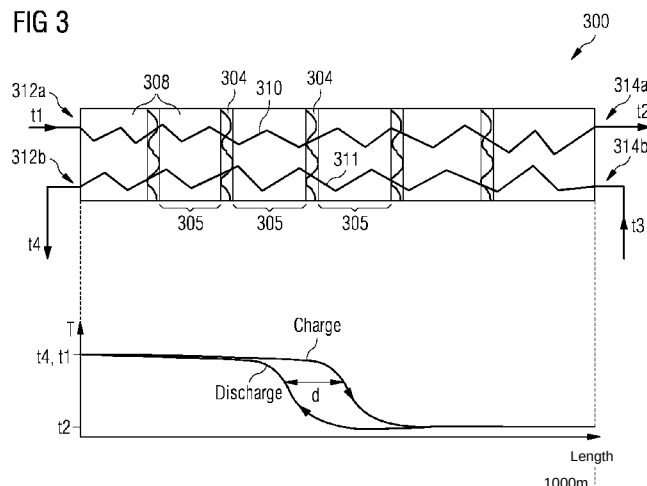
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(54) **Title:** THERMAL ENERGY STORAGE AND RECOVERY WITH A HEAT EXCHANGER ARRANGEMENT HAVING AN EXTENDED THERMAL INTERACTION REGION

FIG 3



(57) **Abstract:** A thermal energy storage and recovery device (100, 300) comprises a heat exchanger arrangement (110, 310), which is configured for guiding a flow of a heat transfer medium between a first end (112a) and a second end (114a) of the heat exchanger arrangement, a heat storage material (108), which surrounds the heat exchanger arrangement in such a manner that a thermal interaction region is formed for thermally coupling the heat transfer medium with the heat storage material and a control unit for controlling the operation of the device. The heat exchanger arrangement is adapted to (a) transport the heat transfer medium from the first end to the second end, if the device is in a first operational mode, in which the heat storage material receives thermal energy from the heat transfer medium and (b) transport the heat transfer medium from the second end to the first end, if the device is in a second operational mode, in which the heat storage material releases thermal energy to the heat transfer medium. The thermal interaction region has at least such a physical length along a transport direction of the heat transfer medium and the control unit is configured for operating the device in such a manner, that when storing thermal energy with a hot heat transfer medium or when recovering thermal energy with a cold heat transfer medium within the device there exists a region (R) where the inlet and outlet temperature of the heat transfer medium of this region is kept constant. Further, a corresponding method and a system comprising such a device are described.

DESCRIPTION

Thermal energy storage and recovery with a heat exchanger arrangement having an extended thermal interaction region

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Field of invention

The present invention relates to the field of temporarily storing thermal energy. In particular, the present invention relates to a thermal energy storage and recovery device comprising a heat exchanger arrangement and a heat storage material. Further, the present invention relates to a thermal energy storage and recovery system comprising such a thermal energy storage and recovery device and to a method for storing and recovering thermal energy with such a thermal energy storage and recovery device.

20 Art Background

The production of electric power from various types of alternative energy sources such as for instance wind turbines, solar power plants and wave energy plants is not continuous. The production may be dependent on environmental parameters such as for instance wind speed (for wind turbines), sunshine intensity (for solar power plant) and wave height and direction (for wave energy plants). There is very often little or no correlation between energy production and energy demand.

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One known approach to solve the problem of uncorrelated electric power production and electric power demand is to temporally store energy, which has been produced but which has not been demanded, and to release the stored energy at times at which there is a high demand. In the past there have been suggested many different methods to temporarily store energy. Suggested methods are for instance (a) mechanical

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energy storage methods e.g. pumped hydro storage, compressed
air storage and flywheels, (b) chemical energy storage meth-
ods e.g. electrochemical batteries and organic molecular
storage, (c) magnetic energy storage, and (d) thermal energy
5 storage.

WO 9214054 A1 discloses a wind-powered energy production and
storing system comprising a wind rotor in driving engagement
with a power generator via transmission means, to which is
10 also connected a heat pump for operation of at least one heat
exchanger unit. The wind rotor is designed as a wind wheel
having a rim in direct driving engagement with a main shaft
positioned in a subjacent engine housing to which main shaft,
in addition to the power generator and the heat pump, a dual
15 circulation pump is coupled for conveying heated and cooled
liquid, from a heating container and a cooling container,
respectively, positioned in the engine housing to separate
heat and cold storing stations. Via a steam separator and a
pumping device, a steam generator may be connected to the
20 heat storing station which via a steam turbine drives an
additional power generator for power production during peri-
ods of slack winds. The storing stations may be buried in
soil having a filling of sand, stones or similar materials.
One disadvantage of this wind-powered energy production and
25 storing system is that there is a direct mechanical connec-
tion between the energy storage and recovery system and the
wind turbine and that all the energy storage equipment,
besides the storing stations, is placed in the wind turbine
resulting in a complex mechanical arrangement of the system
30 components. This causes the known system to be not flexible.

There may be a need for improving the temporal storage of
thermal energy in particular with respect to the flexibility
and the efficiency of a thermal energy storage and recovery
35 system.

Summary of the Invention

This need may be met by the subject matter according to the independent claims. Advantageous embodiments of the present invention are described by the dependent claims.

According to a first aspect of the invention there is provided a thermal energy storage and recovery device comprising a heat exchanger arrangement, which is configured for guiding a flow of a heat transfer medium between a first end of the heat exchanger arrangement and a second end of the heat exchanger arrangement, a heat storage material, which surrounds the heat exchanger arrangement in such a manner that a thermal interaction region is formed for thermally coupling the heat transfer medium with the heat storage material and a control unit for controlling the operation of the thermal energy storage and recovery device. The heat exchanger arrangement is adapted to (a) transport the heat transfer medium from the first end to the second end, if the thermal energy storage and recovery device is in a first operational mode, in which the heat storage material is supposed to receive thermal energy from the heat transfer medium and (b) transport the heat transfer medium from the second end to the first end, if the thermal energy storage and recovery device is in a second operational mode, in which the heat storage material is supposed to release thermal energy to the heat transfer medium. Further, the thermal interaction region has at least such a physical length along a transport direction of the heat transfer medium and the control unit is configured for operating the thermal energy storage and recovery device in such a manner, that when storing thermal energy with a hot heat transfer medium or when recovering thermal energy with a cold heat transfer medium within the thermal energy storage and recovery device there exists a region where the inlet and outlet temperature of the heat transfer medium of this region is kept at least substantially constant.

The described thermal energy storage and recovery device is based on the idea that by employing different transport directions of the heat transfer medium for different operational modes, wherein the physical length of the thermal interaction region is larger than a predetermined lengthwise extension, a highly efficient thermal energy storage can be realized. Specifically, the combination of (a) different transport directions for the two different operational modes and (b) a long physical length allow for achieving an outlet temperature of the heat transfer medium at least at some time during the second operational mode, which outlet temperature is not significantly smaller than the inlet temperature of the heat transfer medium at least at some time during the first operational mode. This means that the during the second operational mode the heat transfer medium can be received from the thermal energy storage and recovery device almost with the same (high) temperature as compared to the temperature with which the heat transfer medium is provided to the thermal energy storage during the first operational mode. In this way, if the hot heat transfer medium comprises heated steam, the heated up (originally) cold heat transfer medium may also comprise heated steam which then may be used directly to drive a steam turbine without any further heating means. Thereby, the efficiency of the heat storage process can be significantly increased.

The described principle of using (a) a first transport direction from the first end to the second end for charging the heat storage material with thermal energy and (b) an opposite second transport direction from the second end to the first end for discharging the heat storage material from thermal energy can be interpreted as employing a counter current principle .

Specifically, in the first operational mode (i.e. charging the heat storage material with thermal energy) , a hot heat

transfer medium is let into the first end. After having transferred at least a part of its thermal energy the at least partially cooled down heat transfer medium is returned at the second end. Correspondingly, in the second operational mode (i.e. discharging thermal energy from the heat storage material), a comparatively cold heat transfer medium is let into the second end. After having received thermal energy from the heat storage material the at least partially heated up heat transfer medium is returned at the first end.

In other words, when taking benefit from the described counter current principle the inlet end of the heat exchanger arrangement for hot heat transfer medium when charging the thermal energy storage and recovery device may be the same as the outlet end of the heat exchanger arrangement for heated up heat transfer medium when discharging the thermal energy storage and recovery device. Correspondingly, the outlet end of the heat exchanger arrangement for cooled down heat transfer medium when charging the thermal energy storage and recovery device may be the same as the inlet end of the heat exchanger arrangement for cold heat transfer medium when discharging the thermal energy storage and recovery device.

The heat transfer medium may be a fluid, i.e. a liquid or a gaseous medium. Preferably, the heat transfer medium may be compressed air or a superheated steam at least when the heat transfer medium is at its higher temperature. This may mean that when charging thermal energy into the described thermal energy storage and recovery device, the heat transfer medium, which is inserted into the heat exchanger arrangement, is at least partially gaseous. When the heat transfer medium leaves the heat exchanger arrangement it may have become liquid again. Correspondingly, when discharging or extracting thermal energy from the described thermal energy storage and recovery device, a cold liquid fluid may be heated up such that it is converted into a gaseous or at least partially gaseous steam. This may be in particular advantageous if the

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extracted thermal energy is used for driving a steam turbine which itself drives an electric power generator.

Because of the described long physical length of the thermal interaction region between the heat transfer medium and the heat storage material in combination with the above described counter current heat exchange principle it can be ensured that the temperature gradients of the thermal storage unit for both charging with a hot fluid (thermal energy storing fluid) and discharging with a cold fluid (thermal energy recovering fluid) are maintained nearly constant throughout the length of the stream of the counter current system. Further, it can be ensured that the inlet and outlet temperature of the thermal storage unit is also nearly constant.

Having a long physical length of the heat exchanger arrangement together with the use of the counter current heat exchange principle may ensure that a nearly constant inlet and outlet temperature of the thermal energy storage and recovery device can be realized. This makes it quite easier to control connected equipment for recovering the stored energy and supplying electrical power to a power grid.

By having a constant outlet temperature of the discharged heat transfer medium a high efficiency can be maintained during the complete thermal energy discharge cycle. This is a big advantage compared to other energy storage solutions such as batteries where the efficiency is reduced during discharge and varies at different discharge rates. The described thermal energy storage and recovery device is also much more efficient than known devices having a smaller interaction region, wherein typically the temperature of the whole heat storage material gradually decreases during a discharge cycle (= second operational mode) resulting in a reduced efficiency.

According to an embodiment of the invention the described region, where the inlet and outlet temperature of the heat transfer medium of the region is kept constant, is longer than other regions of the thermal energy storage and recovery device, where the respective inlet and outlet temperature of the heat transfer medium is not substantially constant.

According to an embodiment of the invention the physical length of the thermal interaction region is at least 200 m, preferably at least 500 m and in particular at least 1000 m.

By having a long physical length of the interaction region between the heat transfer medium and the heat storage material, i.e. the region wherein the heat exchanger arrangement is placed in the heat storage material, and by employing the counter current heat exchange principle it can be ensured that during the second operational mode (i.e. stored thermal energy is recovered from the thermal energy storage and recovery device) the temperature of the cold fluid is increased to the same or nearly the same temperature as the inlet temperature of the hot fluid. In this way, if the hot fluid being provided to the thermal energy storage and recovery device during the first operational mode comprises a temperature as high as a heated steam, the heated up cold fluid may also comprise or be converted to heated steam which then may be used directly to drive a steam turbine without any further heating means. Thereby, a high efficiency of the thermal energy storage capability of the described thermal energy storage and recovery device can be realized.

The first end and the second end may be located at one and the same side of the thermal energy storage and recovery device. By placing the inlet end and the outlet end of the heat exchanger arrangement relatively close to each other a heat loss caused by long fluid (heat transfer medium) feeding pipes and/or long fluid return pipes to or from the heat exchanger arrangement can be minimized.

According to a further embodiment of the invention the heat exchanger arrangement comprises (a) a first heat exchange section being associated with the first end, (b) a second heat exchange section being associated with the second end, (c) a first connecting section connecting the first heat exchange section with the second heat exchange section and (d) a second connecting section connecting the first heat exchange section with the second heat exchange section parallel to the first connecting section. At least one of the connecting sections comprises a valve for controlling the flow of the heat transfer medium through the respective connecting section. This may provide the advantage that the heat exchange capacity of the heat exchanger arrangement and/or the thermal energy storage capacity of the thermal energy storage and recovery device can be adapted to actual operating conditions. For instance by closing (opening) the valve the effective amount or mass of the heat storage material, which contributes to the described thermal heat storage, can be reduced (increased). The same holds for the overall heat transfer rate between the heat exchanger arrangement and the heat storage material.

Generally speaking, by changing the setting or the adjustment of the valve a decrease or an increase of the heat exchange capacity and of the thermal energy storage capacity may be realized. Thereby, the thermal energy storage and recovery device can be adapted to currently present operating conditions.

It is mentioned that apart from one or more valves also heating means and/or cooling means like e.g. heating circuits and/or cooling circuits may be used for operating the thermal energy storage and recovery device within an energy storage and recovery system in order to optimize the inlet and/or outlet temperatures of the described thermal energy storage

and recovery device. Thereby, the energy storage efficiency may be further increased.

5 It is further mentioned that one or more of the valves may be thermostat controlled and/or remote controlled.

According to a further embodiment of the invention the thermal energy storage and recovery device further comprises thermal insulating means (a) for thermally isolating the
10 whole thermal energy storage and recovery device from its environment and/or (b) for thermally isolating different compartments of the thermal energy storage and recovery device from each other. This may provide the advantage that the thermal energy storage and recovery device can be at
15 least partially thermally decoupled from its surrounding environment and/or different compartments or regions of the device can be at least partially thermally decoupled from each such that the effective size of the thermal energy storage and recovery device can be optimized in view of given
20 operating conditions.

The thermal insulation means may comprise e.g. mineral wool, glass wool, rock wool or other preferably similar insulating materials .

25 According to a further embodiment of the invention the compartments are configured in such a manner that along the thermal interaction region a stepwise temperature gradient control can be realized such that in each compartment there
30 is a constant temperature and the temperatures of different compartments are different from each other.

According to a further embodiment of the invention the heat storage material comprises a solid material such as in particular
35 sand, soil, ashes, stones and/or gravel. Of course, also other materials which are preferably also relatively

cheap and which comprise similar thermal properties may be used .

5 According to a further embodiment of the invention the first end comprises a single first opening and the second end comprises a single second opening, wherein (i) in the first operational mode the first opening is used for receiving hot fluid and the second opening is used for emitting a cold fluid representing cooled down hot fluid and (ii) in the
10 second operational mode the second opening is used for receiving cold fluid and the first opening is used for emitting a hot fluid representing heated up cold fluid. This may provide the advantage that a single heat exchanger arrangement is sufficient for realizing the described counter current heat exchange principle.
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According to a further embodiment of the invention the thermal energy storage and recovery device further comprises a further heat exchanger arrangement, which is configured for
20 guiding a flow of a further heat transfer medium between a further first end of the further heat exchanger arrangement and a further second end of the further heat exchanger arrangement, and a further heat storage material, which surrounds the further heat exchanger arrangement in such a
25 manner that a further thermal interaction region is formed for thermally coupling the further heat transfer medium with the further heat storage material. The further heat exchanger arrangement is adapted to (a) transport the further heat transfer medium from the further first end to the further
30 second end, if the thermal energy storage and recovery device is in a further first operational mode, in which the further heat storage material is supposed to receive thermal energy from the further heat transfer medium and (b) transport the further heat transfer medium from the further second end to
35 the further first end, if the thermal energy storage and recovery device is in a further second operational mode, in which the further heat storage material is supposed to re-

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lease thermal energy to the further heat transfer medium. Furthermore, the further thermal interaction region has at least such a further physical length along a further transport direction of the further heat transfer medium and the control unit is further configured for operating the thermal energy storage and recovery device in such a manner, that when storing thermal energy with a hot heat transfer medium being guided within the further heat exchanger arrangement or when recovering thermal energy with a cold heat transfer medium being guided within the further heat exchanger arrangement within the thermal energy storage and recovery device there exists a further region where the inlet and outlet temperature of the heat transfer medium of this further region is kept constant. Thereby, this further region is longer than other further regions of the thermal energy storage and recovery device where the respective inlet and outlet temperature of the heat transfer medium is not constant.

This may provide the advantage that a further heat transfer medium can be used for charging and/or discharging the described thermal energy storage and recovery device. Thereby, the further heat transfer medium may be a different fluid than the heat transfer medium. Alternatively, the further heat transfer medium and the heat transfer medium may be the same fluid, which however are guided through different heat transfer pipes through the heat storage material.

The further heat storage material being associated with the further heat exchanger arrangement may be the same or may be a different material as compared to the heat storage material being associated with the above described heat exchanger arrangement.

The various inlet ends and outlet ends of both the heat exchanger arrangement and the further heat exchanger arrangement may also just be used to let originally cold fluid and

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originally hot fluid flow in separate chambers or tubes of the thermal energy storage and recovery device. Thereby, in order to recover stored energy only the originally cold fluid is flowing through the device and in order to store energy the originally hot fluid is flowing through the device.

According to a further embodiment of the invention the heat exchanger arrangement and the further heat exchanger arrangement form a counter current heat exchanger system. Thereby, the further heat transfer medium and the heat transfer medium are transportable simultaneously and the further heat transfer medium is transportable in an opposite direction with respect to the heat transfer medium.

Generally speaking, the described counter current heat exchanger system may let both heat transfer media travel through the respective pipes of the heat exchanger arrangement respectively of the further heat exchanger arrangement at the same time but in opposite directions with respect to each other. In this way the heat transfer media move in opposite directions along each other in separate chambers or tubes of the counter current heat exchanger system. Thereby, the velocity of the hot inlet flow into the counter current heat exchanger system may differ from the velocity of the cold inlet flow into the counter current heat exchanger system. This may provide the advantage that the stored thermal energy can be slowly tapped or slowly stored depending on the velocity of the cold and/or the hot inlet flows.

According to a further aspect of the invention there is provided a thermal energy storage and recovery system comprising (a) a thermal energy storage and recovery device as defined above, (b) a heat generating arrangement, which is connected directly or indirectly to the thermal energy storage and recovery device and which is adapted to heat up the heat transfer medium, which has been received from the thermal energy storage and recovery device and which is supposed

to be transported to the thermal energy storage and recovery device, and (c) a heat consumption arrangement, which is connected directly or indirectly to the thermal energy storage and recovery device and which is adapted to receive thermal energy from heat transfer medium, which has been heated up by the thermal energy storage and recovery device.

The described thermal energy storage and recovery system is based on the idea, that when the above described thermal energy storage and recovery device co-operates with a heat generating arrangement and with a heat consumption arrangement a highly efficient temporal heat storage and heat recovery can be realized.

The heat generating arrangement may be any device which is capable of converting energy, in particular electric energy, into thermal energy. The generated respectively converted thermal energy is then transferred to the thermal energy storage and recovery device via the heat transfer medium.

In case of a direct (thermal) connection between the thermal energy storage and recovery device and the heat generating arrangement, the heat transfer medium being used by the thermal energy storage and recovery device is the same as the operating medium of the heat generating arrangement. In case of an indirect connection different fluids may be used for the heat transfer medium and for the operating medium. The thermal connection between the two fluids may then be realized by means of a heat exchanger and/or by means of a condenser.

The heat consumption arrangement may be any device, which is capable of converting thermal energy into mechanical and/or electric energy which can be fed for instance into a power grid.

In case of a direct (thermal) connection between the thermal energy storage and recovery device and the heat consumption arrangement, the heat transfer medium being used by the thermal energy storage and recovery device is the same as the operating medium of the heat converting arrangement. In case of an indirect connection different fluids may be used for the heat transfer medium and for the operating medium. The thermal connection between the two fluids may then be realized for instance by means of a heat exchanger and/or by means of an evaporator.

Preferably, the thermal energy storage and recovery device comprises two heat exchanger arrangements, in particular the above described heat exchanger arrangement and the above described further heat exchanger arrangement, wherein one heat exchanger arrangement is associated with the heat generating arrangement and the other heat exchanger arrangement is associated with the heat consumption arrangement.

According to an embodiment of the invention the heat generating arrangement comprises (a) a compressor for feeding the thermal energy storage and recovery device with compressed hot heat transfer medium and (b) a turbine for receiving from the thermal energy storage and recovery device cooled down heat transfer medium. This may provide the advantage that any gas such as for instance compressed air can be used as the heat transfer medium for loading the thermal energy storage and recovery device with thermal energy. Since the thermal energy storage and recovery device will cool down the air during its passage through the heat exchanger arrangement of the thermal energy storage and recovery device, the air pressure at the outlet of the thermal energy storage and recovery device will be smaller than the pressure of the compressed air at the input of the thermal energy storage and recovery device.

According to a further embodiment of the invention the heat generating arrangement further comprises a motor driving the compressor. Thereby, the turbine is mechanically connected to the motor. This may provide the advantage that a high efficiency of the heat generating arrangement can be achieved.

Specifically, if the hot heat transfer medium or fluid comprises a hot compressed air as an inlet to the heat exchanger arrangement in the thermal energy storage and recovery device then a cooled compressed air may be returned at the outlet of the heat exchanger arrangement, wherein the cooled compressed air may be fed into an air-turbine which may be mechanically connected to a shaft being common for the air-turbine and for a compressor helping driving the compressor and thereby increasing the efficiency of the described thermal energy storage and recovery device.

The heat generating arrangement may comprise an electric boiler and/or a heat pump. This may provide the advantage that electric energy, which has been generated in particular by an alternative energy source such as a wind turbine, can be converted into heat which can be stored as thermal energy within the above described thermal energy storage and recovery device. In particular a heat pump may provide the advantage of a very efficient heat generation. When using a heat pump electric energy may be first converted into mechanical energy of a compressor, which in accordance with the well known physical principle of a heat pump compresses a gaseous heat pump medium and circulates the same around a closed loop comprising inter alia a condenser and an evaporator. Thereby, the energy being released within the condenser may be used to heat up the heat transfer medium which is then forwarded to the thermal energy storage and recovery device. In this respect it is mentioned that the described evaporator may be driven by air, by a further cooling means and/or by pumped return water e.g. from a district heating installation.

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According to a further embodiment of the invention the heat consumption arrangement comprises a steam turbine, which in the second operational state receives hot heat transfer medium from the thermal energy storage and recovery device.

5 This may provide the advantage that a highly efficient conversion of the recovered thermal energy can be achieved.

In this respect "hot heat transfer medium" may mean that because of its previous passage through the thermal energy storage and recovery device the originally cooler or cold heat transfer medium has been heated up.

A rotating shaft of the steam turbine may be connected to an electric power generator, which is capable of converting the mechanical energy being provided by the steam turbine into electric energy, which can be easily fed to a power grid and/or which can be directly consumed by at least one electric consumer.

20 The steam turbine may be connected to a condenser, wherein the operating medium of the steam turbine, after it has been delivered its energy to the steam turbine, is converted into its liquid phase.

25 The described condenser may be a part of a further closed loop, which apart from the steam turbine and the condenser may comprise inter alia a pump and an evaporator. Thereby, energy being released from the thermal energy storage and recovery device may be transferred to the steam turbine via the mentioned evaporator, wherein the operating medium of the steam turbine is transferred from the liquid phase into the gaseous phase.

35 The described condenser may be driven by air, by a further cooling means and/or by pumped return water from a district heating installation.

According to a further embodiment of the invention the heat consumption arrangement further comprises a circulation pump for feeding a cold heat transfer medium to the thermal energy storage and recovery device.

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In this respect "cold heat transfer medium" may mean that during its following passage through the thermal energy storage and recovery device the cold heat transfer medium will be heated up.

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According to a further embodiment of the invention the heat consumption arrangement further comprises a district heating installation system, which (a) receives heat transfer medium from the steam turbine and (b) provides heat transfer medium to the circulation pump.

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The district heating installation system may comprise a heat exchanger system which thermally connects the heat transfer medium with a fluid such as for instance water. Thereby, the district heating installation may receive comparatively cold water from a water installation via a water inlet and may provide hot or warm water to the water installation via a water outlet.

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It is mentioned that the thermal energy storage and recovery system may further comprise a control unit, which is connected to at least one of (a) the thermal energy storage and recovery device, (b) the heat generating arrangement and (c) the heat consumption arrangement. Thereby, the control unit is adapted to control the operation of the thermal energy storage and recovery system.

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Specifically, the control unit may be coupled to one or more of the following components: (a) compressor of the heat generating arrangement, (b) a valve of the heat generating arrangement, (c) at least one valve of the thermal energy storage and recovery device, (d) at least one circulation

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pump driving the heat transfer medium through the thermal energy storage and recovery device, (e) a (steam) turbine of the heat consumption arrangement, (f) a feed pump of the heat converting arrangement, (g) a circulation pump for a cold medium being cycled within a cold reservoir cycle, wherein the cold medium drives (g1) an evaporator of the heat generating arrangement (realized by means of the above described heat pump) and/or (g2) a condenser of the heat consumption arrangement (comprises inter alia a steam turbine).

According to a further aspect of the invention there is provided a method for storing and recovering thermal energy with a thermal energy storage and recovery device having a heat exchanger arrangement, which comprises a first end and a second end, and a heat storage material, which surrounds the heat exchanger arrangement in such a manner that a thermal interaction region is formed for thermally coupling a heat transfer medium being guided within the heat exchanger arrangement with the heat storage material. The provided method comprises (a) transporting the heat transfer medium from the first end to the second end, if the thermal energy storage and recovery device is in a first operational mode, in which the heat storage material is receiving thermal energy from the heat transfer medium, and (b) transporting the heat transfer medium from the second end to the first end, if the thermal energy storage and recovery device is in a second operational mode, in which the heat storage material is releasing thermal energy to the heat transfer medium. Further, the thermal energy and storage device is operated in such a manner and the thermal interaction region has at least such a physical length along a transport direction of the heat transfer medium, that when storing thermal energy with a hot heat transfer medium or when recovering thermal energy with a cold heat transfer medium within the thermal energy storage and recovery device there exists a region where the inlet and outlet temperature of the heat transfer medium of this region is kept at least substantially constant.

The described method is based on the idea that when a thermal energy and recovery device is operated in such a manner that a region develops, wherein the inlet and outlet temperature of the heat transfer medium of this region is kept substantially constant, a maximum temperature difference between the inlet temperature of the heat transfer medium entering this region and the outlet temperature of the heat transfer medium leaving this region can be achieved. Thereby, the efficiency of the energy storage and recovery procedure can be maximized.

Specifically, when charging the heat storage material with thermal energy the inlet temperature of the originally hot heat transfer medium entering this region will be at least almost the same as the temperature of the (hot) heat transfer medium entering the whole thermal energy storage and recovery device. Further, the outlet temperature of the cooled down heat transfer medium leaving this region will be at least almost the same as the temperature of the heat transfer medium leaving the whole thermal energy storage and recovery device .

Correspondingly, when discharging the heat storage material the originally cold heat transfer medium entering this region will be at least almost the same as the temperature of the (cold) heat transfer medium entering the whole thermal energy storage and recovery device. Further, the outlet temperature of the heated up heat transfer medium leaving this region will be at least almost the same as the temperature of the heat transfer medium leaving the whole thermal energy storage and recovery device.

It is mentioned that by increasing the physical length of the thermal interaction region along the transport direction of the heat transfer medium this region having a constant inlet and outlet temperature will become larger. Therefore, by

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increasing the physical length of the thermal interaction region the efficiency of the whole thermal energy storage and recovery procedure can be significantly increased.

5 It has to be noted that embodiments of the invention have been described with reference to different subject matters. Specifically, some embodiments have been described with reference to claims being directed to a thermal energy stor-
age and recovery device whereas other embodiments have been
10 described with reference to claims being directed to a thermal energy storage and recovery system or to a method for storing and recovering thermal energy with such a thermal energy storage and recovery device. However, a person skilled in the art will gather from the above and the following
15 description that, unless other notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters is considered as to be disclosed with this document. Further, when taking benefit of the
20 disclosure of this document the person skilled in the art will understand the operation of the described thermal energy storage and recovery device and system.

The aspects defined above and further aspects of the present
25 invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of embodi-
ment but to which the invention is not limited.

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Brief Description of the Drawing

Figure 1 shows a sectional top view of a thermal energy
35 storage and recovery device with a heat exchanger arrangement, which comprises a first heat exchange section being associated with the first end, a second heat exchange section

being associated with the second end and three connecting sections connecting in parallel the first heat exchange section with the second heat exchange section.

5 Figure 2 shows a sectional top view of the thermal energy storage and recovery device depicted in Figure 1.

Figure 3 shows a thermal energy storage and recovery device with a lengthy heat exchanger arrangement and the correspond-
10 ing temperature behavior along the pipe of the lengthy heat exchanger arrangement.

Figure 4 shows a schematic illustration of a thermal energy storage and recovery system in accordance with a first em-
15 bodiment of the invention.

Figure 5 shows a schematic illustration of a thermal energy storage and recovery system in accordance with a second
20 embodiment of the invention.

Figure 6 illustrates the temperature behavior along the pipe of a heat exchanger arrangement having a long thermal inter-
action length with the surrounding heat storage material when the thermal energy storage and recovery device is charged in
25 several steps by a hot inlet heat transfer medium.

Figure 7 illustrates a stepwise temperature behavior along a pipe of a heat exchanger arrangement, wherein the thermal
energy storage and recovery device comprises different com-
30 partments being thermally isolated from each other.

Figure 8 illustrates a temperature gradient along the pipe of a heat exchanger arrangement, wherein during a thermal charg-
ing the temperature gradient moves in one direction and
35 during a thermal discharging the temperature gradient moves in the opposite direction.

Detailed Description

The illustration in the drawing is schematically. It is noted
5 that in different figures, similar or identical elements are
provided with the same reference signs or with reference
signs, which are different from the corresponding reference
signs only within the first digit.

10 Figure 1 shows a sectional top view of a thermal energy
storage and recovery device 100. The thermal energy storage
and recovery device 100 comprises a casing 102, which com-
prises an insulating material. Therefore, the casing 102
15 represents an outer insulation wall 108 of the thermal energy
storage and recovery device 100. The thermal energy storage
and recovery device 100 further comprises inner insulation
walls 104, which segment the volume of the thermal energy
storage and recovery device 100 into different regions.
20 According to the embodiment described here both the outer
insulation walls 108 and the inner insulation walls 104
comprise a mineral wool.

The casing 102 is filled with a heat storage material 108.
25 The heat storage material 108 may comprise sand, soil, ashes,
gravel, stone and/or other kind of solid material, which
preferably comprises a large specific heat capacity. The
whole thermal energy storage and recovery device 100 is
embedded within ground 120, which may also comprise soil,
30 gravel, stones, rock, ashes and/or sand or similar materials.

The thermal energy storage and recovery device 100 further
comprises a heat exchanger arrangement 110. The heat ex-
changer arrangement 110 is embedded with the heat storage
35 material 108. The heat exchanger arrangement 110 comprises a
first heat exchange section 112 being associated with a first
end 112a of the heat exchanger arrangement 110, a second heat

exchange section 114 being associated with a second end 114a of the heat exchanger arrangement 110 and three connecting sections 116, 117 and 118 connecting in parallel the first heat exchange section 112 with the second heat exchange section 114. Within each connecting sections 116, 117 and 118 there is provided a valve 116a, 117a and 118a, respectively. The valves 116a, 117a and 118a can be controlled by a non depicted control unit such that each of the three connecting sections 116, 117 and 118 can be opened, closed or partially opened/closed individually. By closing one or more of the valves 116a, 117a and 118a a flow of heat transfer medium through the heat exchanger arrangement 110 can be controlled. Thereby, sub-regions of the thermal energy storage and recovery device 100, which are associated with a closed valve, can be effectively decoupled from the remaining regions of the thermal energy storage and recovery device 100. This means that by opening one valve and closing one or more of the other valves the energy storage capacity may be decreased or increased as the used capacity of the heat exchanger arrangement 100 is decreased or increased.

The described thermal energy storage and recovery device 100 may be of the size of more than 1000 m long, 100 m wide and 5 m deep. This results in a volume of 500, 000 m³. As has already been mentioned above the heat storage material may be sand filled with sand, which has a specific heat capacity of 0,8 kJ/(kg K) and a sand density of 1740 kg/m³. When the sand 108 is heated up from a temperature of 20°C to 200°C (=temperature difference of 180°C), this results in a heat storage capacity of up to 125280 GJ. This corresponds to 34.8 GWh.

Of course, also thermal energy storage and recovery devices having other sizes and other operating temperatures may be used in order to get other heat storage capacities.

When operating the thermal energy storage device 100 different operational modes are used (a) for charging the thermal energy storage and recovery device 100 with thermal energy and (b) for discharging the thermal energy storage and recovery device 100, i.e. for retrieving thermal energy from the thermal energy storage and recovery device 100. Specifically, in a first operational mode in which the thermal energy storage and recovery device 100 is charged by receiving thermal energy from the heat transfer medium, the heat transfer medium is transported from the first end 112a to the second end 114a. In a second operational mode in which the thermal energy storage and recovery device 100 is discharged by providing thermal energy to the heat transfer medium, the heat transfer medium is transported from the second end 114a to the first end 112a. This dependency of the transport direction of the heat transfer medium from the operational state can be seen as employing a counter current principle. By using this counter current principle, when thermal energy is recovered from the thermal energy storage and recovery device 100, it is possible to heat up the cold heat transfer medium to nearly the same temperature as the inlet temperature of the hot heat transfer medium when thermal energy is inserted into the thermal energy storage and recovery device 100. This makes the thermodynamic efficiency of the described thermal energy storage and recovery device 100 very high.

It is mentioned that according to the embodiment described here the thermal energy storage and recovery device 100 further comprises a further not depicted further heat exchanger arrangement having a further first heat exchange section with a further first end and a further second heat exchange section with a further second end. Hot fluid may then be fed into one of the first ends and returned in one of the second ends and a cold fluid may be fed into the other first end and returned in the other second end using the counter current principle. Thereby, with respect to the heat

exchanger arrangement 110 the further heat exchanger arrangement may comprise separate cavities or tubes.

5 Figure 2 shows a sectional top view of the thermal energy storage and recovery device 100. The ends 112a and 114a of the heat exchanger arrangement 100 can be seen on the front side of the thermal energy storage and recovery device 100. Further, in accordance with the embodiment described above,
10 on the right side of the thermal energy storage and recovery device 100 there are provided the first end 112a and a further first end 112b of the further heat exchanger arrangement. Accordingly, on the left side of the thermal energy storage and recovery device 100 there are provided the second
15 end 114a and a further second end 114b of the further heat exchanger arrangement.

It is mentioned that in the orientation depicted in Figure 2 the thermal energy storage and recovery device 100 may be
20 placed down into the ground 120.

Figure 3 shows a thermal energy storage and recovery device 300 according to a further embodiment of the invention. The
25 thermal energy storage and recovery device 300 comprises a heat exchanger arrangement 310 and a further heat exchanger arrangement 311. Both heat exchanger arrangements 310 and 311 have a long physical interaction length with heat storage material 308 .

30 As can be seen from Figure 3, the thermal energy storage and recovery device 300 is divided into several compartments 305, which are separated from each other via inner insulation walls 304.

35 The heat exchanger arrangement 310 comprises an inlet end 312a and an outlet end 314a. The further heat exchanger

arrangement 311 comprises an inlet end 314b and an outlet end 312b. For storing thermal energy into the thermal energy storage and recovery device 300 a hot charging fluid with a temperature t_1 is fed into the inlet end 312a and is returned via the outlet end 314a with the temperature t_2 . For recovering thermal energy from the thermal energy storage and recovery device 300 a comparatively cold discharging fluid with a temperature t_3 is fed into the inlet end 314b and is returned via the outlet 312b with a temperature t_4 .

As can be seen in the bottom of Figure 3, the discharging fluid reaches almost the same temperature t_4 as the inlet temperature t_1 of the charging fluid. This advantageous temperature behavior is realized because of two reasons:

(A) The long thermal interaction length between (a) the heat exchanger arrangement 310 and the further heat exchanger arrangement 311 and (b) the heat storage material 308. In the embodiment described here this thermal interaction length is 1000 m.

(B) The use of a counter current heat exchange principle for charging/discharging the thermal energy storage and recovery device 300, where the temperature gradients for both charge and discharge of the thermal energy storage and recovery device 300 are maintained at least approximately constant throughout the length of the stream of the counter current system. The temperature curve for the discharge fluid looks almost the same as the temperature curve for the charge fluid, it is just displaced by a distance d while the inlet temperature and outlet temperature are the same or nearly the same for the two fluids.

Figure 4 shows a schematic illustration of a thermal energy storage and recovery system 430 in accordance with a first embodiment of the invention. To store energy within a thermal energy storage and recovery device 400 a heat generating arrangement 470 is used. To recover energy from the thermal

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energy storage and recovery device 400 a heat consumption arrangement 490 is used.

As can be seen from Figure 4, the heat generating arrangement 470 comprises a compressor 472, which is driven by a motor 476. The compressor 472 comprises an air inlet 472a. The air in the air inlet 472a may have a temperature of e.g. 20 Celsius degrees and a pressure of e.g. 1 bar. During compression of the air the pressure may rise to e.g. 25 bar and the temperature may rise to e.g. 500 Celsius degrees. This heated up and compressed air is fed into an inlet of a heat exchanger arrangement 410 of the thermal energy storage and recovery device 400. The compressed air then returns via an outlet of the heat exchanger arrangement 410 now having a temperature of e.g. 20 Celsius degrees and a pressure of still nearly 25 bar.

The compressed outlet air is then fed into an air turbine 474. According to the embodiment described here the air turbine 474 and the motor 476 and the compressor 472 have a common shaft 477. This provides the advantage that the air turbine 474 will help the motor 476 driving the compressor 472 such that the efficiency of the heat generating arrangement 470 will be increased.

The temperature of expanded outlet air being provided by the air turbine 474 via an air outlet 474a may e.g. fall to minus one degrees Celsius (-1°C) when the air is expanded from a pressure of 25 bar to 1 bar. This makes the expanded outlet air from the air turbine 474 suitable for cooling purposes, e.g. for air conditioning of the surrounding air in one or more rooms in one or more buildings.

To recover stored energy a cold fluid with a temperature of e.g. 20 degrees Celsius is fed into an inlet of a further heat exchanger arrangement 411 of the thermal energy storage and recovery device 400. According to the embodiment de-

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scribed here this is done by a circulation pump 492. The circulation pump 492 collects water from a district heating installation 498 which comprises a water inlet 498a.

5 After passage through the further heat exchanger arrangement 411 the fluid has an outlet temperature, which is significantly larger than the inlet temperature of the fluid at the inlet of the further heat exchanger arrangement 411. Due to (a) the described counter current fluid flow within the
10 thermal energy storage and recovery device 400 and (b) the long physical interaction length between the heat exchanger arrangement 411 and the heat storage material of the thermal energy storage and recovery device 400 the outlet temperature of the fluid leaving the further heat exchanger arrangement
15 411 is almost the same as the inlet temperature of the hot compressed air, which has entered the heat exchanger arrangement 410.

In this way the cold fluid is converted to steam which may be
20 further overheated by heating means (not depicted) before the steam is let into a steam turbine 494 which drives an electric power generator 496 through a shaft connection. Optionally, the steam may further be let into a condenser (not shown) where it turns into water. This condenser may be
25 driven by air (ambient air, stationary or ventilation) . Alternatively or in combination return water from the district heating installation 498 may be pumped through the condenser in order to cool the steam. The condensed water may
30 be pumped back to the district heating installation 498 and returned by a water outlet 498b of the district heating installation 498. The electric power generator 496 may be connected to a utility grid (not shown) as well as a wind turbine or other kind of alternative energy resources (not shown) .

35 In this way electrical energy produced by e.g. a wind turbine may be used by the motor 476 to drive the compressor 472 and

to feed compressed air through the thermal energy storage and recovery device 400 and to store the thermal energy in the heat storage material such as sand or other similar solid material with high heat capacity. In periods with no or with little wind or perhaps in periods with too high wind speeds where the wind turbines stands still water may be pumped through the thermal energy storage and recovery device 400 heating it up to steam which then drives the steam turbine 494. The steam turbine 494 drives the electrical power generator 496 which supplies electrical energy to the utility grid .

Figure 5 shows a schematic illustration of a thermal energy storage and recovery system 530 in accordance with a second embodiment of the invention. In this embodiment, a district heating installation or a thermal power generation plant 535 is connected to a utility grid 550 and to a thermal energy storage and recovery device 500. According to the embodiment described here the district heating installation or power generation plant 535 comprises a steam turbine 540 with a condenser (not shown) and a connected electrical power generator 545 and a compressor 572 with a built in motor. The compressor 572 may be replaced by an electrical boiler or may be supplemented by means of a heat pump system or other heating means.

The district heating installation or thermal power generation plant 535 is connected to the thermal energy storage and recovery device 500 both for energy storage and for recovering of stored energy. Also here a wind turbine 560 or other kind of alternative energy resources may be connected to the utility grid 550.

The compressor 572 with a built-in electrical motor may also comprise a mechanical connected air turbine (not shown) helping driving the compressor 572 together with the electri-

cal motor. The air turbine may be connected to an outlet of a heat exchanger arrangement of the thermal energy storage and recovery device 500 receiving the cooled compressed air in the outlet.

5

Figure 6 illustrates the temperature behavior along the pipe of a heat exchanger arrangement having a long thermal interaction length with the surrounding heat storage material when the thermal energy storage and recovery device is charged in several steps by an originally hot inlet heat transfer medium. On the abscissa there is plotted the length L of the heat exchanger arrangement running through the thermal energy storage and recovery device from an inlet end (first end) at a position L_1 to an outlet end (second end) L_2 . On the ordinate there is plotted the temperature T of the heat storage material .

In Figure 6 the charging steps are indicated with encircled numbers "1", "2", "3", "4", "5" and "6". Thereby, the step numbers reflect the sequence of the steps. Step 1 is performed at an initial state of the thermal energy storage and recovery device wherein all the heat storage material is at an initial low temperature. According to the embodiment described here this initial temperature is 20°C . Further, in this embodiment the temperature of the heat transfer medium, which is entering the thermal energy storage and recovery device at its first end L_1 is 500°C . It is mentioned that these temperatures are exemplary and that of course also other temperatures may be employed for operating the thermal energy storage and recovery device.

In the first shown three steps "1", "2" and "3" the charging heat transfer medium gets rid of all its thermal energy from a temperature of 500°C down to 20°C until the temperature of the outlet of the thermal energy storage device begins to rise beginning with step "4" from the initial temperature of

20°C up towards 500°C due to the fact that the thermal energy storage and recovering device gets more and more saturated by thermal energy. In the embodiment described here a full thermal saturation will show up shortly after step "6".

5

As can be seen from Figure 6, the most efficient charging region is a region R where the whole temperature difference can be used. In this region R the inlet temperature of this region R is at least approximately the same as the temperature (here 500°C) of the heat transfer medium which is supplied to the thermal energy storage and recovery device at its inlet end at the position LI. Further, the outlet temperature of the heat transfer medium leaving this region R is at least approximately the same as the temperature (here 20°C) of the heat transfer medium which is released from the thermal energy storage and recovery device at its outlet end at the position L2.

It can be elucidated from Figure 6 that a longer physical length of the thermal interaction region along the transport direction of the heat transfer medium of the thermal energy storage and recovery device increases the size of the most efficient charging region R.

It is pointed out that the inlet and outlet temperature of this efficient charging region R is substantial constant as long as the thermal energy storage and recovery device is in a state which corresponds to the thermal regime being represented by step "3".

30

When discharging, the area to the left of the efficient charging region R should be avoided as the temperature here drops down from the shown 500°C to the initial temperature of 20°C corresponding to the ambient temperature and/or the inlet temperature of the discharging fluid and it will require some thermal energy charging to reach again the fluid inlet temperature (here 500°C).

35

In other words a longer physical length of the thermal interaction region along a transport direction of the heat transfer medium of the thermal energy storage and recovery increases the region where the charging and the discharging of the thermal energy storage and recovery device is performed without reaching a thermal energy saturation level limiting the efficiency of the thermal energy storage and/or thermal energy recovery procedure.

Figure 7 illustrates a stepwise temperature behavior along a pipe of a heat exchanger arrangement, wherein the thermal energy storage and recovery device comprises different compartments being thermally isolated from each other. For charging thermal energy into the respective thermal energy storage and recovery device a hot fluid is fed into an inlet end being located on the left side of Figure 7 and cooled down fluid is outputted at an outlet end being located at the right side of Figure 7. As a consequence, compartments being located more to the left side will have a higher temperature than compartments being located more to the right side of Figure 7. Specifically, the compartment being located directly at the left input end will adopt a temperature t_1 (e.g. 560°C) and the compartment being located directly at the right output end will adopt a lower temperature t_2 (e.g. 20°C).

Figure 8 illustrates a temperature gradient along the pipe of a heat exchanger arrangement 810 which is surrounded by a heat storage material 808. As has already been mentioned above, the heat storage material 808 may comprise for instance sand, soil or spoil or any combination of these substances. A thermal energy storage and recovery device 800 being formed by the heat exchanger arrangement 810 and the surrounding heat storage material 808 is charged with thermal

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energy by inputting a hot fluid into the left end of the heat exchanger arrangement 810 and by outputting the cooled down fluid from the right end of the heat exchanger arrangement 810. Correspondingly, thermal energy is released from the thermal energy storage and recovery device 800 by inputting a cold fluid into the right end of the heat exchanger arrangement 810 and by outputting heated up fluid at the left end of the heat exchanger arrangement 810.

The thermal energy storage and recovery device 800 has such a physical length that when the thermal energy storage and recovery device 800 is partially loaded with thermal energy there has been developed a hot region 810a being located next to the left end of the heat exchanger arrangement 810, wherein the temperature within the hot region 810a is at least approximately constant at e.g. 560°C. Accordingly, there is a cold region 810c being located next to the right end of the heat exchanger arrangement 810, wherein the temperature within the cold region 810c is at least approximately constant at e.g. 20°C. In between the regions 810a and 810c there is an intermediate region 810b, wherein there is a comparatively strong temperature gradient between the hot temperature of the hot region 810a and the cold temperature of the cold region 810c. This situation is depicted in the insert diagram given directly below the thermal energy storage and recovery device 800.

When the thermal energy storage and recovery device 800 is further charged with thermal energy, the location of the intermediate region 810b comprising the described temperature gradient is shifted towards the right side. The resulting temperature profile is illustrated in the insert diagram being located on the bottom left side of Figure 8.

When the thermal energy storage and recovery device 800 is further discharged from thermal energy, the location of the intermediate region 810b comprising the described temperature

gradient is shifted towards the left side. The resulting temperature profile is illustrated in the insert diagram being located on the bottom right side of Figure 8.

- 5 The temperature gradient may preferably develop within a length of 10 to 20 meters or more depending on different physical parameters like e.g. the flow speed of the fluid passing the heat storage medium.
- 10 The thermal interaction region between the fluid and the heat storage medium 808 may have a length of 80 m, though preferably 500 m up to 1000 m or more.
- 15 It should be noted that the term "comprising" does not exclude other elements or steps and the use of articles "a" or "an" does not exclude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims
- 20 should not be construed as limiting the scope of the claims.

List of reference signs:

	100	thermal energy storage and recovery device
	102	casing / outer insulation wall
5	104	inner insulation wall
	108	heat storage material
	110	heat exchanger arrangement
	112	first heat exchange section
	112a	first end
10	112b	further first end
	114	second heat exchange section
	114a	second end
	114b	further second end
	116	first connecting section
15	116a	valve
	117	second connecting section
	117a	valve
	118	third connecting section
	118a	valve
20	120	ground
	300	thermal energy storage and recovery device
	304	inner insulation walls
	305	compartments
25	308	heat storage material
	310	heat exchanger arrangement
	311	further heat exchanger arrangement
	312a	inlet end
	312b	outlet end
30	314a	outlet end
	314b	inlet end
	T	temperature

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	400	thermal energy storage and recovery device
	410	heat exchanger arrangement
	411	further heat exchanger arrangement
	430	thermal energy storage and recovery system
5	470	heat generating arrangement
	472	compressor
	472a	air inlet
	474	air turbine
	474a	air outlet (for air conditioning)
10	476	motor
	477	common shaft
	490	heat consumption arrangement
	492	circulation pump
	494	steam turbine
15	496	electric power generator
	498	district heating installation
	498a	water inlet
	498b	water outlet
20	500	thermal energy storage and recovery device
	530	thermal energy storage and recovery system
	535	district heating installation / thermal power generation plant
	540	steam turbine
25	545	electric power generator
	550	utility grid
	560	wind turbine
	572	compressor
30	L	length
	LI	inlet end for heat transfer medium into thermal energy storage and recovery device
	L2	outlet end for heat transfer medium from thermal energy storage and recovery device
35	R	region with constant inlet and outlet temperature

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- 800 thermal energy storage and recovery device
- 808 heat storage material
- 810 heat exchanger arrangement
- 810a hot region
- 5 810b intermediate region
- 810c cold region

CLAIMS :

1. A thermal energy storage and recovery device comprising
5 a heat exchanger arrangement (110, 310, 410, 810), which is configured for guiding a flow of a heat transfer medium between a first end (112a) of the heat exchanger arrangement (110, 310, 410) and a second end (114a) of the heat exchanger arrangement (110, 310, 410, 810),
10 a heat storage material (108, 808), which surrounds the heat exchanger arrangement (110, 310, 410, 810) in such a manner that a thermal interaction region is formed for thermally coupling the heat transfer medium with the heat storage material (108, 808) and
15 a control unit for controlling the operation of the thermal energy storage and recovery device,
- wherein the heat exchanger arrangement (110, 310, 410, 810) is adapted to
(a) transport the heat transfer medium from the first end
20 (112a) to the second end (114a), if the thermal energy storage and recovery device (100, 300, 400, 500, 800) is in a first operational mode, in which the heat storage material (108, 808) is supposed to receive thermal energy from the heat transfer medium and
(b) transport the heat transfer medium from the second end
25 (114a) to the first end (112a), if the thermal energy storage and recovery device (100, 300, 400, 500, 800) is in a second operational mode, in which the heat storage material (108, 808) is supposed to release thermal energy to the heat transfer medium, and
30 - wherein the thermal interaction region has at least such a physical length along a transport direction of the heat transfer medium and the control unit is configured for operating the thermal energy storage and recovery device in such
35 a manner, that when storing thermal energy with a hot heat transfer medium or when recovering thermal energy with a cold heat transfer medium within the thermal energy storage and

recovery device there exists a region (R) where the inlet and outlet temperature of the heat transfer medium of this region (R) is kept constant.

5 2. The thermal energy storage and recovery device as set forth in the preceding claim, wherein the region (R), where the inlet and outlet temperature of the heat transfer medium of this region is kept constant, is longer than other regions of the thermal energy storage and recovery device where the
10 respective inlet and outlet temperature of the heat transfer medium is not constant.

3. The thermal energy storage and recovery device as set forth in any one of the preceding claims, wherein
15 the physical length of the thermal interaction region is at least 80 m, preferably at least 500 m and in particular at least 1000 m.

4. The thermal energy storage and recovery device as set
20 forth in any one of the preceding claims, wherein the heat exchanger arrangement (110) comprises
a first heat exchange section (112) being associated with the first end (112a),
a second heat exchange section (114) being associated
25 with the second end (114a),
a first connecting section (116) connecting the first heat exchange section (112) with the second heat exchange section (114) and
a second connecting section (117, 118) connecting the
30 first heat exchange section (112) with the second heat exchange section (114) parallel to the first connecting section (116),
wherein at least one of the connecting sections (116, 117, 118) comprises a valve (116a, 117a, 118a) for controlling the
35 flow of the heat transfer medium through the respective connecting section (116, 117, 118).

5. The thermal energy storage and recovery device as set forth in any one of the preceding claims, further comprising thermal insulating means (102, 104)

(a) for thermally isolating the whole thermal energy storage and recovery device (100, 300, 400, 500) from its environment and/or

(b) for thermally isolating different compartments (305) of the thermal energy storage and recovery device (100, 300, 400, 500) from each other.

6. The thermal energy storage and recovery device as set forth in the previous claim, wherein the compartments (305) are configured in such a manner that along the thermal interaction region a stepwise temperature gradient control can be realized such that in each compartment there is a constant temperature and the temperatures of different compartments (305) are different from each other.

7. The thermal energy storage and recovery device as set forth in any one of the preceding claims, wherein the heat storage material (108, 808) comprises a solid material such as in particular sand, soil, ashes, stones and/or gravel .

8. The thermal energy storage and recovery device as set forth in any one of the preceding claims, wherein the first end (112a) comprises a single first opening and the second end (114a) comprises a single second opening, wherein

- in the first operational mode the first opening is used for receiving hot fluid and the second opening is used for emitting a cold fluid representing cooled down hot fluid and
- in the second operational mode the second opening is used for receiving cold fluid and the first opening is used for emitting a hot fluid representing heated up cold fluid.

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9. The thermal energy storage and recovery device as set forth in any one of the preceding claims, further comprising

a further heat exchanger arrangement (311, 411), which is configured for guiding a flow of a further heat transfer medium between a further first end (112b) of the further heat exchanger arrangement (311, 411) and a further second end (114b) of the further heat exchanger arrangement (311, 411), and

a further heat storage material, which surrounds the further heat exchanger arrangement (311, 411) in such a manner that a further thermal interaction region is formed for thermally coupling the further heat transfer medium with the further heat storage material,

- wherein the further heat exchanger arrangement (311, 411) is adapted to

(a) transport the further heat transfer medium from the further first end (112b) to the further second end (114b), if the thermal energy storage and recovery device (100, 300, 400, 500) is in a further first operational mode, in which

the further heat storage material is supposed to receive thermal energy from the further heat transfer medium and

(b) transport the further heat transfer medium from the further second end (114b) to the further first end (112b), if the thermal energy storage and recovery device (100, 300,

400, 500) is in a further second operational mode, in which the further heat storage material is supposed to release thermal energy to the further heat transfer medium, and

- wherein the further thermal interaction region has at least such a further physical length along a further transport

direction of the further heat transfer medium and the control unit is further configured for operating the thermal energy storage and recovery device in such a manner, that when storing thermal energy with a hot heat transfer medium being guided within the further heat exchanger arrangement (311,

411) or when recovering thermal energy with a cold heat transfer medium being guided within the further heat exchanger arrangement (311, 411) within the thermal energy

storage and recovery device (100, 300, 400, 500) there exists a further region where the inlet and outlet temperature of the heat transfer medium of this further region is kept constant, wherein this further region is longer than other further regions of the thermal energy storage and recovery device where the respective inlet and outlet temperature of the heat transfer medium is not constant.

10. The thermal energy storage and recovery device as set forth in the preceding claim, wherein the heat exchanger arrangement (110, 310, 410) and the further heat exchanger arrangement (311, 411) form a counter current heat exchanger system, wherein the further heat transfer medium and the heat transfer medium are transportable simultaneously and wherein the further heat transfer medium is transportable in an opposite direction with respect to the heat transfer medium.

11. A thermal energy storage and recovery system comprising a thermal energy storage and recovery device (400) as set forth in any one of the preceding claims, a heat generating arrangement (470), which is connected directly or indirectly to the thermal energy storage and recovery device (400) and which is adapted to heat up the heat transfer medium, which has been received from the thermal energy storage and recovery device (400) and which is supposed to be transported to the thermal energy storage and recovery device (400), and a heat consumption arrangement (490), which is connected directly or indirectly to the thermal energy storage and recovery device (400) and which is adapted to receive thermal energy from heat transfer medium, which has been heated up by the thermal energy storage and recovery device (400).

12. The thermal energy storage and recovery system as set forth in the preceding claim, wherein

the heat generating arrangement (470) comprises

a compressor (472) for feeding the thermal energy storage and recovery device (400) with compressed hot heat transfer medium and

5 a turbine (474) for receiving from the thermal energy storage and recovery device (400) cooled down heat transfer medium.

13. The thermal energy storage and recovery system as set forth in the preceding claim, wherein

the heat generating arrangement (470) further comprises

a motor (476) driving the compressor (472), wherein the turbine is mechanically connected to the motor (476) .

15 14. The thermal energy storage and recovery system as set forth in the preceding claim, wherein

the heat consumption arrangement (490) comprises

a steam turbine (494), which in the second operational state receives hot heat transfer medium from the thermal energy storage and recovery device (400) .

15. The thermal energy storage and recovery system as set forth in the preceding claim, wherein

the heat consumption arrangement (490) further comprises

25 a circulation pump (492) for feeding a cold heat transfer medium to the thermal energy storage and recovery device (400) .

16. The thermal energy storage and recovery system as set forth in the preceding claim, wherein

the heat consumption arrangement (490) further comprises

a district heating installation system (498), which receives heat transfer medium from the steam turbine (494) and

35 which provides heat transfer medium to the circulation pump (492) .

17. Method for storing and recovering thermal energy with a thermal energy storage and recovery device having a heat exchanger arrangement (110, 310, 410, 810), which comprises a first end (112a) and a second end (114a), and a heat storage material (108), which surrounds the heat exchanger arrangement (110, 310, 410, 810) in such a manner that a thermal interaction region is formed for thermally coupling a heat transfer medium being guided within the heat exchanger arrangement (110, 310, 410, 810) with the heat storage material (108, 808), the method comprising

transporting the heat transfer medium from the first end (112a) to the second end (114a), if the thermal energy storage and recovery device (100, 300, 400, 500, 800) is in a first operational mode, in which the heat storage material (108, 808) is receiving thermal energy from the heat transfer medium, and

transporting the heat transfer medium from the second end (114a) to the first end (112a), if the thermal energy storage and recovery device (100, 300, 400, 500, 800) is in a second operational mode, in which the heat storage material (108, 808) is releasing thermal energy to the heat transfer medium,

wherein the thermal energy storage device is operated in such a manner and the thermal interaction region has at least such a physical length along a transport direction of the heat transfer medium, that when storing thermal energy with a hot heat transfer medium or when recovering thermal energy with a cold heat transfer medium within the thermal energy storage and recovery device there exists a region (R) where the inlet and outlet temperature of the heat transfer medium of this region (R) is kept substantial constant.

FIG 1

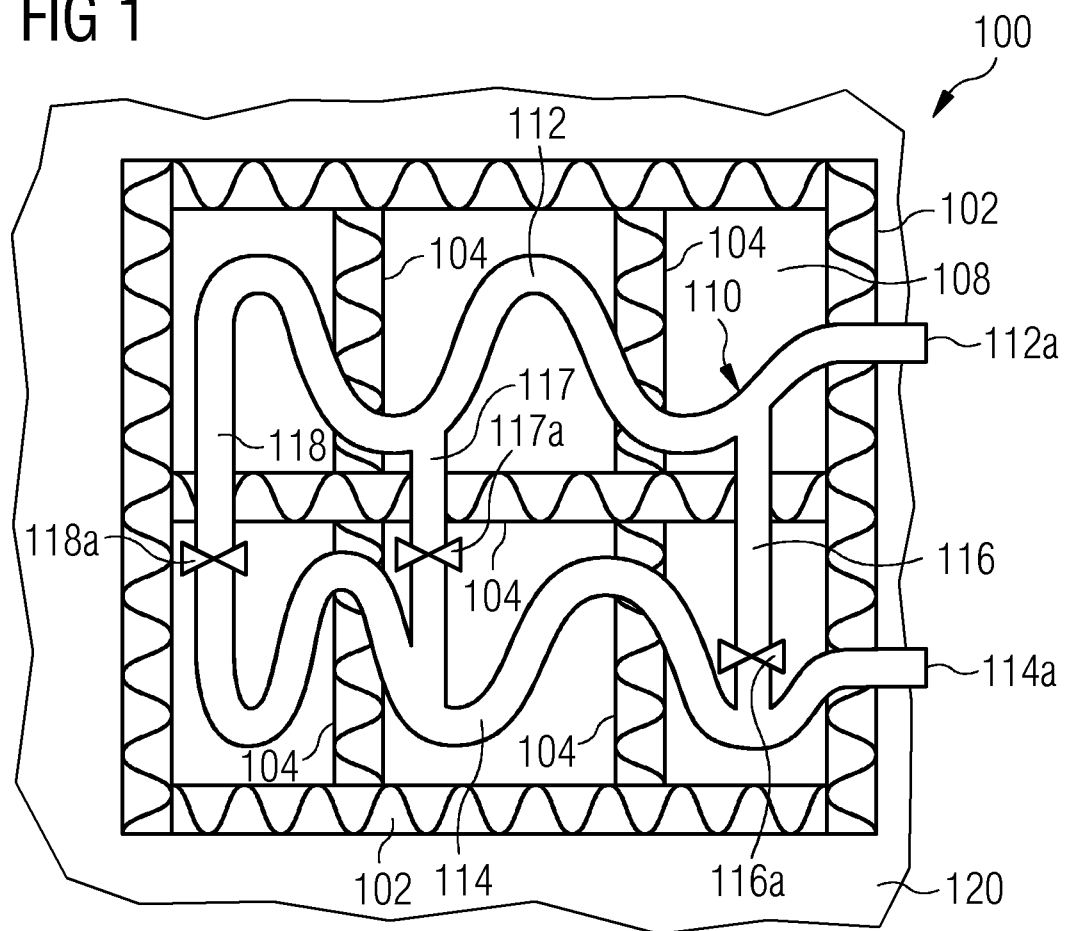


FIG 2

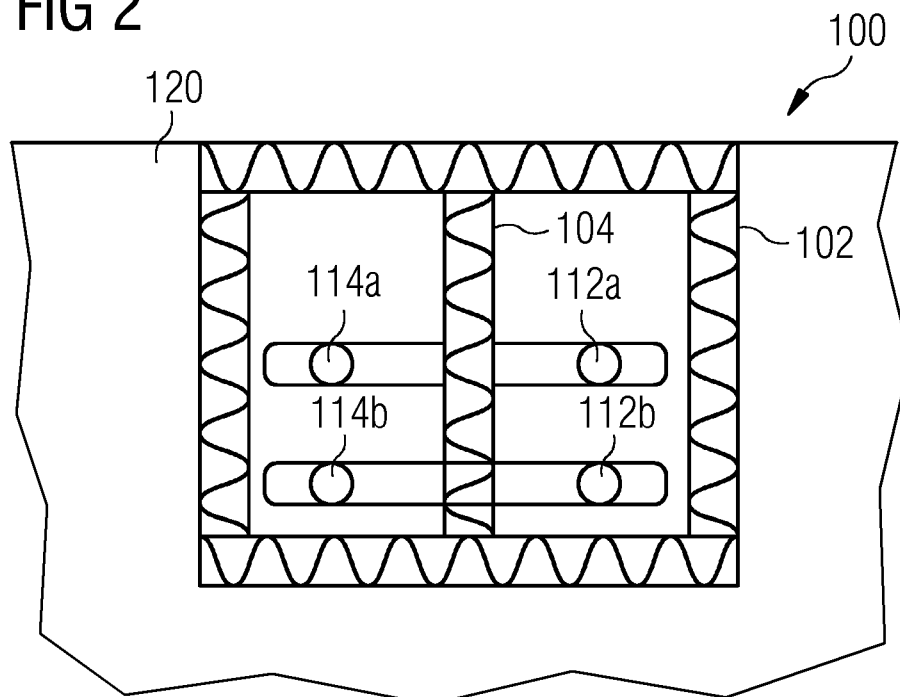


FIG 3

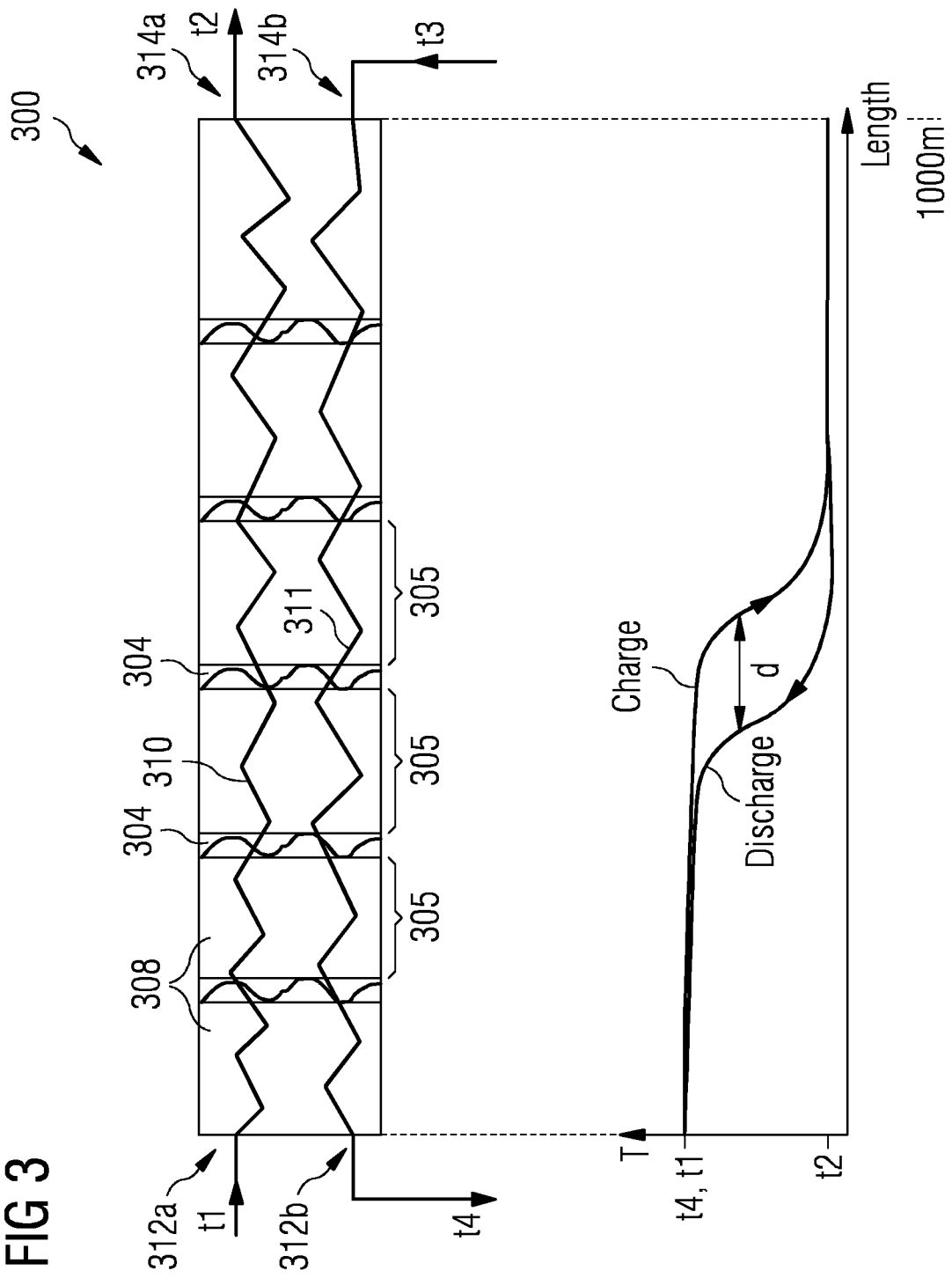


FIG 4

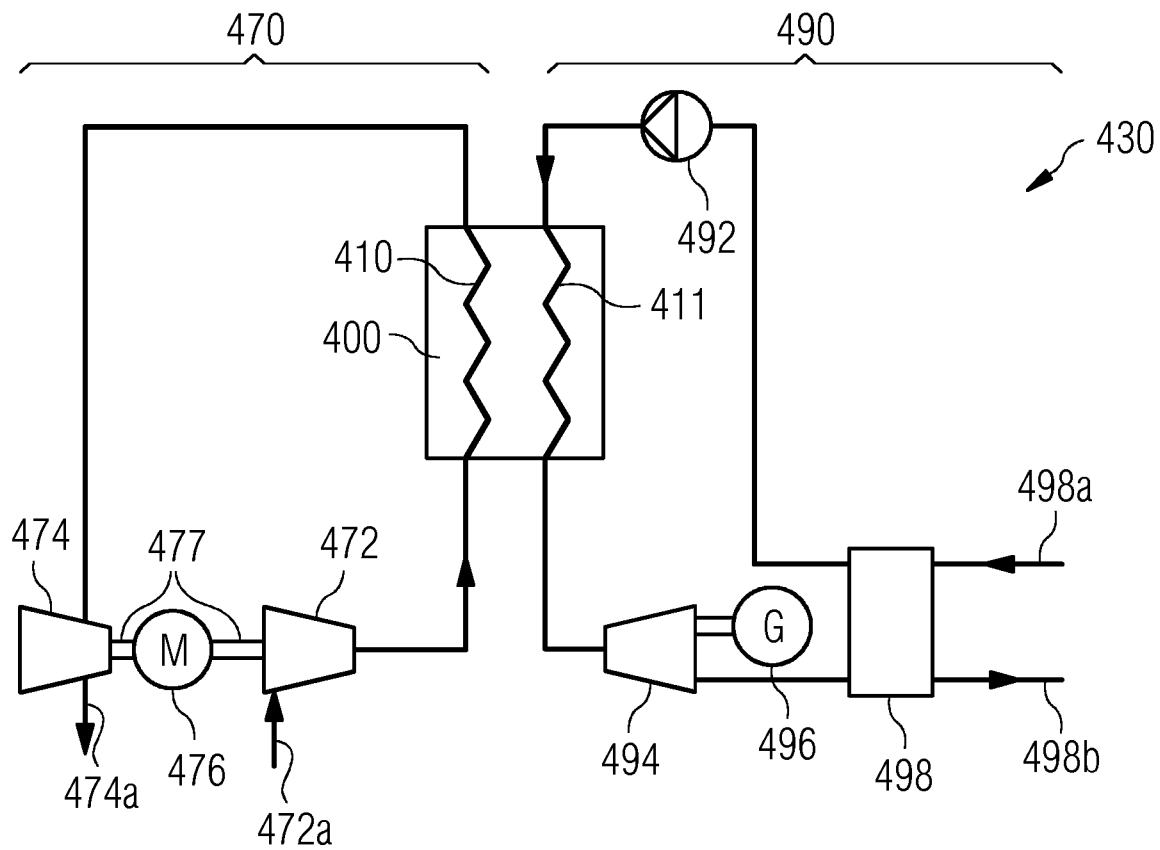


FIG 5

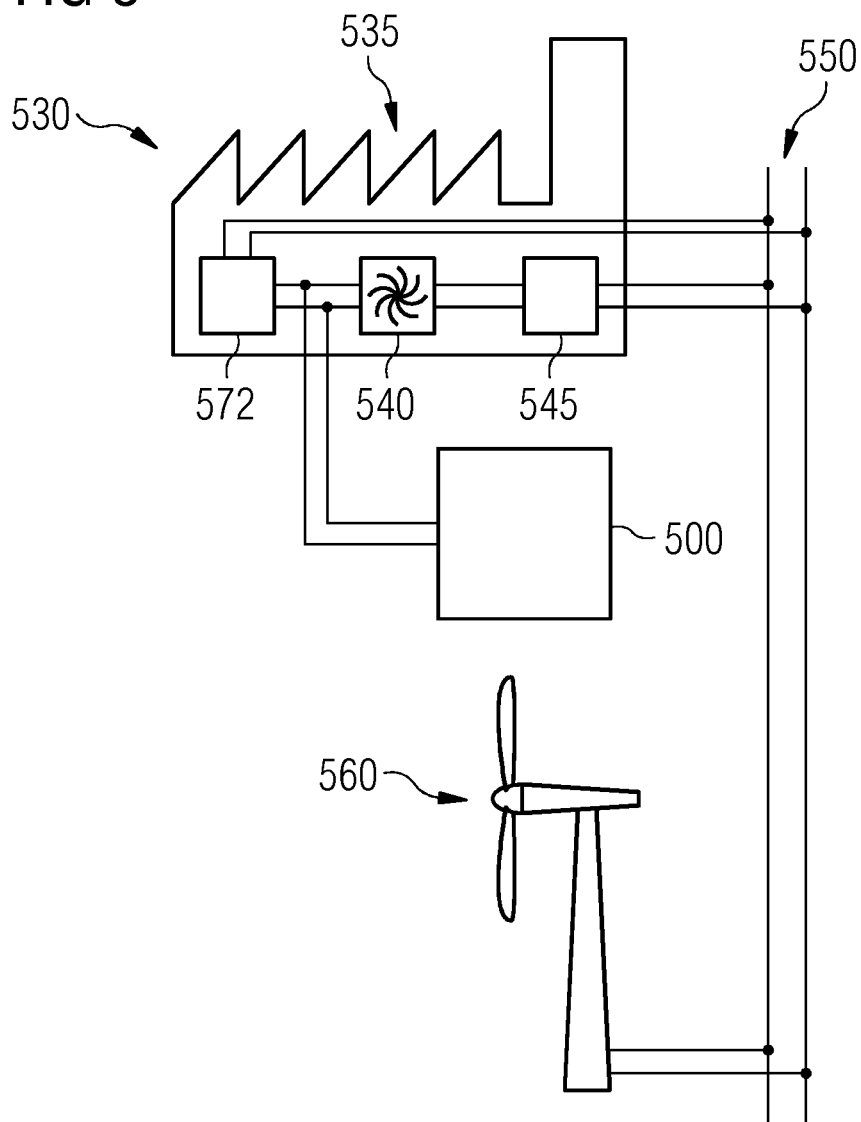


FIG 6

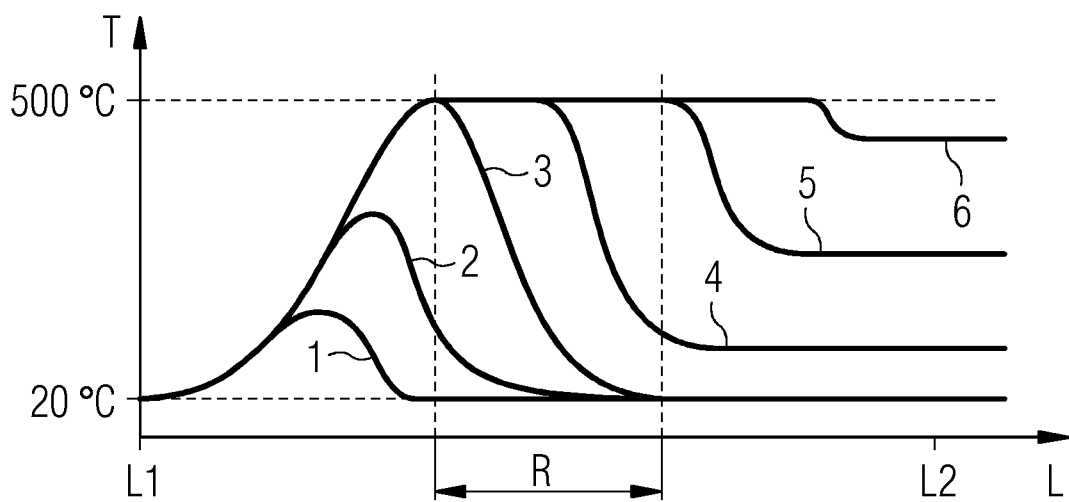


FIG 7

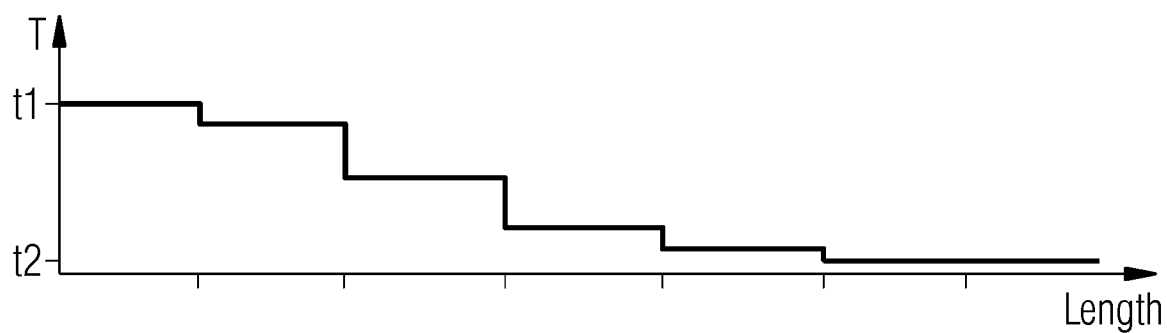


FIG 8

