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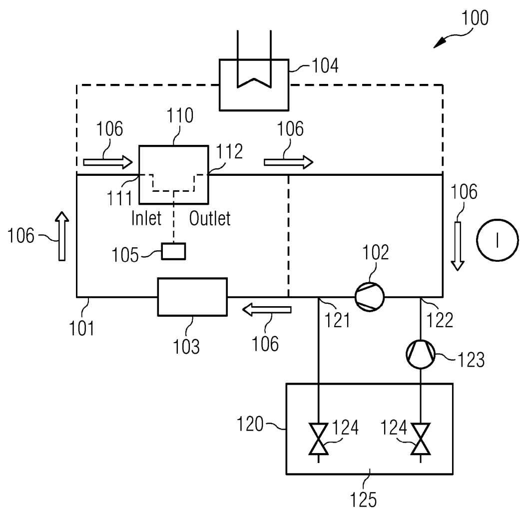
(54) DYNAMIC PRESSURE CONTROL IN A CLOSED LOOP HEAT STORAGE SYSTEM

(57) The present invention relates to a system (100) for storing heat energy comprising a fluid cycle (101) through which working fluid is streamable, and a heat storage device (110) configured for storing heat energy, wherein the heat storage device (110) comprises a first fluid opening (111) and a second fluid opening (112) each being coupled to the fluid cycle (101) such that the working fluid is streamable between the first fluid opening (111) and the second fluid opening (112) through heat storage device (110) transferring thermal energy between the heat storage device (110) and the working fluid. The system (100) further comprise a mass regulation device (120) which is coupled to the fluid cycle (101), wherein the mass regulation device (120) is configured for adjusting the mass of the working fluid in the fluid cycle (101) on the basis of the pressure and/or the temperature of the working fluid. A mass regulation device (120) is coupled to the fluid cycle (101), wherein the mass regulation device (120) is configured for adjusting the mass of the working fluid in the fluid cycle (101) on the basis of the pressure and/or the temperature of the working fluid, and wherein the mass regulation device (120) comprises a pressure control valve (124) for adjusting the pressure difference between fluid cycle (101) and the surrounding system, thereby adjusting the absolute pressure in the fluid cycle and thereby exhausting and/or feeding mass of working fluid out of or into the fluid cycle (101).

FIG 1



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Description

Field of the invention

[0001] The present invention relates to a system for storing heat energy and a method for operating a system for storing heat energy.

Art background

[0002] A thermal energy storage uses heat that is converted from electrical energy, available as residual (waste) heat or taken from an existing heat cycle and then stored in a heat storage device comprising heat storage material, e.g. rocks.

[0003] At a later point in time the heat stored in the heat storage device is used for district heating or other purposes such as industrial processes requiring heat or it is reconverted into electrical energy and fed into the grid during periods of high demand.

[0004] In energy storage systems using a closed cycle, the mass of the working fluid within the cycle is constant. Due to the huge temperature difference of the working fluid in the operation of charging, idle or discharge, the pressure varies greatly. As a result of this, the storage and the adjacent pipes act as a pressure vessel.

[0005] In addition, the connecting pipelines are subjected to pressures under high temperatures which could drastically reduce the lifetime of the components in this circuit. Further, the blower which is used to guide the working fluid through the energy storage device creates an additional pressure gradient within the cycle. The pressure downstream of the blower may be higher than the pressure upstream of the blower.

Summary of the invention

[0006] It may be an object of the present invention to provide a pressure and/or temperature control for a heat storage system.

[0007] This object is solved by a system for storing heat energy and by a method for operating a system for storing heat energy according to the subject matters of the independent claims.

[0008] According to a first aspect of the invention a system for storing heat energy is presented. The system comprises a fluid cycle (in particular a closed fluid cycle) through which working fluid is streamable and a heat storage device configured for storing heat energy. The heat storage device comprises a first fluid opening and a second fluid opening each being coupled to the fluid cycle such that the working fluid is streamable between the first opening and the second fluid opening through the heat storage device transferring thermal energy between the heat storage device and the working fluid. The mass regulation device comprises a pressure control valve for adjusting the pressure difference between fluid cycle and the surrounding system, thereby adjusting the absolute pressure in the fluid cycle and thereby exhausting and/or feeding mass of working fluid out of or into the fluid cycle.

[0009] The system further comprises a mass regulation device which is coupled to the fluid cycle, wherein the mass regulation device is configured for adjusting the mass of the working fluid in the fluid cycle on the basis of the pressure and/or the temperature of the working fluid.

[0010] According to a further aspect of the present invention, a method for operating a system for storing heat energy as described above is presented. The method comprises adjusting the mass of the working fluid in the fluid cycle on the basis of the pressure and/or the temperature of the working fluid.

[0011] The working fluid may be a gaseous medium, such as air. The working fluid is flowable through the heat storage device in order to receive in a discharging cycle thermal energy from the heat storage device and to provide in a charging cycle thermal energy to the heat storage device. Specifically, the working fluid is heated up by a heating source, such as the below described heater, of the system.

[0012] The fluid cycle comprises respective piping tubes/pipes forming respective paths and piping, respectively, for the working fluid and connecting the respective functional units of the system, such as the heat storage device, the pump, the heater, the heat exchanger and/or the mass regulation device. The respective paths of the fluid cycle are formed by respective tubes. Furthermore, the fluid cycle comprises respective flaps, regulation valves and/or guiding switches in order to direct the working fluid through a desired path through the tubes of the fluid cycle.

[0013] The heat storage device is adapted for receiving thermal energy from a heated working fluid in order to store the thermal energy. The heat storage device includes heat storage material. 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. The heat storage device is coupled with the first and second opening to the fluid cycle. However, also more than two openings of the heat storage device may be provided which are coupled to the fluid cycle.

[0014] The fluid cycle comprises for example a first fluid path for transferring heat from the working fluid into the heat storage device. Furthermore, the fluid cycle may comprise a second fluid path for transferring heat from the heat storage device to the colder working fluid. Hence, if thermal energy is demanded by a further process (e.g. by a heat exchanger), the heat stored in the heat storage device is transferred to the working fluid and is used for district heating or other purposes such as industrial processes requiring heat (such as in a heat exchanger) and/or it is reconverted into electrical energy and fed into the grid during periods of high demand.

[0015] However, upon streaming of the working fluid through the heat storage device, the pressure of the working fluid decreases from a fluid inlet of the heat storage device to a fluid outlet of the heat storage device. This may cause the high pressure difference with respect to the surrounding atmospheric pressure which negatively affects the lifetime of the components of the system. Furthermore, at the inlet or at the outlet of the storage device, the working fluid may comprise an extremely high temperature which also negatively affects the lifetime of the components of the system.

[0016] Hence, according to the approach of the present invention, a mass regulation device is coupled to the fluid cycle in order to adjust the pressure of the working fluid with respect to the surrounding atmospheric pressure and to adjust the temperature of the working fluid. The mass regulation device according to the present invention is configured for injecting or for exhausting stored working fluid in or out of the fluid cycle. Hence, by increasing or decreasing the mass of the working fluid within the fluid cycle by the mass regulation device, the overall pressure of the working fluid within the fluid cycle and by mixing additional working fluid into the fluid cycle, also the temperature of the working fluid may be adjusted. Hence, a proper pressure and temperature control of the working fluid within the fluid cycle is provided for increasing the overall lifetime of the components of the system. Furthermore, the components of the system may be adapted to the proper temperature and pressure levels, such that cheaper and more lightweight components can be used.

[0017] The pressure control valve of the mass regulation device exhausts or injects mass of working fluid. If the pressure in the fluid cycle at an exhaust point is higher than the atmospheric pressure, the pressure control valve may be used in order to selectively exhausta desired amount of mass out of the working fluid out of the fluid cycle. For example, instead of a positive pressure (relative to the atmospheric pressure) provided along the complete heat storage device, the pressure inside the heat storage device comprises a negative pressure section and a positive pressure section with respect to the atmospheric pressure. By the implemented mass regulation device a pressure regulation system for adding and releasing working fluid to/from the closed air cycle is provided. Hence, the pressure difference along the heat storage device, e.g. at the inlet and at the outlet, remains the same as before, but the pressure difference relative to the atmospheric pressure can be adjusted and reduced, respectively. Therefore, equipment like piping or insulation can be designed for lower operating pressures which in turn can be cost saving.

[0018] Furthermore, the mass regulation device can also be used to protect components in the system, such as the blower, from high operating temperatures. This protection can be achieved by venting hot air to the atmosphere and by injecting colder air when the operating pressure of the working fluid is greater than atmospheric pressure or dilute hot air (working fluid) with ambient air if the operating pressure is lower than atmospheric pressure. In effect this venting/diluting protects parts of the system from high operational temperatures which could improve the operating conditions of the storage system during both charge and/or discharge. According to an exemplary embodiment of the present invention, the system comprises a pump coupled to the fluid cycle, wherein the pump is configured for driving the working fluid along a streaming direction through the heat storage device. Upstream of the pump, the working fluid is at a lower pressure, wherein the pump pressurizes the working fluid such that downstream of the pump, the working fluid is at a higher pressure. Thereby, the working fluid flows through the respective flow path from the high pressure side of the pump to the low pressure side of the pump.

[0019] According to a further exemplary embodiment, the mass regulation device comprises a first coupling section with the fluid cycle downstream of the pump, wherein the mass regulation device is configured for exhausting and/or feeding working fluid via the first coupling section out of or into the fluid cycle. By exhausting the working fluid from the downstream, high pressure side of the pump, a proper exhausting of the working fluid out of the fluid cycle is possible, since generally the pressure level at the downstream side of the pump is above the atmospheric pressure. However, it is also possible to inject mass of working fluid in the downstream side of the pump in order to increase the overall mass of the working fluid within the fluid cycle, if working fluid with a sufficient pressure can be provided.

[0020] According to a further exemplary embodiment, the mass regulation device further comprises a second coupling section with the fluid cycle upstream of the pump, wherein the mass regulation device is configured for exhausting and/or feeding working fluid via the second coupling section out of or into the fluid cycle. By feeding the working fluid at the upstream, low pressure side of the pump, a proper and more energy saving feeding of the working fluid into the fluid cycle is possible, since generally the pressure level at the upstream side of the pump is closer (sometimes below) the atmospheric pressure. However, it is also possible to exhaust mass of working fluid at the upstream side of the pump in order to reduce the overall mass of the working fluid within the fluid cycle, if the working fluid has sufficient pressure with respect to the environment.

[0021] According to a further exemplary embodiment, the system comprises a heater for heating the working fluid, wherein the heater is coupled in the fluid cycle between the pump and the heat storage device, such that a first flow path directed from the pump through the heater and the heat storage device is providable. The heater may be for example a heat exchanger receiving waste heat from other industrial processes. Furthermore, the heater may be a resistive heater. The heat for the heater may be received by renewable energy sources, such as solar power plants, for example.

[0022] According to a further exemplary embodiment, the system further comprises a heat exchanger for transferring the thermal energy of the working fluid to a further process (e.g. a steam turbine process), wherein the heat exchanger is coupled in the fluid cycle between the heat storage device and the pump, such that a second flow path directed from the pump through the heat storage device and further through the heat exchanger is providable. Hence, the working fluid streaming along the second flow path receives thermal energy from the stored heat of the storage device. The heated working fluid may provide the thermal energy to the heat exchanger transferring heat energy to a further thermodynamic process.

[0023] According to a further exemplary embodiment, the mass regulation device comprises a further pump for generating a pressurized working fluid injectable into the fluid cycle. The further pump increases the pressure of the working fluid subjected to be injected into the fluid cycle at a level equal or above the working fluid within the fluid cycle at the point of injection. Hence, a proper and quick injection of working fluid within the fluid cycle is provided. Specifically, it may be beneficial to install the further pump and the second coupling section upstream of the pump of the fluid cycle, since the pressure level of the working fluid in the fluid cycle is lower at the upstream side of the pump.

[0024] According to a further exemplary embodiment, the mass regulation device comprises a reservoir for storing pressurized working fluid. The reservoir may function as a storage for the working fluid. Specifically, a predefined pressure of the working fluid subjected to be injected into the fluid cycle may be adjusted, for example by the above described further pump. Hence, a quick increase of the mass in the fluid cycle can be provided, since pressurized working fluid can be stored in the reservoir.

[0025] According to a further exemplary embodiment, the reservoir is configured for selectively storing working fluid exhausted from the fluid cycle and for injecting the pressurized fluid into the fluid cycle. Hence, the working fluid in the reservoir may be pressurized by injecting working fluid from the fluid cycle in an operation mode, where the mass of the working fluid in the fluid cycle should be reduced. In a further operation mode, in which the mass of the working fluid in the fluid cycle should be increased, the pre-pressurized working fluid in the reservoir can be used. Hence, an energy saving embodiment for pressurizing the working fluid in the fluid cycle may be provided.

[0026] According to a further exemplary embodiment, the system further comprises a pressure sensor system for measuring the pressure at a measuring location in the fluid cycle or the heat storage device (for example at the first fluid opening and the second fluid opening of the heat storage device). The mass regulation device is configured for adjusting the mass of the working fluid in the fluid cycle or the heat storage device, on the basis of the pressure of the working fluid measured at the measuring location, in particular at the first fluid opening and/or the second fluid opening.

[0027] In case of measuring and adjusting the pressure, the measuring location and the target location, where a desired pressure should be adjusted, may be the same or may differ with respect to each other. For example, the pressure measured at the measurement location can be predicted (e.g. on the basis of line loss etc.) for the target location. Hence, since the pressure at the first fluid opening and the second fluid opening is known, the desired pressure difference with respect to the atmospheric pressure may be adjusted by injecting or exhausting mass of working fluid in the fluid cycle. For example, if the pressure of working fluid at the fluid inlet is too high, respective mass of the working fluid may be exhausted in order to reduce the pressure difference to the atmospheric pressure at the fluid inlet. Respectively, if the pressure of the working fluid at the fluid outlet of the heat storage device is too low and therefore a pressure difference with respect to the atmospheric pressure is too high, working fluid may be injected into the fluid cycle in order to increase the overall pressure of the working fluid inside the fluid cycle.

[0028] According to a further exemplary embodiment, the system further comprises a temperature sensor system for measuring the temperature of the working fluid at a measuring location in the fluid cycle or the heat storage device, in particular upstream of the pump, wherein the mass regulation device is configured for adjusting the mass of the working fluid in the fluid cycle or the heat storage device on the basis of the temperature of the working fluid measured at the measuring location, e.g. upstream of the pump. Hence, overheating of components, in particular of the pump, may be avoided.

[0029] Hence, according to a further exemplary embodiment of the method, the method comprises also the step of measuring an atmospheric pressure surrounding the heat storage device, a measuring of the pressure of the working fluid at a measuring location in the fluid cycle or the heat storage device, e.g. at the first fluid opening and the second fluid opening of the heat storage device, and an adjusting of the mass of the working fluid on the basis of the measured pressure of the working fluid at a target location, e.g. at the first fluid opening and the second fluid opening of the heat storage device, such that the predetermined difference between the pressure of the working fluid at the target location with respect to the atmospheric pressure is adjusted.

[0030] According to a further exemplary embodiment of the method, the predetermined difference between the pressure of the working fluid at the first fluid opening and the pressure at the second fluid opening with respect to the atmospheric pressure is adjusted in such a manner, that a neutral point, where the pressure is equal to the atmospheric pressure, is located at a predefined location of the system. In an exemplary embodiment, the neutral point may be adjusted inside the heat storage device, in particular halfway between the first fluid opening and the second fluid opening. However, the neutral point may also be adjusted outside of the heat storage device.

[0031] As described above, the pressure at an inlet opening of the heat storage device is higher than the pressure at an outlet opening of the heat storage device. Specifically, in a regulated state, at the inlet opening, the pressure of the working fluid is above the atmospheric pressure and at the outlet opening, the pressure of the working fluid is below the atmospheric pressure. In order to reduce the maximum positive or negative pressure difference to the atmospheric pressure, it is beneficial to adjust the neutral point of the pressure, where the pressure of the working fluid is equal to the atmospheric pressure, in such a way, that the neutral point is arranged within the heat storage device. In order to locate the neutral point within the heat storage device, the mass regulation device adjusts the mass of the working fluid in the fluid cycle such that the pressure at the fluid inlet and the fluid outlet of the heat storage device is increased or lowered and the location of the neutral point is adjusted, respectively.

[0032] The aspects defined above and further aspects of the present 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 embodiment but to which the invention is not limited.

Brief Description of the Drawings

[0033]

Fig. 1 shows a schematic view of a system for storing heat energy illustrating a first flow path, in which the working fluid transfers thermal energy to the heat storage device, according to an exemplary embodiment of the present invention.

Fig. 2 shows a diagram of a pressure decrease of the working fluid between an inlet and an outlet of the heat storage device, if the working fluid flows along the first flow path shown in Fig. 1, according to an exemplary embodiment.

Fig. 3 shows a schematic view of a system for storing heat energy illustrating a second flow path, in which the heat storage device transfers thermal energy to the working fluid, according to an exemplary embodiment of the present invention.

Fig. 4 shows a diagram of a pressure decrease of the working fluid between an inlet and an outlet of the heat storage device, if the working fluid flows along the second flow path shown in Fig. 3, according to an exemplary embodiment.

Detailed Description

[0034] The illustrations in the drawings are schematically. It is noted that in different figures, similar or identical elements are provided with the same reference signs.

[0035] **Fig. 1** shows a schematic view of a system 100 for storing heat energy illustrating a first flow path I, in which the working fluid transfers thermal energy to the heat storage device ("charging mode"), according to an exemplary embodiment of the present invention. **Fig. 2** shows a diagram of a pressure decrease of the working fluid between an inlet and an outlet of the heat storage device 110, if the working fluid flows along the first flow path I as shown in Fig. 1.

[0036] The system 100 comprises a fluid cycle 101 through which working fluid is streamable and a heat storage device 110 configured for storing heat energy, wherein the heat storage device 110 comprises a first fluid opening 111 and a second fluid opening 112 each being coupled to the fluid cycle 101 such that the working fluid is streamable between the first fluid opening and the second fluid opening through heat storage device 110 transferring thermal energy from the heat storage device 110 to the storage device 110. The system 100 further comprise a mass regulation device 120 which is coupled to the fluid cycle 101, wherein the mass regulation device 120 is configured for adjusting the mass of the working fluid in the fluid cycle 101 on the basis of the pressure and/or the temperature of the working fluid.

[0037] The fluid cycle 101 comprises respective tubes/pipes forming respective paths for the working fluid and connecting the respective functional units of the system, such as the heat storage device 110, a pump 102, a heater 103, a steam generation unit 104 and/or the mass regulation device 120. The respective paths I, II (see path II in Fig. 3) of the fluid cycle are formed by respective tubes. Furthermore, the fluid cycle 101 comprises respective flaps, regulation valves and/or guiding switches in order to direct the working fluid through a desired path through the tubes of the fluid cycle.

[0038] The fluid cycle 101 comprises for example a first fluid path I (shown in Fig. 1 with bold lines) for transferring heat from the working fluid into the heat storage device 110 (charging mode).

[0039] The heat storage device 110 is adapted for receiving thermal energy from a heated working fluid in order to store the thermal energy. The heat storage device 110 includes for example storage elements, such as granulated material, e.g. rock material and pebble stone material, respectively.

[0040] As shown in Fig. 2, upon streaming of the working fluid through the heat storage device 110, the pressure p of the working fluid decreases from a fluid inlet (first fluid opening 111 in first flow path I, pressure of working fluid at first fluid opening 111 = p_{inlet}) of the heat storage device 110 to a fluid outlet (second fluid opening 112 in first flow path I, pressure of working fluid at second fluid opening 112 = p_{outlet}) of the heat storage device. This may cause the high pressure difference with respect to the surrounding atmospheric pressure p_{atm} (dotted line in Fig. 2) which negatively affects the lifetime of the components of the system 100. Furthermore, at the inlet or at the outlet of the storage device 110, the working fluid may have an extremely high temperature which also negatively affects the lifetime of the components of the system 100 and requires mor robust and expensive components.

[0041] The mass regulation device 120 is coupled to the fluid cycle 101 in order to adjust the pressure of the working fluid with respect to the surrounding atmospheric pressure p_{atm} and to adjust the temperature of the working fluid. The mass regulation device 120 according to the present invention is configured for injecting or for exhausting stored working fluid into or from the fluid cycle 101. Hence, by increasing or decreasing the mass of the working fluid within the fluid cycle 101 by the mass regulation device 120, the overall pressure of the working fluid within the fluid cycle 101 and by mixing additional working fluid into the fluid cycle 101, also the temperature of the working fluid may be adjusted.

[0042] As can be taken from Fig. 2, the heat storage device 100 comprises a negative pressure section and a positive pressure section with respect to the atmospheric pressure p_{atm}. By the implemented mass regulation device 120 a pressure regulation system for adding and releasing working fluid to/from the closed fluid cycle 101 is provided. Hence, the pressure difference along the heat storage device 110, e.g. at the inlet (first fluid opening 111) and at the outlet (second fluid opening 112), remains the same as before, but the pressure difference relative to the atmospheric pressure p_{atm} at the first fluid opening 111 and the second fluid opening 112 can be adjusted and reduced, respectively. Therefore, equipment like piping or insulation can be designed for lower operating pressures which in turn can be cost saving.

[0043] Furthermore, the pump 102 is coupled to the fluid cycle 101, wherein the pump 102 is configured for driving the working fluid along a streaming direction 106 through the heat storage device 110. Upstream of the pump 102, the working fluid is at a lower pressure relative to the atmospheric pressure, wherein the pump pressurizes the working fluid such that downstream of the pump, the working fluid is at a higher pressure relative to the atmospheric pressure. Thereby, the working fluid flows through the respective flow path from the high pressure side of the pump to the low pressure side of the pump.

[0044] As shown in Fig. 1, the mass regulation device 120 comprises a first coupling section 121 with the fluid cycle 101 downstream of the pump 102, wherein the mass regulation device 120 is configured for exhausting and/or feeding working fluid via the first coupling section 121 out of or in the fluid cycle.

[0045] The mass regulation device 120 further comprises a second coupling section 122 with the fluid cycle 101 upstream of the pump 102, wherein the mass regulation device 120 is configured for exhausting and/or feeding working fluid via the second coupling section 122 out of or in the fluid cycle.

[0046] The system 100 further comprises a heater 103 for heating the working fluid, wherein the heater 103 is coupled in the fluid cycle 101 between the pump 102 and the heat storage device 110, such that the first flow path I directed from the pump 102 through the heater 103 and the heat storage device is providable.

[0047] The system 100 further comprises the steam generation unit 104 for generating steam on the basis of the thermal energy of the working fluid, wherein the steam generation unit 104 is coupled in the fluid cycle 101 between the heat storage device 110 and the pump 102, such that the second flow path II (see Fig. 3) directed from the pump 102 through the heat storage device 110 and further through the steam generation unit 104 is providable.

[0048] The mass regulation device 120 comprises a further pump 123 for pressurizing a working fluid injectable into the fluid cycle. The further pump 123 increases the pressure of the working fluid subjected to be injected into the fluid cycle 101 at a level equal or above the working fluid within the fluid cycle 101 at the point of injection (for example at the first coupling section 121 or the second coupling section 122). Hence, a proper and quick injection of working fluid within the fluid cycle is provided. Specifically, it may be beneficial to install the further pump 123 and the second coupling section 122 upstream of the pump 102 of the fluid cycle 101, since the pressure level of the working fluid in the fluid cycle 101 is lower at the upstream side of the pump 102. Furthermore, the further pump 123 may also be used to pressurize fluid from the reservoir 125 in order to inject the pressurized fluid upstream of the pump 102. However, the further pump 123 may be installed at the coupling section 121 downstream of the pump 102, such that fluid from the reservoir 125 may be pressurized for being injected downstream of pump 102. Furthermore, the further pump 123 may generate an underpressure for exhausting working fluid out of the fluid cycle.

[0049] The mass regulation device 120 further comprises pressure control valves 124 for allowing exhausting or injecting mass of working fluid out of/into the fluid cycle 101. If the pressure in the fluid cycle 101 at an exhausting point is higher than the atmospheric pressure p_{atm}, a pressure control valve 124 is opened or closed for exhausting a desired amount of mass of the working fluid out of the fluid cycle 101.

[0050] Furthermore, a reservoir 125 for storing pressurized working fluid is provided. The reservoir 125 may function as a storage for the working fluid. Specifically, a predefined pressure of the working fluid subjected to be injected into the fluid cycle 101 may be adjusted, for example by the above described further pump 123.

[0051] A pressure sensor system 105 is provided for measuring the pressure at the first fluid opening 111 and the second fluid opening 112 of the heat storage device 110. The mass regulation device 120 is configured for adjusting the mass of the working fluid in the fluid cycle 101 on the basis of the pressure of the working fluid at the first fluid opening 111 and the second fluid opening 112.

[0052] As shown in Fig. 2, there is a high pressure p_{inlet} upstream of the heat storage device 110 and low pressure p_{outlet} downstream of the heat storage device 110, both relative to the atmospheric pressure p_{atm}. The pressure conditions inside the heat storage device 110 during charging (flow path I) are depicted in Fig. 2. The pressure difference between the upstream side (at first fluid opening 111) and downstream side (at second fluid opening 112) of the heat storage device 110 results in a decreasing pressure along the heat storage device 110 (between C=0 to C=1). It should be noted that the pressure curve is not necessarily linear. The atmospheric pressure p_{atm} (represented by the dotted line) will be reached at some point along the pressure curve between the inlet 111 and outlet 112 of the heat storage device 110. The mass regulation device 120 is used to shift the location of the neutral point 201, where the pressure of the working fluid equals the atmospheric pressure p_{atm}. Additional air (working fluid) can be fed into the fluid cycle 101 through the part of the pressure regulation device 120 located upstream of the blower/pump 102 (e.g. at the second coupling section 122). This would increase the overall pressure level in the fluid cycle and therefore shift the neutral point 201 of $p = p_{atm}$ downstream (towards the outlet/second fluid opening 112). To shift the neutral point 201 upstream (towards the inlet/first fluid opening 111) air/working fluid is extracted from the fluid cycle 101 through the path of the pressure regulation device 120 located downstream of the pump 102 (e.g. at the first coupling section 121), thus lowering the overall pressure level of the fluid cycle 101.

[0053] Since the pressure at the first fluid opening 111 and the second fluid opening 112 is measured by pressure sensor system 105, a desired pressure difference (p_{inlet} - p_{atm} or p_{atm} - p_{outlet}) with respect to the atmospheric pressure p_{atm} may be adjusted by injecting or exhausting mass of working fluid in the fluid cycle 101.

[0054] **Fig. 3** shows a schematic view of the system 100 as shown in Fig. 1 illustrating a second flow path II, in which the heat storage device 110 transfers thermal energy to the working fluid (discharging mode). Hence, if thermal energy is demanded e.g. by the heat exchanger 104, the heat stored in the heat storage device 110 is transferred to the working fluid and is used for e.g. district heating or other purposes such as industrial processes requiring heat (such as in a steam generation unit) and/or it is reconverted into electrical energy and fed into the grid during periods of high demand.

[0055] Hence, the working fluid streaming along the second flow path II receives thermal energy from the stored heat of the storage device 110. The heated working fluid may provide the thermal energy to the heat exchanger 104.

[0056] **Fig. 4** shows a diagram of a pressure decrease of the working fluid between an inlet and an outlet of the heat storage device 110, if the working fluid flows along the second flow path II shown in Fig. 3. In the discharging mode, the pressure conditions inside the heat storage device 110 are essentially mirrored with respect to the charging mode shown in Fig. 2. The working fluid enters the heat storage device 110 at the second fluid opening 112 with a respective inlet pressure p_{inlet}. Along the flow direction 106 from the second fluid opening 112 to the first fluid opening 111, the pressure decreases to an outlet pressure p_{outlet} of the working fluid. The neutral point 201 is adjusted almost in the center (approx. halfway (C=0,5) of the path (streaming direction 106) through the heat storage device 110) of the heat storage device 110.

[0057] Accordingly, feeding additional air/working fluid into the fluid cycle 101 shifts the location of the atmospheric pressure p_{atm} downstream (towards the outlet, first fluid opening 111). Releasing air from the fluid cycle shifts the atmospheric pressure p_{atm} upstream (towards the inlet, second fluid opening 112).

[0058] Summarizing, by injecting or exhausting working fluid into or from the fluid cycle 101 by the mass regulation device 120, the desired location of the neutral point 201 and therefore also the pressure differences of the working fluid with respect to the atmospheric pressure p_{atm} within the heat storage device 110 can be adjusted. Assuming a linear pressure curve as shown in Fig. 2 and Fig. 4, the lowest pressure differences between piniet and p_{atm} and p_{outlet} and p_{atm} can be achieved if the neutral point 201 is located approximately halfway C=0,5 between C=0 (e.g. the fluid inlet 111) and C=1 (e.g. at the fluid outlet 112):

$$C = \frac{p_{atm} - p_{Inlet}}{p_{Outlet} - p_{Inlet}}$$

[0059] For C=0,5 the atmospheric pressure p_{atm} is reached in an exemplary embodiment in the center of the heat storage device 110. For C=0, p_{atm} is reached e.g. at the inlet of the heat storage device 110 and for C=1 e.g. at the outlet of the heat storage device 110. C is below 0 if the atmospheric pressure p_{atm} is e.g. reached in the piping of the fluid cycle 101 upstream of the inlet and is above 1 if the atmospheric pressure p_{atm} is reached e.g. in the piping downstream of the outlet of the heat storing device 110. However, the neutral point 201 may also be located outside of the heat storage device 110.

[0060] It should be noted that the term "comprising" does not exclude other elements or steps and "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 should not be construed as limiting the scope of the claims.

Claims

1. System (100) for storing heat energy, the system (100) comprising
a fluid cycle (101) through which working fluid is streamable,
a heat storage device (110) configured for storing heat energy,
wherein the heat storage device (110) comprises a first fluid opening (111) and a second fluid opening (112) each being coupled to the fluid cycle (101) such that the working fluid is streamable between the first fluid opening (111) and the second fluid opening (112) through the heat storage device (110) transferring thermal energy between the heat storage device (110) and the working fluid,
a mass regulation device (120) which is coupled to the fluid cycle (101),
wherein the mass regulation device (120) is configured for adjusting the mass of the working fluid in the fluid cycle (101) on the basis of the pressure and/or the temperature of the working fluid,
wherein the mass regulation device (120) comprises a pressure control valve (124) for adjusting the pressure difference between fluid cycle (101) and the surrounding system, thereby adjusting the absolute pressure in the fluid cycle and thereby exhausting and/or feeding mass of working fluid out of or into the fluid cycle (101).

2. System (100) according to claim 1, further comprising
a pump (102) coupled to the fluid cycle (101),
wherein the pump (102) is configured for driving the working fluid along a streaming direction (106) through the heat storage device (110).

3. System (100) according to claim 2,
wherein the mass regulation device (120) comprises a first coupling section (121) with the fluid cycle (101) downstream of the pump (102),
wherein the mass regulation device (120) is configured for exhausting and/or feeding working fluid via the first coupling section (121) out of or into the fluid cycle (101).

4. System (100) according to claim 2 or 3,
wherein the mass regulation device (120) comprises a second coupling section (122) with the fluid cycle (101) upstream of the pump (102),
wherein the mass regulation device (120) is configured for exhausting and/or feeding working fluid via the second coupling section (122) out of or into the fluid cycle (101).

5. System (100) according to one of the claims 2 to 4, further comprising
a heater (103) for heating the working fluid,
wherein the heater (103) is coupled in the fluid cycle (101) between the pump (102) and the heat storage device (110), such that a first flow path (I) directed from the pump (102) through the heater (103) and the heat storage device (110) is providable.

6. System (100) according to one of the claims 2 to 5, further comprising
a heat exchanger (104) for transferring heat of the thermal energy of the working fluid to a further process, wherein the heat exchanger (104) is coupled in the fluid cycle (101) between the heat storage device (110) and the pump (102), such that a second flow path (II) directed from the pump (102) through the heat storage device (110) and further through the heat exchanger (104) is providable.

7. System (100) according to one of the claims 1 to 6, wherein the mass regulation device (120) comprises a further pump (123) for generating a pressurized working fluid injectable into the fluid cycle (101) and/or for generating an underpressure for exhausting working fluid out of the fluid cycle (101).

8. System (100) according to one of the claims 1 to 7, wherein the mass regulation device (120) comprises a reservoir (125) for storing pressurized working fluid.

9. System (100) according to claim 8,
wherein the reservoir (125) is configured for selectively storing working fluid exhausted from the fluid cycle (101) and for injecting the pressurized working fluid into the fluid cycle (101).

10. System (100) according to one of the claims 1 to 9, further comprising
a pressure sensor system (105) for measuring the pressure at a measuring location in the fluid cycle (101) or the heat storage device (110),
wherein the mass regulation device (120) is configured for adjusting the mass of the working fluid in the fluid cycle (101) or the heat storage device (110), on the basis of the pressure of the working fluid measured at the measuring location.

11. System (100) according to one of the claims 2 to 10, further comprising
a temperature sensor system for measuring the temperature of the working fluid at a measuring location in the fluid cycle (101) or the heat storage device (110), in particular upstream of the pump (102),
wherein the mass regulation device (120) is configured for adjusting the mass of the working fluid in the fluid cycle (101) or the heat storage device (110)

on the basis of the temperature of the working fluid measured at the measuring location.

12. Method for operating a system (100) for storing heat energy, wherein the system (100) comprises a fluid cycle (101) through which working fluid is streamable, and a heat storage device (110) configured for storing heat energy,
wherein the heat storage device (110) comprises a first fluid opening (111) and a second fluid opening (112) each being coupled to the fluid cycle (101) such that the working fluid is streamable between the first fluid opening (111) and the second fluid opening (112) through heat storage device (110) transferring thermal energy between the heat storage device (110) and the working fluid,
wherein a mass regulation device (120) is coupled to the fluid cycle (101),
wherein the method comprises

adjusting the mass of the working fluid in the fluid cycle (101) on the basis of the pressure and/or the temperature of the working fluid, and adjusting the pressure difference between fluid cycle (101) and the surrounding system by a pressure control valve (124) of the mass regulation device (120), thereby adjusting the absolute pressure in the fluid cycle and thereby exhausting and/or feeding mass of working fluid out of or into the fluid cycle (101).

13. Method according to claim 12, wherein adjusting the mass of the working fluid comprises
exhausting and/or feeding working fluid via a first coupling section (121) out of or into the fluid cycle (101), wherein the first coupling section (121) is coupled with the fluid cycle (101) downstream of the pump (102), and/or
exhausting and/or feeding working fluid via a second coupling section (122) out of or into the fluid cycle (101), wherein the second coupling section (122) is coupled with the fluid cycle (101) upstream of the pump (102).

14. Method according to claim 13, wherein adjusting the mass of the working fluid further comprises
measuring an atmospheric pressure surrounding the heat storage device (110),
measuring the pressure of the working fluid at a measuring location in the fluid cycle (101) or the heat storage device (110),
adjusting the mass of the working fluid on the basis of the measured pressure of the working fluid in the fluid cycle (101) or the heat storage device (110), such that a predetermined difference between the pressure of the working fluid at the target location with respect to the atmospheric pressure is adjusted.

15. Method according to claim 14, wherein adjusting the mass of the working fluid further comprises
adjusting the predetermined difference between the pressure of the working fluid at the first fluid opening (111) and/or the pressure at the second fluid opening (112) with respect to the atmospheric pressure in such a manner, that a neutral point, where the pressure is equal to the atmospheric pressure, is located at a predefined location of the system (100) .

FIG 1

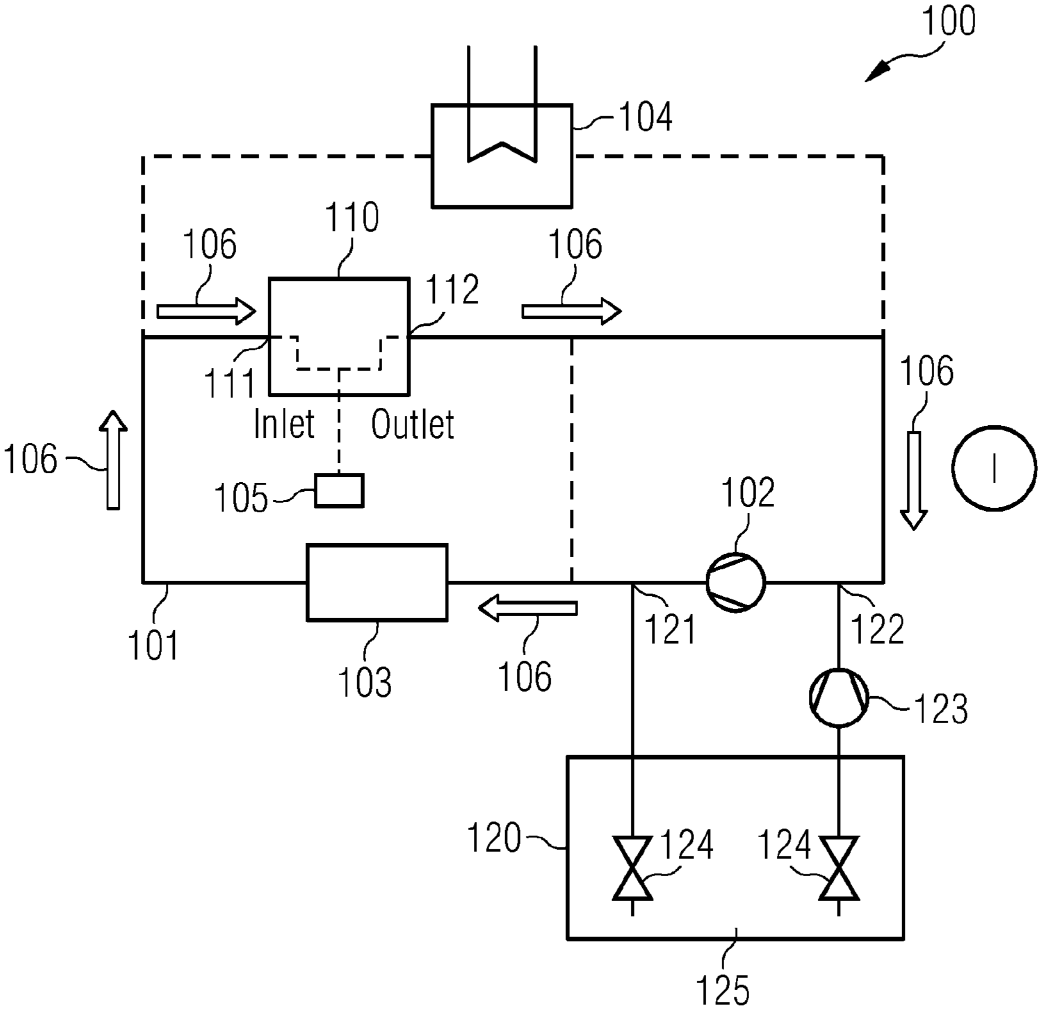
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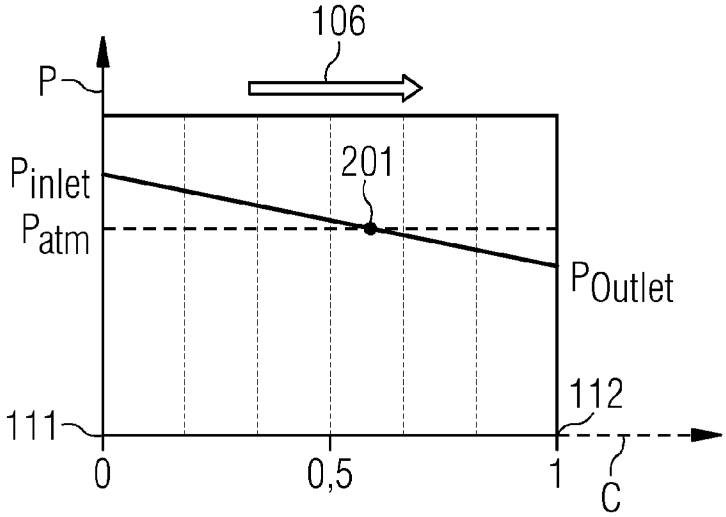
FIG 2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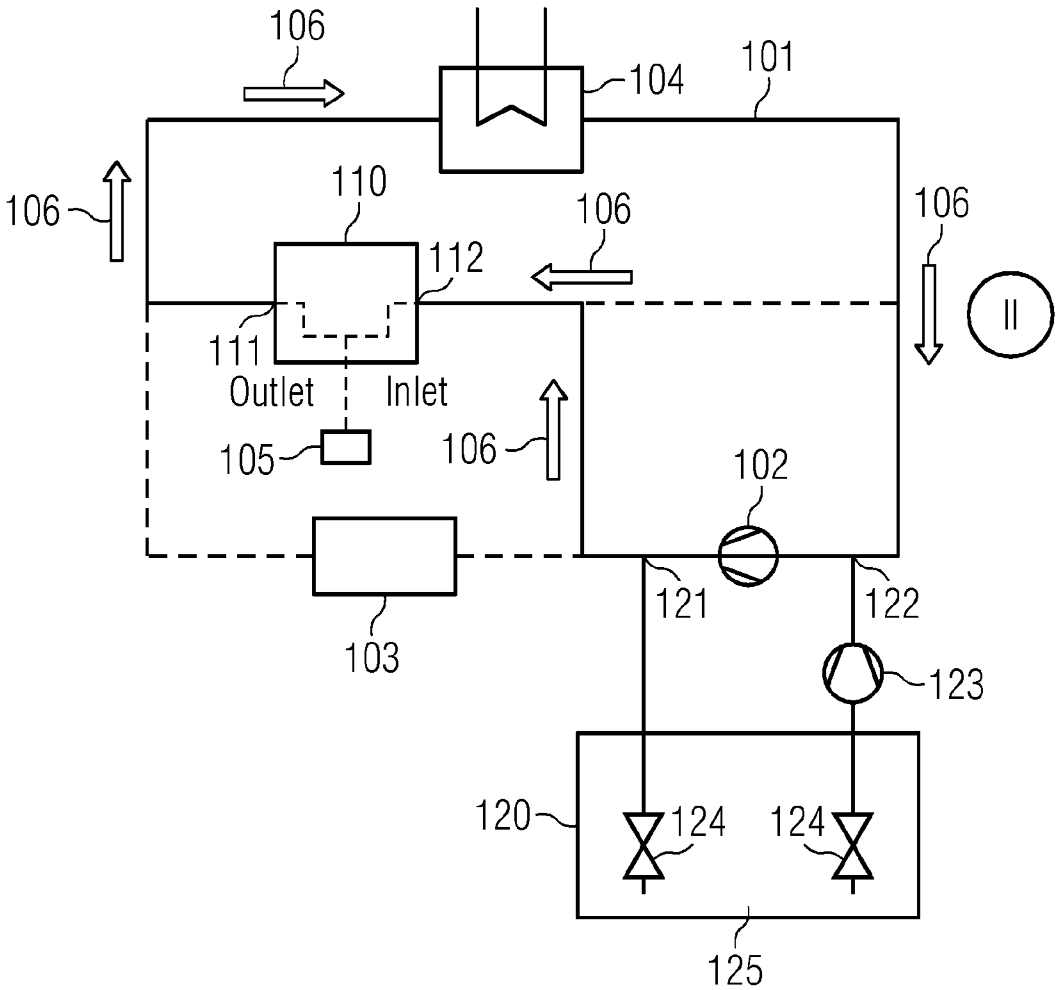
C

FIG 3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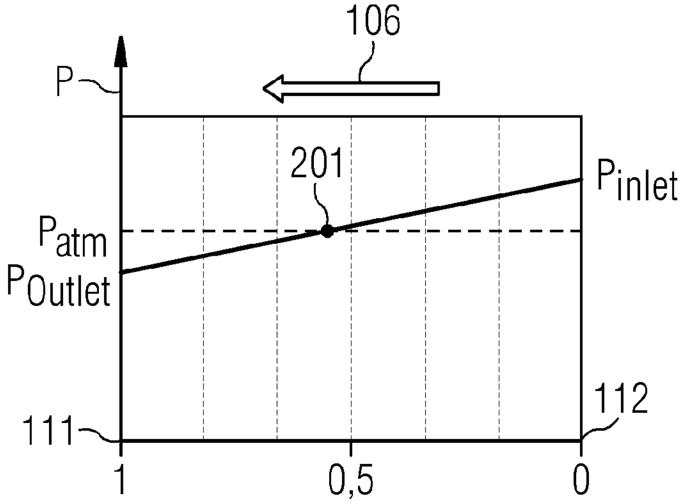
125

FIG 4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EUROPEAN SEARCH REPORT

Application Number
EP 20 20 1441

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2016/150459 A1 (SIEMENS AG [DE]) 29 September 2016 (2016-09-29) * abstract; figures 1, 3, 7 * * page 24, line 33 - page 29, line 12 * * page 36, line 16 - page 40, line 2 * * page 30, line 34 - page 32, line 28 * -----	1-15	INV. F01K3/00 F01K3/14
A	EP 3 259 456 A1 (SIEMENS AG [DE]) 27 December 2017 (2017-12-27) * abstract; figures 4, 7 * * paragraphs [0104] - [0109], [0119] - [0130] * -----	1-15	
A	EP 3 245 388 A1 (SIEMENS AG [DE]) 22 November 2017 (2017-11-22) * abstract; figures 1, 2 * * paragraphs [0066] - [0083] * -----	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	2 March 2021	Varelas, Dimitrios

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02-03-2021

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