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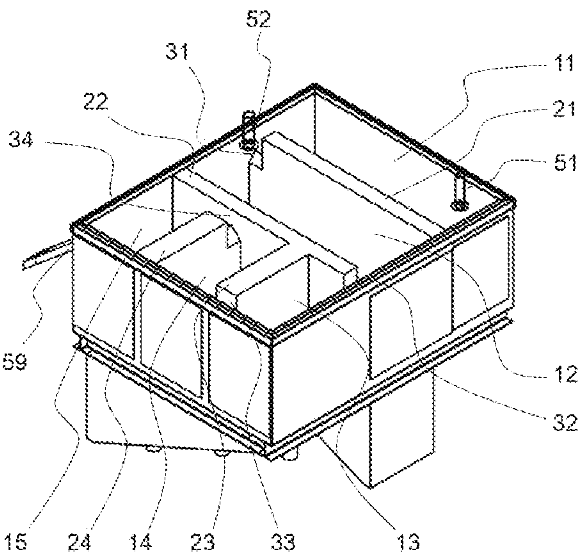
A DISCHARGING DEVICE AND A METHOD FOR AN ENERGY STORAGE SYSTEM

(57) Tiivistelmä - Sammandrag - Abstract

Purkulaite hyödyntää kiinteitä partikkeleita (5), esimerkiksi hiekanjyviä, joita lämmitetään uusiutuvan energian voimalaitoksen sähköllä. Kiinteät partikkelit (5) leijutetaan kaasulla staattisesta kiinteästä tilasta dynaamiseen nestemäiseen tilaan. Purkauslaitteessa on useita vierekkäisiä lämmönsiirtomoduuleja (11 - 18), jotka kukin on erotettu osittain moduuliseinällä (21 - 27). Moduulin seinässä (21 - 27) vierekkäisten lämmönsiirtomoduulien välillä on aukko (31 - 34) moduulin seinässä (21 - 27), jotta leijutetut kiinteät partikkelit (5) voivat kulkea viereiseen lämmönsiirtomoduuliin (11 - 18). Leijutetut kiinteät hiukkaset (5) kulkevat vaakasuunnassa partikkelien sisääntuloaukosta vierekkäisten lämmönsiirtomoduulien (11 - 18) kautta ja mainitun aukon (31 - 34) kautta viimeisen lämmönsiirtomoduulin (14, 15, 18) hiukkasten ulostuloon (59).

A discharging device utilizes solid particles (5), for example sand particles, which are heated by the electric power from the renewable energy power plant. The solid particles (5) are fluidized by gas from a static solid–like state to a dynamic fluid–like state. The discharging device has multiple adjacent heat transfer modules (11 – 18), which are each partially separated by a module wall (21 - 27). The module wall (21 - 27) between adjacent heat transfer modules has an opening (31 – 34) in the module wall (21 - 27) to allow the fluidized solid particles (5) to travel to adjacent heat transfer module (11 – 18). The fluidized solid particles (5) travel horizontally from the particle inlet via adjacent heat transfer modules (11 – 18) and through said opening (31 - 34) to the particle outlet (59) of the last heat transfer module (14, 15, 18).



A DISCHARGING DEVICE AND A METHOD FOR AN ENERGY STORAGE SYSTEM

BACKGROUND

The invention relates to heat storage plants that are using solid heat storage material.

Renewable energy resources, such as wind or solar power, provide energy with variable rate according to available sunlight or wind. Energy usage peaks often occur at different times than renewable energy production peaks. Therefore, energy storage systems are important to balance the difference between power supply and demand.

Known energy storage systems include battery technologies, pumped hydroelectricity storages, molten salt storage systems and storage systems using solid particles such as sand. Sand–based heat storage systems comprise fluidized beds that aerate the sand and thereby enable easy transfer of the sand and increase heat transfer power per area. Sand may be heated by excess of the energy production. For example, the electric energy may be stored and released as thermal energy. Known energy storage systems have known disadvantages, that sand–based heat storage systems may at least partially solve. But also, sand–based heat storage systems may face certain problems.

Over time, the sand particles may experience temperature variations, leading to stratification within the solid particles. This can impact the system's overall efficiency and heat transfer capabilities. The choice of materials for the sand particles and the containment structure must consider compatibility with high temperatures and thermal cycling to prevent degradation or breakdown over time.

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Designing and maintaining an effective sand–based heat storage system can be complex. The fluidization and circulation of sand require careful engineering to ensure optimal performance. Sand particles may agglomerate or clump together over time, affecting the fluidization process and reducing the efficiency of the overall process.

SUMMARY

This summary is provided to introduce a selection of concepts in a simplified form that will be further described below in the detailed description. This summary is intended to neither identify key features or essential features of the claimed subject matter nor to be used to limit the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all of the disadvantages noted in any part of this disclosure.

A discharging device and a method for an energy storage system are disclosed herein. The energy storage system receives energy typically from excess energy from an electric power grid, or more directly, from a renewable energy power plant, a photovoltaic power station or a wind farm. The discharging device utilizes solid particles, for example sand particles, which have been heated by the electric power from the energy power plant and stored as hot solid particles. The solid particles are fluidized by gas from a static solid–like state to a dynamic fluid–like state.

The discharging device has multiple adjacent heat transfer modules, which are partially separated by a module wall. The module wall between adjacent heat transfer modules has an opening in the module wall to allow the fluidized solid particles to travel to adjacent heat transfer module. The fluidized solid particles travel horizontally from the particle inlet via adjacent heat transfer modules and through said opening to the particle outlet of the last heat transfer module.

The fluidization is affected through adjacent heat transfer modules, where the solid particles travel from the first heat transfer module as hot particles and exit through the outlet of the last heat transfer module as cooled solid particles. The fluidization airflow may be recirculated to recover the heat for used on other processes of the energy storage system.

Each heat transfer module comprises a fluid tube comprising circulating working fluid for receiving thermal energy from solid particles to the working fluid. In one embodiment, the discharging device comprises multiple particle inlets at various heat transfer modules for the solid particles. The arrangement allows more effective temperature management for the discharging device output. The heat storage system may often be in the process of heating the solid particles to maximum temperature or the thermal energy may have already been consumed from the heat storage. The working fluids may be directed to the application that benefits most of the available temperature range. Examples of various applications in the heat storage system are a reheater, a superheater, a boiler bank, a steam generator, an evaporator, a heat pump application, a district heat application, industrial heat application, or multiple counter flow phases for an economizer.

As one example of solid particles, sand has a relatively high specific heat capacity, allowing it to store large amounts of thermal energy. Sand enables low heat loss with the system disclosed herein during the storage phase, enhancing overall efficiency. The discharging device as disclosed herein can be designed with modular configurations, allowing for scalability based on energy storage requirements.

The modular configurations enable injecting solid particles to the discharging device at different phases. The solid particles that are not yet in the full temperature range, or fully heated, may travel different route along the discharging device than the fully heated solid particles. This improves the effectiveness of the discharging device and allows it to be used with short stints of excess energy or energy consumption. For example, short periods of cheap or negatively priced electrical energy may be captured more efficiently.

The arrangement of moving solid particles, such as sand, functions safely under faults or process stops. The process may be halted at any point, wherein the solid particles merely stop the fluidized state and remain still. The fluidization process may be restarted without causing harm to the heat storage system or to the discharging device.

Many of the attendant features will be more readily appreciated as they become better understood by reference to the following detailed description considered in connection with the accompanying drawings. The embodiments described below are not limited to implementations which solve any or all the disadvantages of known energy storage systems or discharging devices.

BRIEF DESCRIPTION OF THE DRAWINGS

The present description will be better understood from the following detailed description read in light of the accompanying drawings, wherein

FIG. 1 illustrates schematically a top view of one exemplary embodiment of a discharging device;

FIG. 2 illustrates schematically an isometric view of the same exemplary embodiment of the discharging device;

FIG. 3 illustrates schematically a side view of one exemplary embodiment of the discharging device with a fluidization system;

FIG. 4 illustrates schematically an isometric view from below, of one exemplary embodiment of the discharging device;

FIG. 5 illustrates schematically a top view of one exemplary embodiment of the discharging device; and

FIG. 6 illustrates schematically a flowchart of a method for discharging thermal energy for an energy storage system.

Like reference numerals are used to designate like parts in the accompanying drawings.

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DETAILED DESCRIPTION

The detailed description provided below in connection with the appended drawings is intended as a description of the present examples and is not intended to represent the only forms in which the present example may be constructed or utilized. However, the same or any equivalent functions and sequences may be accomplished by different examples.

Although the present examples are described and illustrated herein as being implemented in a discharging device utilizing sand as solid particles, they are provided as an example and not a limitation. As those skilled in the art will appreciate, the present examples are suitable for application in a variety of different types of solid particles suitable for operating in temperature ranges for energy storage systems.

In this context directions, such as up, down, horizontal, vertical, etc., are described in reference to the gravity and conventional operational directions. Throughout this document, sequences and definitions relating to a sequence, such as “first“ or “last”, are defined according to the flow of solid particles through the discharging device.

Energy consumption at the electric grid is not constant. However, the amount of electricity fed into the electricity grid must always be equal to the amount of electricity consumed. At times, the energy production exceeds the demand, and the excess electrical energy must be consumed, for example by an energy storage system.

Renewable energy may be very intermittent by nature – solar energy is not available during the nighttime, or the wind may completely calm down. To enable these renewable energy systems being viable energy sources that could replace continuous energy production plants, the energy storage system may be used to balance peaks in energy production or consumption. One exemplary energy storage system uses solid particles, for example sand, to transform the electrical energy to thermal energy. Later, the thermal energy may be converted into electrical energy, for example by a steam turbine or a Stirling engine. Simplified process of a sand–based heat storage system comprises three phases: charging, storage and discharging.

The charging phase relates to heat absorption. During periods of excess or low–cost renewable energy, for example from windmills, photovoltaic cells, solar collectors or industrial processes, a heating element provides thermal energy through a bed of sand. The heating element may be an electric heating element or a pipe transferring hot fluid through a bed of sand. The electric heating element may be resistive, inductive, arced or any other means that convert electrical energy to thermal energy. The sand absorbs and stores the thermal energy. Exemplary, but not limiting exemplary temperature range for solid particles being considered cold or cool is up to 300 °C. Exemplary, but not limiting, temperature range for solid particles being considered hot or heated is between 500 °C and 2200 °C, depending on the choice of solid particles being used. Examples of solid particles are natural sand, aluminium oxide, quartz sand and graphite powder. Particle size distribution is in one example 50 – 1000 micron, in one example 100 – 250 microns.

In the storage phase the thermally charged sand acts as a heat reservoir, holding the absorbed energy until it is needed. The sand is suitable for retaining heat and to provide an efficient storage. The storage is insulated. The storage may be a silo or a container extending over ground level, or the storage may be positioned at least partially under ground level.

In the discharging phase, thermal energy is retrieved from the sand. When there is a demand for electric energy, for example during the night or on cloudy days, a working fluid is circulated through the now–hot sand. In one example, the discharging device is used to extract thermal energy from the heat storage, for example to be used at industrial process. As the working fluid passes through the hot, fluidized sand bed, it absorbs the stored thermal energy, becoming hot in the process. This hot working fluid can then be utilized for various applications. In one embodiment, the working fluid is water flowing via pipes through the hot sand converting into superheated steam. The superheated steam rotates a turbine generator that converts the thermal energy into electric energy.

The energy storage system described herein may cycle all residual thermal energy to other phases of the process. The energy storage system may be insulated as a whole, wherein the insulation may be the only component losing thermal energy from the energy storage system.

FIG. 1 illustrates schematically a top view of one exemplary embodiment of the discharging device. The discharging device comprises multiple adjacent heat transfer modules 11, 12, 13, 14, 15; denoted 11 – 15 hereinafter. The number of adjacent heat transfer modules 11 – 15 is five in the example of FIG.1, but embodiments are not limited to five heat transfer modules or any other number – other alternative heat transfer module configurations are possible. For example, in FIG. 3 are heat transfer modules 11 – 14; and in FIG. 5 are heat transfer modules 11 – 18.

The heat storage system may comprise multiple discharging devices, in addition to single discharging device comprising multiple heat transfer modules. In one embodiment, multiple discharging devices are arranged sequentially. In one embodiment, multiple discharging devices are arranged in parallel.

In FIG. 1, each heat transfer module 11 – 15 comprises a particle chamber 10 for fluidizable solid particles 5. A first heat transfer module 11 comprises a first particle inlet 51 for receiving solid particles 5, such as sand. In the present example the first particle inlet 51 is on the ceiling of the first heat transfer module 11, where the solid particles 5 may fall into the discharging device. In one embodiment, the flow of solid particles 5 is controlled by gravity and air flow. Alternatively, the first particle inlet 51 is positioned at the wall. In one embodiment, the path for the solid particles 5 to the first particle inlet 51 is inclined. In one embodiment, the flow to the first particle inlet 51 is controlled by the inclination angle of the path leading to the first particle inlet 51. In one embodiment, the flow to the first particle inlet 51 is controlled by a valve. In one embodiment, the flow to the first particle inlet 51 is controlled by a L valve. The L valve is a nonmechanical device that can control solid particle flow in high–pressure, high–temperature systems. One example of the L valve is a right angled, L-shaped pipe applied to transfer solid particles between two vessels, using gas injection and pipe geometry for controlling the flow of particulate solids.

Similar embodiments as to the first particle inlet 51 may be applied to any instance of a second particle inlet 52. In one embodiment, at least one of the heat transfer modules 12 – 15 following the first heat transfer module 11 comprises a second particle inlet 52 for the solid particles 5. In one embodiment, at least two of the heat transfer modules following the first heat transfer module comprises a particle inlet for the solid particles; as illustrated in the example of FIG. 1; the second particle inlet 52 at the second heat transfer module 12. A second instance of the second particle inlet 52 may be positioned at any of the following heat transfer modules 13 – 15. This arrangement may be modified, in that in one embodiment the discharging device comprises more than three particle inlets in any of the heat transfer modules 11 – 15. The position of the particle inlets 51 – 52 may be different in alternative embodiments. In one embodiment, a single heat transfer module 11 – 15 comprises more than one particle inlet 51, 52.

In one embodiment, the first particle inlet 51 and the second particle inlet 52 are controllable. Alternatively, or in addition, one of the multiple particle inlets 51 – 52 is controllable. Any of the particle inlets 51 – 52 may be fully open, fully closed or partially open.

In one embodiment, at least one of the heat transfer modules 11 – 15 is configured to receive via the second particle inlet 52 solid particles 5 having different temperature than solid particles 5 received into the first heat transfer module 11. The discharging device may receive at least two different temperature flows of solid particles 5, that are guided to different inlets 51, 52. This may be used to control the heat management inside the discharging device, as the heat storage system may be used to accommodate and optimize with different usage scenarios. In one embodiment, the first particle inlet 51 and the second particle inlet 52 receive portions of the same flow of solid particles 5, having the same temperature.

The last heat transfer module 15 comprises a particle outlet 59 for the solid particles 5, from where the solid particles 5 may travel into a conveyor, a cool storage phase or into the charging phase. Different phases of the heat storage system may be stacked vertically or placed laterally.

Adjacent heat transfer modules 11 – 15 are partially separated by module walls 21, 22, 23, 24 and partially connected by openings 31, 32, 33, 34. The module walls 21, 22, 23, 24 are hereinafter denoted as 21 – 24. The number of module walls 21 – 24 is four in the example of FIG.1, but embodiments are not limited to four module walls or to any other number – other module wall configurations are possible. The openings 31, 32, 33, 34 are hereinafter denoted as 31 – 34. The number of openings 31 – 34 is four in the example of FIG.1, but embodiments are not limited to four openings or to any other number – other configurations of wall openings are possible.

A fluid tube 30 is configured to receive thermal energy from the solid particles 5 in the particle chamber 10. In this example, each heat transfer module 11 – 15 comprises multiple fluid tubes 30, visible only in FIG. 3. In one embodiment, one heat transfer module 11 – 15 comprises one fluid tube 30. The fluid tubes 30 carry circulating working fluid, such as water that may be boiled to steam and/or the steam may be superheated. Examples of alternative working fluids are air, gas, water, oil, molten metals, or other liquids suitable for the temperatures used in the discharging device. In one embodiment, the working fluid is pressurized. In one example, the solid particles 5 of natural sand heat the fluid tubes 30 and the working fluid to a maximum temperature range between 1400 °C and 1600 °C. In one example, the solid particles 5 of aluminium oxide heat the fluid tubes 30 and the working fluid to a maximum temperature of 2200 °C. In one example the working fluid is heated to a temperature range between 800 °C and 1200 °C. The working fluid pressure range and temperature range may be selected to relate to the heating application.

One example of the working fluid pressure range is 2 bar … 20 bar.

One example of the working fluid pressure range is 20 bar … 275 bar.

One example of the working fluid pressure range is 20 bar … 340 bar.

FIG. 2 illustrates schematically an isometric view of one exemplary embodiment of the discharging device, where the partial separation of the module walls 21 – 24 is illustrated. The fluidized solid particles 5 travel horizontally from the first particle inlet 51 via adjacent heat transfer modules 11 – 15 and through said openings 31 – 34 to the particle outlet 59. In this context, travelling horizontally refers to a mass of particles, as any single particle may travel random path from the particle inlet 51 to the particle outlet 59.

As shown in FIG. 1 and FIG. 2, in one embodiment, the openings 31 – 34 are alternated on opposite sides for each heat transfer module 11 – 15. In one embodiment, at least two of the consecutive openings 31 – 34 are at the same side. As the particle outlet 59 is the lowest release spot in the space for the solid particles 5, the flow of solid particles 5 travels in a zig–zag pattern from the first particle inlet 51 to the particle outlet 59. The particle outlet 59 defines the height from which the solid particles 5 are removed from the last heat transfer module 15. As the fluidized solid particles 5 behave like a liquid, the surface portion of the bed of solid particles 5 flows out of the last heat transfer module 15. The surface portion of the fluidized solid particles 5 may contain the hottest solid particles 5. This arrangement of compartmentalized solid particles 5 controls the power transfer ratio between each heat transfer module 11 – 15 and makes controlling the temperatures easier. Any singular heat transfer module's 11 – 15 power may be controlled. This makes management of various temperature ranges in each heat transfer module 11 – 15 easier.

In one embodiment, the openings 31 – 34 in the module walls 21 – 24 between adjacent heat transfer modules 11 – 15 comprises a vertical section extending from a top portion of the module wall 21 – 24 to a lower portion of the module wall 21 – 24, as illustrated in FIG. 2. In one embodiment, at least one of the openings 31 – 34 does not extend to the floor of the heat transfer module 11 – 15; but instead forms a threshold for the solid particles 5 at lowest portion of the particle bed. The threshold may retain the lowest portion of the solid particles 5 in the heat transfer module 11 – 15, while the upper solid particles 5 may travel to the next transfer module. The height of the threshold may vary between each opening 31 – 34. In one embodiment, the first threshold is higher than the next threshold, the last threshold being the lowest. The height difference between consecutive thresholds is in one example 5 cm. The height differences improve the phasing between different heat transfer modules 11 – 15.

In one embodiment, the improved heat management inside the discharging device, with multiple particle inlets 51, 52 and the possibility to control the flow of solid particles 5 by various methods enables the discharging device to function without an attemperator. Attemperators are often used to even out the output temperature of the superheater, with spray water. The spray water may cause problems to the steam turbine, or pressurized tubes, as the spray water is not as clean as the saturated steam from a drum. Turbines or tubes may suffer from fouling.

FIG. 3 illustrates schematically a simplified side view of a fluidization system of one exemplary embodiment of the discharging device. In this example, the discharging device has four heat transfer modules 11, 12, 13, 14; denoted 11-14 in this example. In one embodiment, the fluidization system comprises at least one fluidizing chamber 64 below the particle chambers 10, and a fluidization inlet 61 for receiving fluidizing gas into the fluidizing chamber 64. The fluidization chamber evens the pressure before leading the fluidizing gas into the heat transfer modules 11 - 14. At least one fluidizing nozzle 63 leads the fluidizing gas from the fluidizing chamber 64 to each particle chamber 10. In one embodiment, each heat transfer module 11 – 14 comprises an individual fluidizing chamber 64. The fluidization inlet 61 may be positioned on the wall, floor, or ceiling of the fluidizing chamber 64.

The fluidizing chamber 64 may be partitioned 64, 64’, 64’’, 64’’’, as in the example of FIG. 3. In one embodiment, the fluidizing chamber 64 is arranged to provide different chamber pressures to different partitions. For example, the fluidizing gas pressure may be highest in the last heat transfer module 14, where the fluidizing chamber 64 provides a first pressure. Consequently, the second heat transfer module 12 according to the example is partitioned to second fluidizing chamber partition 64’, having a second pressure. The last heat transfer module 14 is partitioned to fourth fluidizing chamber 64’’’, while providing the lowest chamber pressure. In one embodiment, the fluidizing system comprises means for adjusting chamber pressure leading to each heat

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transfer module 11 – 14. In one embodiment, the fluidizing system comprises means for adjusting chamber pressure leading to each fluidizing nozzle 63. In one embodiment, the fluidizing chamber 64 comprises means for removing any solid particles 5 that may have travelled into the chamber 64 or to any part of it. In one embodiment, each of the fluidizing chambers 64'…64''' comprises means for adjusting the chamber pressure.

In one embodiment, each particle chamber 10 comprises multiple fluidizing nozzles 63. In one embodiment, the fluidizing nozzles 63 are located near the floor of the particle chamber 10. The nozzles may direct the fluidizing gas down, to prevent the solid particles 5 entering the fluidizing chamber 64 when the heat storage system or the fluidizing gas flow is shut down and the solid particles 5 fall to particle chamber 10 floor. The fluidizing nozzles 63 may comprise a cover preventing falling solid particles to enter the nozzle when the heat storage system is shut down. In one embodiment, floor of each particle chamber 10 comprise distributor holes to let the fluidizing gas to flow from fluidizing chamber 64.

The fluid tubes 30 are in one embodiment arranged staggered. The fluid tubes 30 are in one embodiment arranged inline.

The fluidizing gas flows out of the heat exchanger via a fluidization outlet 62. In one embodiment, the fluidization outlet 62 is arranged at the last heat transfer module 14. In one embodiment, the fluidization outlet 62 is at the wall of the last heat transfer module 14. In one embodiment, the fluidization outlet 62 is at the ceiling of the last heat transfer module 14. In one embodiment, the fluidization outlet 62 leads the fluidization gas to preheating the working fluid or solid particles 5 in the cold storage system any of the heating applications. The fluidizing gas flow may be further used to transport solid particles 5 in the heat storage system. In one embodiment, the fluidization outlet 62 leads the fluidization gas out of the energy storage system, for example to ambient air. In one embodiment, the fluidization outlet 62 leads the fluidization gas to an economizer or to an industrial process. Examples of such industrial processes are oil refinery processes or limestone calcination.

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The fluidization system converts granular solid particles 5 to a dynamic fluid–like state. In the present embodiment, gas such as air is passed up through the solid particles 5. When the air flow is introduced through the bottom of a bed of solid particles 5, it will move upwards through the bed via the empty spaces between the particles. At an increased air flow velocity, the aerodynamic drag forces on the solid particles 5 will begin to counteract the gravitational forces, wherein the upward drag forces equal the downward gravitational forces, causing the solid particles 5 to become suspended within the air flow. Increasing the air flow would cause the solid particles 5 to travel along the air flow. Selecting a suitable air flow rate causes the solid particles 5 to act in the fluidized state, where the bed of solid particles 5 will behave like a liquid. Example velocity for the fluidizing gas is in the range between 0,1 and 0,5 m/s. In one example the velocity is about 0,2 m/s. The pressure of the fluidizing gas in one example in the range of 0,1 – 0,7 bar. In one example the pressure is 0,3 bar.

FIG. 4 illustrates schematically an isometric view of an underside of one exemplary embodiment of the discharging device. One embodiment of the discharging device comprises multiple particle draining outlets 65. The particle draining outlet 65 is controllable, as it may be used for emptying the discharging device from solid particles 5. In the present example, the discharging device comprises five draining outlets 65. Below the discharging device may be a safe, fireproof pool or a container having refractory material that withstands the temperatures of hot solid particles 5 if the solid particles 5 are drained under emergency situation. This allows the discharging device to be quickly emptied even during the fluidizing system malfunctioning, maintenance personnel may reach the components inside the discharging device.

The floor of the fluidizing chamber 64 may be angled, causing the residual solid particles 5 to fall out to the corner of the floor, without blocking the fluidization inlet 61 positioned at the wall or the fluidization nozzle 63. The fluidizing chamber 64 may be emptied through dedicated outlets that are not illustrated.

In one embodiment, all heat transfer modules 11 – 15 comprise the particle draining outlet 65, as they may be used as intermediate take off for external/internal process purposes, in case of emergency, or during maintenance, to quickly empty all solid particles 5. The particle draining outlet 65 may reside at the bottom of any heat transfer module 11 – 15. The emergency drain process is not required in conventional process stoppage, as the solid particles 5, for example sand, would just fall to the floor of the discharging device and restarting the fluidization system would fluidize the solid particles 5 again. Emergency drain may be used, for example, in case of process system failure such as pumps or rupture of tubes. In one embodiment, the roof of the discharging device comprises a rupture area configured to rupture and to release pressure controllably in case of the fluid tube 30 breakage.

The heat storage system may comprise solid particles 5 having different sizes. In one embodiment, solid particles 5 of distinct size may accumulate into selected spots inside the discharging device, wherein the particle draining outlets 65 may be positioned during the design phase near those spots.

In one embodiment, the wall construction of the discharging device comprises a refractory wall. The material of the refractory wall is selected to be refractory material withstanding the temperatures being used and continuous impacts of the solid particles 5. The refractory wall is surrounded by insulation layer that maintains the thermal energy inside the discharging device. Refractory materials are chemically and physically stable at high temperatures. In one embodiment, the refractory wall is made of ceramic material, such as ceramic bricks. In one embodiment, the wall comprises a layer made of plate steel on the inner surface combined with insulation material on the outer surface. The refractory wall may be a layer on the inner surface of the wall.

Heat transfer module arrangements may be different. In one embodiment, the openings in adjacent walls of the module wall comprise a vertical section at different distances from a common corner. In one exemplary embodiments of the heat transfer module arrangement, three adjacent heat transfer modules share a corner. Various alternatives or embodiments may follow the outer structure of the discharging device or available space in the heat storage system.

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One exemplary embodiment of the heat transfer module arrangement at least portion of the discharge device comprises curved module walls or at least a portion of the module wall is curved. In one embodiment, for the adjacent heat transfer modules the module walls are curved. This arrangement may mitigate the wear that rapidly moving solid particle may cause to the module walls. The heat transfer module may comprise four walls, wherein at least one of those walls may be curved.

FIG. 5 illustrates schematically another embodiment, where the discharging device structure is donut–shaped, and the walls of consecutive heat transfer modules 11 – 18 are curved. In the illustrated example the partially open walls 21 - 27 are straight while the outer and inner walls of the heat transfer module 11 – 18 are curved. In this example the first particle inlet 51 is on the outer wall, solid particles 5 travelling from a middle portion of the donut–shaped structure and the particle outlet 59 being on the inner wall. In one embodiment, the discharging device is arranged on a silo–shaped structure, where the storage may reside above the discharging device. The solid particles 5 may be moved pneumatically with an airflow, by gravitation, or by a conveyor leading to the cold storage or to the charging phase.

In one embodiment, the working fluids are configured to flow from the at least two of the heat transfer modules to at least two different applications, selected from: a reheater, a superheater, a boiler bank, a steam generator, an evaporator, a heat pump application, a district heat application, industrial heat application and at least one phase of an economizer. The different heat transfer modules may produce different temperatures and outlets for the working fluid.

One example of the economizer temperature range is 105 °C … 374 °C.

One example of the superheater temperature range is 200 °C … 650 °C.

One example of the boiler bank temperature range is 200 °C … 374 °C.

One example of the reheater temperature range is 300 °C … 650 °C.

One example of the district heating temperature range is 50 °C … 140 °C.

The exemplary embodiment of FIG. 1 illustrates a counter current heat exchanger system being applied for the three phases of the economizer. The

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solid particles 5 flow through heat exchanger modules 13, 14 and 15 sequentially. The solid particles 5 dissipate thermal energy to the working fluid as each heat exchanger module 13 – 15, causing the last heat exchanger module 15 to being the coolest. In the counter current flow, the working fluid passes through fluid tubes 30 in the heat exchangers in a reversed order 15, 14, 13. The cool working fluid becomes gradually hotter as it travels through multiple heat exchanger modules 15 – 13, each being hotter than the previous one. In one embodiment, any of the heat exchanger modules 11 – 15 may have its own assigned purpose. For example, the last heat exchanger module 15 may be used for priming district heating to a temperature range between 80 °C and 120 °C. Any of the fluid tubes 30 from any of the heat exchanger modules 11 – 15 may be connected to a Stirling engine. In one embodiment, heat from the heat exchanger module is used for heating the hot end of the Stirling engine.

FIG. 6 illustrates schematically a flowchart of a method for discharging thermal energy for an energy storage system. The method comprises a step 70 of receiving, via the first particle inlet, solid particles into the discharging device. Step 71 comprises fluidizing the solid particles. Step 72 comprises circulating working fluid for receiving thermal energy from the solid particles to the working fluid. In step 73, fluidized solid particles travel horizontally from the particle inlet via adjacent heat transfer modules and through said openings to the particle outlet.

A discharging device for an energy storage system is disclosed herein. The discharging device comprises multiple adjacent heat transfer modules. Each heat transfer module comprises a particle chamber for fluidizable solid particles; a fluid tube comprising circulating working fluid for receiving thermal energy from solid particles to the working fluid; and a fluidization system for fluidizing the solid particles. A first heat transfer module comprises a first particle inlet for receiving solid particles into the discharging device. Adjacent heat transfer modules are partially separated by a module wall and partially connected by an opening in the module wall. A last heat transfer module comprises a particle outlet for the solid particles, wherein the fluidized solid particles travel horizontally from the particle inlet via adjacent heat transfer modules and

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through said openings to the particle outlet. In one embodiment, a floor of the particle chamber comprises at least one particle draining outlet. In one embodiment, the fluidization system comprises at least one fluidizing chamber below the particle chambers, a fluidization inlet for receiving fluidizing gas into the fluidizing chamber and at least one fluidizing nozzle leading the fluidizing gas from the fluidizing chamber to each particle chamber. In one embodiment, the device comprises a fluidization outlet leading the fluidization gas to preheating solid particles. In one embodiment, at least one of the other heat transfer modules than the first heat transfer module comprises a second particle inlet for the solid particles. In one embodiment, the first particle inlet and the second particle inlet are controllable. In one embodiment, at least one of the heat transfer modules is configured to receive via the second particle inlet solid particles having different temperature than solid particles received into the first heat transfer module. In one embodiment, at least two of the heat transfer modules are configured to heat fluid tubes to different temperature ranges. In one embodiment, the working fluids are configured to flow from the at least two of the heat transfer modules to at least two different applications, selected from: a reheater, a superheater, a boiler bank, a steam generator, an evaporator, a heat pump application, a district heat application, industrial heat application and at least one phase of an economizer.

Alternatively, or in addition, a method for discharging thermal energy for an energy storage system is disclosed. The system comprises multiple adjacent heat transfer modules. Each heat transfer module comprises a particle chamber for fluidizable solid particles; a fluid tube comprising working fluid; a fluidization system; and a first heat transfer module comprising a first particle inlet. The method comprises the steps of receiving, via the first particle inlet, solid particles into the discharging device; fluidizing the solid particles; and circulating working fluid for receiving thermal energy from the solid particles to the working fluid. Adjacent heat transfer modules are partially separated by a module wall and partially connected by an opening in the module wall; and a last heat transfer module comprises a particle outlet for the solid particles. The method comprises a step of fluidized solid particles travelling horizontally from the particle inlet via adjacent heat transfer modules and through said openings to

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the particle outlet. In one embodiment, the fluidization system comprises at least one fluidizing chamber below the particle chambers; and the method comprises receiving, via a fluidization inlet, fluidizing gas into the fluidizing chamber; and leading the fluidizing gas from the fluidizing chamber to each particle chamber by at least one fluidizing nozzle. In one embodiment, at least one of the other heat transfer modules than the first heat transfer module comprises a second particle inlet for the solid particles, and the method comprises the step of controlling the particle flow through the first particle inlet and at least one of the second particle inlets. In one embodiment, the method comprises the step of receiving, via the first inlet, the solid particles into the first heat transfer module at a first temperature and receiving, via at least one of the second particle inlets, solid particles to at least one heat transfer module at a different temperature than the first temperature. In one embodiment, the method comprises the step of heating the fluid tubes of at least two of the heat transfer modules to different temperature ranges. In one embodiment, the method comprises the step of causing the working fluids to flow from the at least two of the heat transfer modules to at least two different applications, selected from: a reheater, a superheater, a boiler bank, a steam generator, an evaporator, a heat pump application, a district heat application, industrial heat application and at least one phase of an economizer.

Any range or device value given herein may be extended or altered without losing the effect sought.

Although at least a portion of the subject matter has been described in language specific to structural features and/or acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as examples of implementing the claims and other equivalent features and acts are intended to be within the scope of the claims.

It will be understood that the benefits and advantages described above may relate to one embodiment or may relate to several embodiments. The embodiments are not limited to those that solve any or all of the stated problems or those that have any or all of the stated benefits and advantages. It will further be understood that any reference to ‘an’ item refers to one or more of those items.

The steps of the methods described herein may be carried out in any suitable order, or simultaneously where appropriate. Additionally, individual blocks may be deleted from any of the methods without departing from the spirit and scope of the subject matter described herein. Aspects of any of the examples described above may be combined with aspects of any of the other examples described to form further examples without losing the effect sought.

The term ‘comprising’ is used herein to mean including the method blocks or elements identified, but that such blocks or elements do not comprise an exclusive list and a method or apparatus may contain additional blocks or elements.

It will be understood that the above description is given by way of example only and that various modifications may be made by those skilled in the art. The above specification, examples and data provide a complete description of the structure and use of exemplary embodiments. Although various embodiments have been described above with a certain degree of particularity, or with reference to one or more individual embodiments, those skilled in the art could make numerous alterations to the disclosed embodiments without departing from the spirit or scope of this specification.

CLAIMS

1. A discharging device for an energy storage system, comprising:
 multiple adjacent heat transfer modules (11 – 18), wherein each heat transfer module (11 – 18) comprises:
 a particle chamber (10) for fluidizable solid particles (5);
 a fluid tube (30) comprising circulating working fluid for receiving thermal energy from solid particles (5) to the working fluid;
 a fluidization system for fluidizing the solid particles (5); and
 a first heat transfer module (11) comprising a first particle inlet (51) for receiving solid particles (5) into the discharging device;
 c h a r a c t e r i z e d in that:
 adjacent heat transfer modules (11 – 18) are partially separated by a module wall (21 - 27) and partially connected by an opening (31 - 34) in the module wall (21 - 27); and
 a last heat transfer module (14, 15, 18) comprises a particle outlet (59) for the solid particles (5), wherein the fluidized solid particles (5) travel horizontally from the particle inlet (51) via adjacent heat transfer modules (11 – 18) and through said openings (31 – 34) to the particle outlet (59).

2. A discharging device according to claim 1, c h a r a c t e r i z e d in that a floor of the particle chamber (10) comprises at least one particle draining outlet (65).

3. A discharging device according to claim 1 or claim 2, c h a r a c t e r i z e d in that the fluidization system comprises at least one fluidizing chamber (64, 64’, 64’’, 64’’’) below the particle chambers (10), a fluidization inlet (61) for receiving fluidizing gas into the fluidizing chamber (64, 64’, 64’’, 64’’’) and at least one fluidizing nozzle (63) leading the fluidizing gas from the fluidizing chamber (64, 64’, 64’’, 64’’’) to each particle chamber (10).

4. A discharging device according to any of the claims 1 to 3, c h a r a c t e r i z e d by comprising a fluidization outlet (62) leading the fluidization gas to preheating solid particles (5), to an economizer or to an industrial process.

5. A discharging device according to any of the claims 1 to 4, c h a r a c t e r i z e d in that at least one of the other heat transfer modules (12 – 18) than the first heat transfer module (11) comprises a second particle inlet (52) for the solid particles (5).

6. A discharging device according to claim 5, c h a r a c t e r i z e d in that the first particle inlet (51) and the second particle inlet (52) are controllable.

7. A discharging device according to claim 5 or claim 6, c h a r a c t e r i z e d in that at least one of the heat transfer modules (11 – 18) is configured to receive via the second particle inlet (52) solid particles (5) having different temperature than solid particles (5) received into the first heat transfer module (11).

8. A discharging device according to any of the claims 1 to 7, c h a r a c t e r i z e d in that at least two of the heat transfer modules (11 – 18) are configured to heat fluid tubes (30) to different temperature ranges.

9. A discharging device according to claim 8, c h a r a c t e r i z e d in that the working fluids are configured to flow from the at least two of the heat transfer modules (11 – 18) to at least two different applications, selected from: a reheater, a superheater, a boiler bank, a steam generator, an evaporator, a heat pump application, a district heat application, industrial heat application and at least one phase of an economizer.

10. A method for discharging thermal energy for an energy storage system, the system comprising:

multiple adjacent heat transfer modules (11 – 18), wherein each heat transfer module (11 – 18) comprises:

a particle chamber (10) for fluidizable solid particles (5);

a fluid tube (30) comprising working fluid;

a fluidization system; and

a first heat transfer module (11) comprising a first particle inlet (51);

wherein the method comprises the steps of:

receiving, via the first particle inlet (51), solid particles (5) into the discharging device;

fluidizing the solid particles (5); and

circulating working fluid for receiving thermal energy from the solid particles (5) to the working fluid,

c h a r a c t e r i z e d in that:

adjacent heat transfer modules (11 – 18) are partially separated by a module wall (21 - 27) and partially connected by an opening (31 - 34) in the module wall (21 - 27); and

a last heat transfer module (14, 15, 18) comprises a particle outlet (59) for the solid particles (5), wherein the method comprises:

fluidized solid particles (5) travelling horizontally from the particle inlet (51) via adjacent heat transfer modules (11 – 18) and through said openings (31 – 34) to the particle outlet (59).

11. A method according to claim 1, c h a r a c t e r i z e d in that the fluidization system comprises at least one fluidizing chamber below the particle chambers (10); and

receiving, via a fluidization inlet (61), fluidizing gas into the fluidizing chamber (64, 64’, 64’’, 64’’’); and

leading the fluidizing gas from the fluidizing chamber (64, 64’, 64’’, 64’’’) to each particle chamber (10) by at least one fluidizing nozzle (63).

12. A method according to claim 10 or claim 11, characterized in that at least one of the other heat transfer modules (12 – 18) than the first heat transfer module (11) comprises a second particle inlet (52) for the solid

particles (5), and controlling the particle flow through the first particle inlet (51) and at least one of the second particle inlets (52).

13. A method according to any of the claims 12, c h a r a c t e r i z e d by leading, by a fluidization outlet (62), the fluidization gas to preheating solid particles (5), to an economizer or to an industrial process.

14. A method according to claim 12 or claim 13, c h a r a c t e r i z e d by receiving, via the first inlet, the solid particles (5) into the first heat transfer module (11) at a first temperature and receiving, via at least one of the second particle inlets (52), solid particles (5) to at least one heat transfer module (12 – 18) at a different temperature than the first temperature.

15. A method according to any of the claims 10 to 14, c h a r a c t e r i z e d by heating the fluid tubes (30) of at least two of the heat transfer modules (11 – 18) to different temperature ranges.

16. A method according to claim 15, c h a r a c t e r i z e d by causing the working fluids to flow from the at least two of the heat transfer modules (11 – 18) to at least two different applications, selected from: a reheater, a superheater, a boiler bank, a steam generator, an evaporator, a heat pump application, a district heat application, industrial heat application and at least one phase of an economizer.

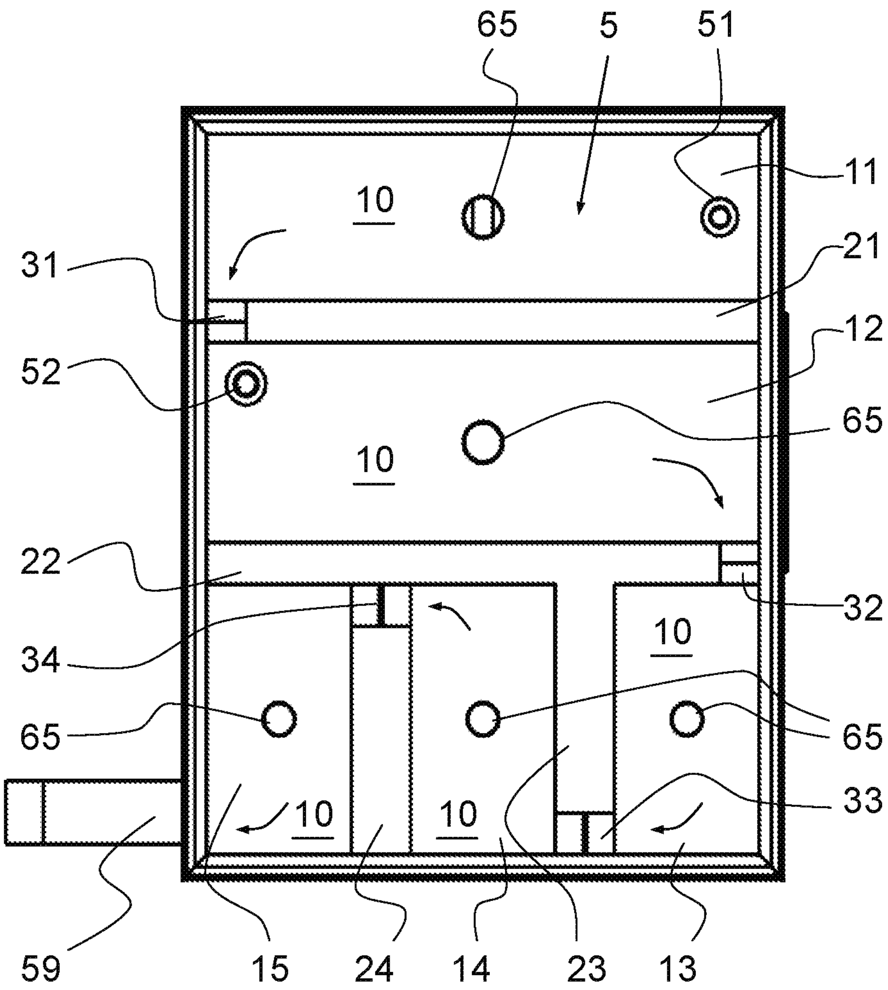
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Fig. 1

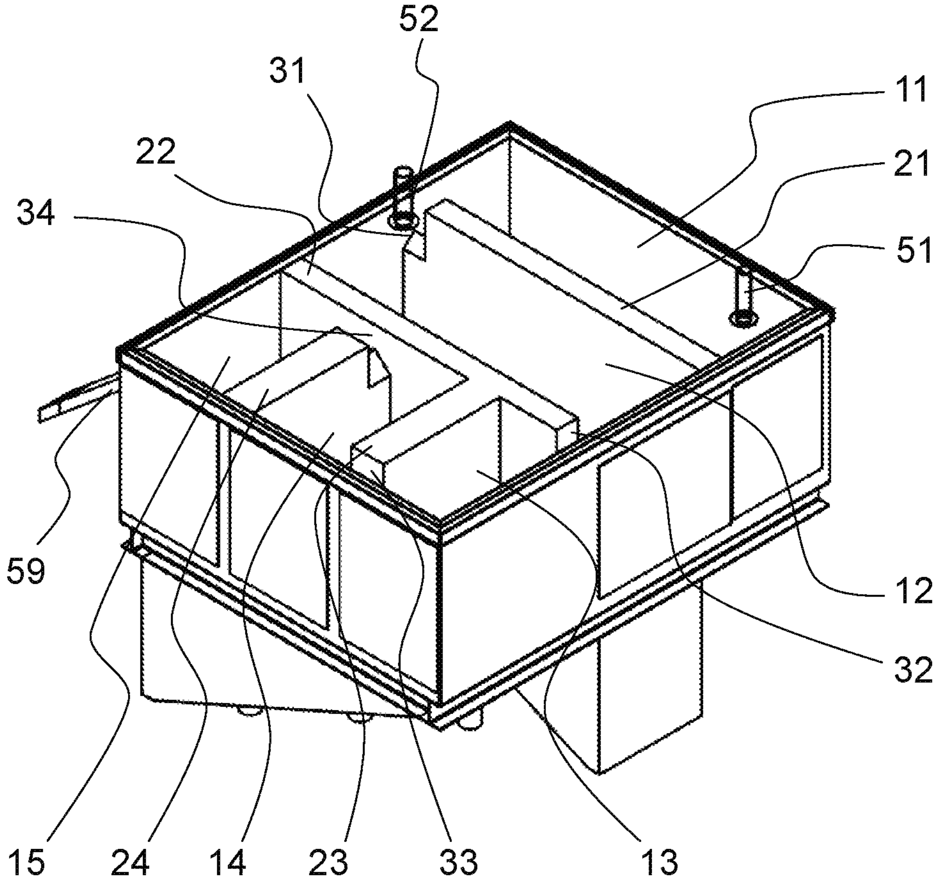

Fig. 2

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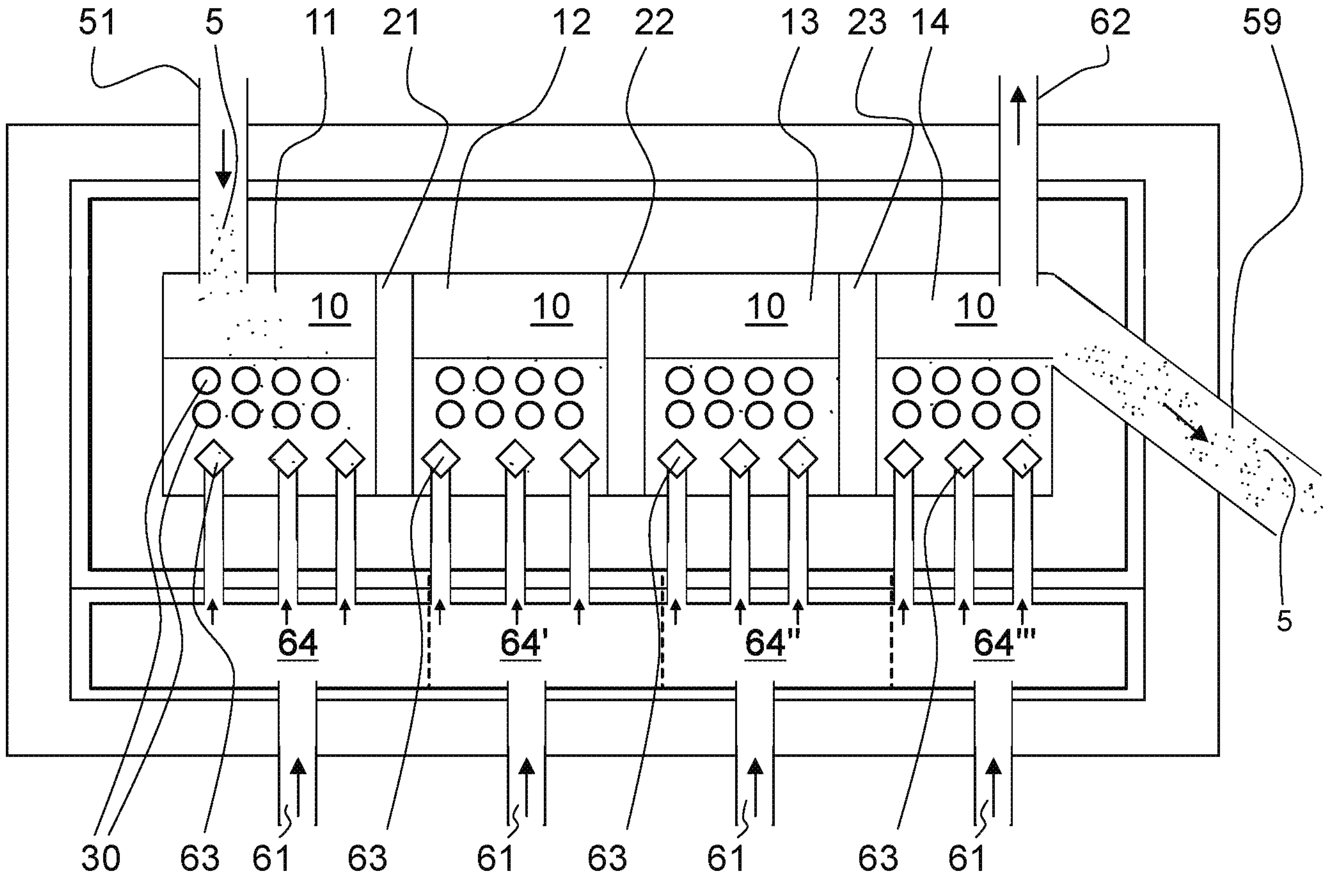

Fig. 3

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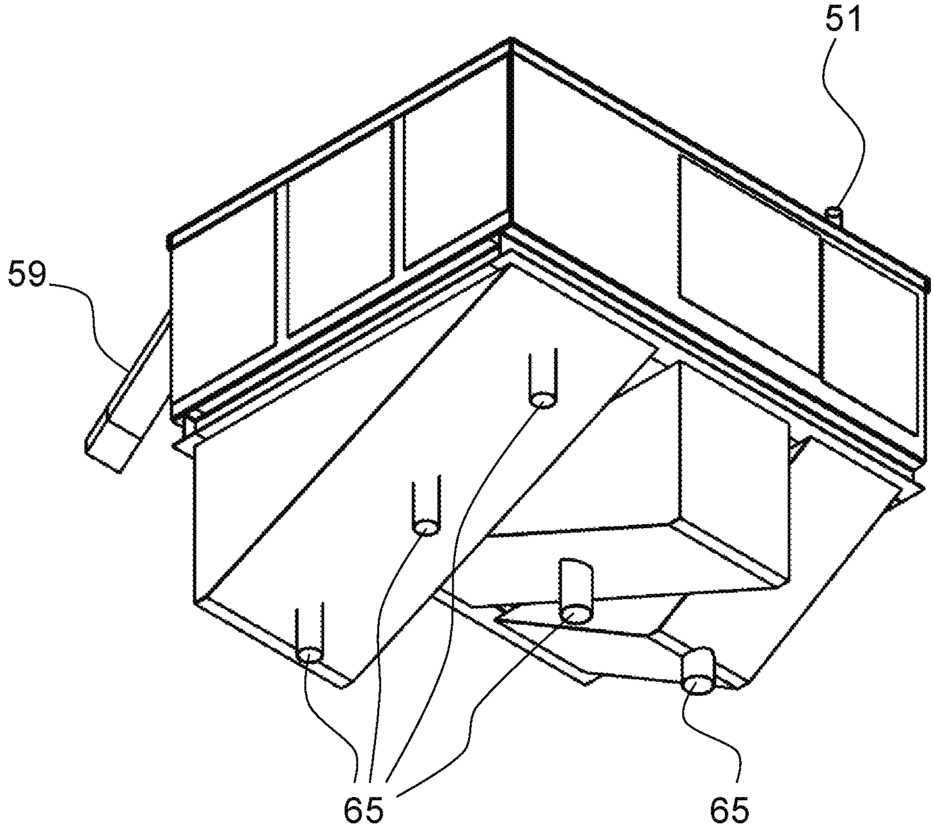


Fig. 4

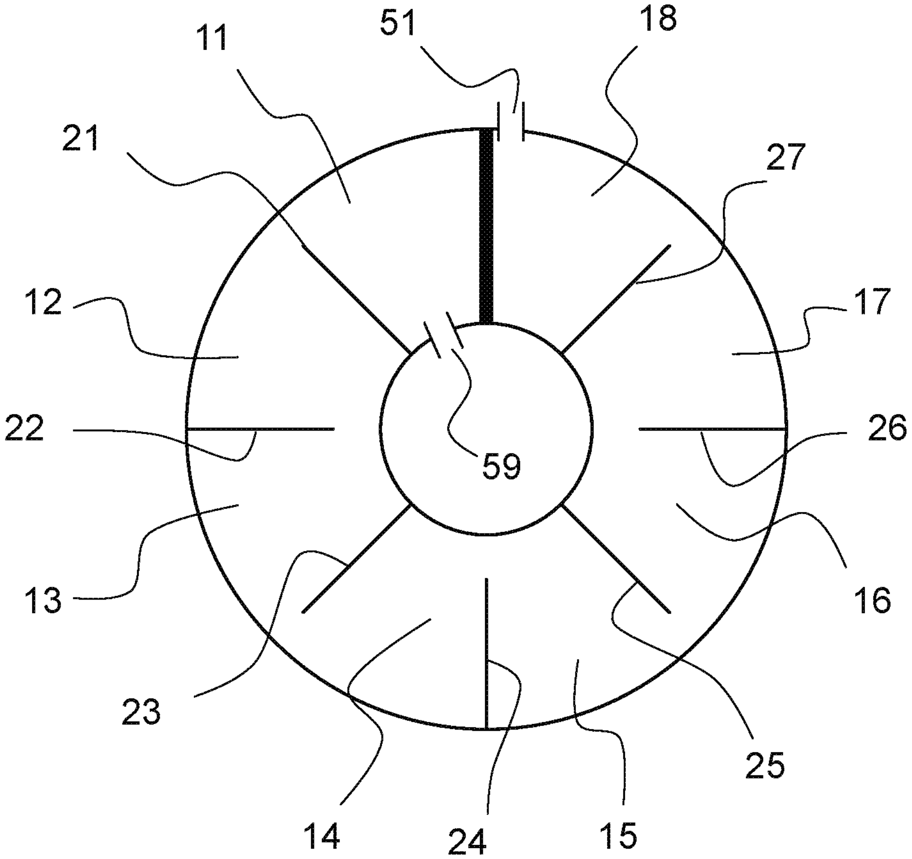
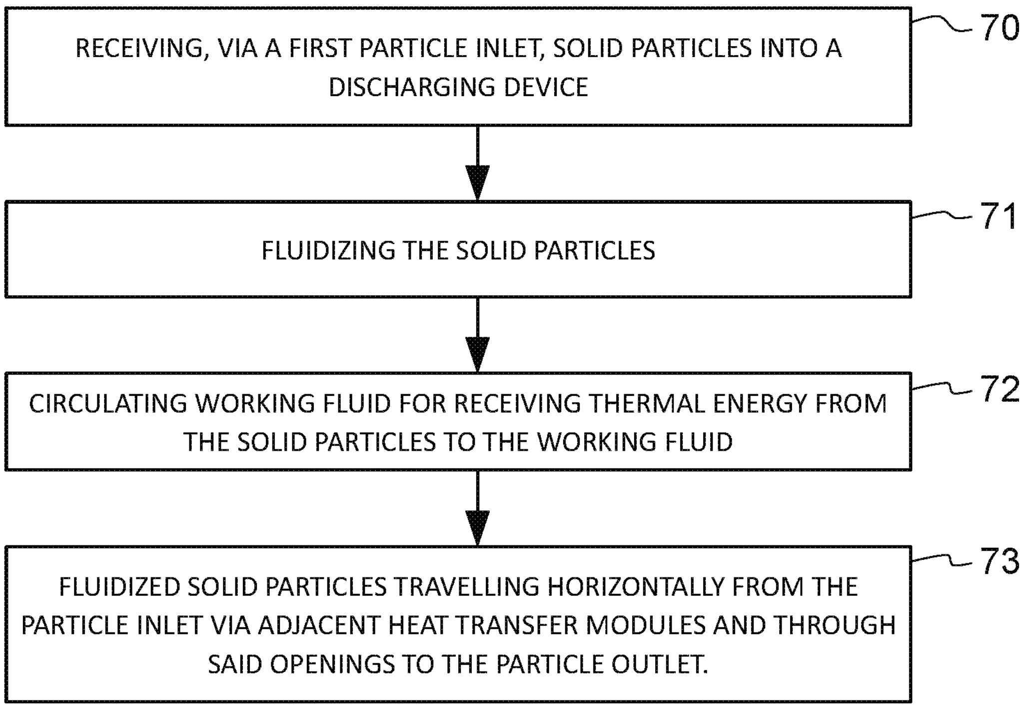


Fig. 5


RECEIVING, VIA A FIRST PARTICLE INLET, SOLID PARTICLES INTO A DISCHARGING DEVICE
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FLUIDIZING THE SOLID PARTICLES
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CIRCULATING WORKING FLUID FOR RECEIVING THERMAL ENERGY FROM THE SOLID PARTICLES TO THE WORKING FLUID
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FLUIDIZED SOLID PARTICLES TRAVELLING HORIZONTALLY FROM THE PARTICLE INLET VIA ADJACENT HEAT TRANSFER MODULES AND THROUGH SAID OPENINGS TO THE PARTICLE OUTLET.
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Fig. 6

FINNISH PATENT AND REGISTRATION OFFICE **SEARCH REPORT**

Finnish Patent and Registration Office
FI-00091 PRH

PATENT APPLICATION No.	CLASSIFICATION	
20245073	IPC ***F28D 13/00*** (2006.01) ***F28D 17/00*** (2006.01) ***F28D 20/00*** (2006.01) ***F24H 7/02*** (2022.01)	CPC **F28D 13/00** **F28D 17/005** **F28D 2020/0013** **F24H 7/0233** Y02E 70/30

PATENT CLASSES SEARCHED (classification systems and classes)
IPC: F28D, F24H

DATABASES CONSULTED DURING THE SEARCH
EPODOC, EPO-Internal full-text databases, Full-text translation databases from Asian languages, WPIAP, IPRally

DOCUMENTS CONSIDERED TO BE RELEVANT

Category*)	Bibliographic data on the document and relevant passages	Relevant to claims
X Y	US 2014311479 A1 (MARYAMCHIK MIKHAIL [US] et al.) 23 October 2014 (23.10.2014) whole document, especially abstract; paragraphs [0071]-[0090]; figures 1-6	1, 3, 4, 8-11, 13, 15, 16 2, 5-7, 12, 14
Y	US 2021372610 A1 (LEHTONEN PEKKA [FI] et al.) 02 December 2021 (02.12.2021) whole document, especially abstract; paragraphs [0073]-[0076]; figures 1-11	2, 5-7, 12, 14
A	CN 116989474 A (UNIV TSINGHUA) 03 November 2023 (03.11.2023) figures 1-5 & abstract [online] EPOQUENET EPODOC & WPI & machine translation in English [online] EPOQUENET TXPMTCEA, especially pages 4-9	1-16

Continued on the next sheet ☒

*) X Document indicating that the invention is not novel or does not involve an inventive step with respect to the state of the art.
Y Document indicating that the invention does not involve an inventive step with respect to the state of the art if combined with one or more other documents in the same category.
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P Document published prior to the filing date but not prior to the earliest priority date.
T Document published after the filing date or priority date and illustrating the principle or theory underlying the invention.
E Earlier patent or utility model application that either is Finnish or designates Finland published on or after the filing date (priority date).
D Document that is mentioned in the application.
L Document which may throw doubts on priority claim(s), is cited to establish the publication date of another citation or is referred to for some other reason.

& Document member of the same patent family.

This document has been electronically signed. **Further information given in the annex** ☐

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14.08.2024

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FI-00091 PRH

PATENT APPLICATION No.
20245073

DOCUMENTS CONSIDERED TO BE RELEVANT, CONTINUED		
Category*)	**Bibliographic data on the document and relevant passages**	**Relevant to claims**
A	WO 2023031975 A1 (MAGALDI POWER SPA [IT]) 09 March 2023 (09.03.2023) abstract; figures 1-11	1-16