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**LÄMMÖNVAIHDIN JA MENETELMÄ ENERGIAVARASTOJÄRJESTELMÄÄN**
**VÄRMEVÄXLARE OCH FÖRFARANDE FÖR ENERGILAGRINGSSYSTEM**
**A HEAT EXCHANGER AND A METHOD FOR AN ENERGY STORAGE SYSTEM**

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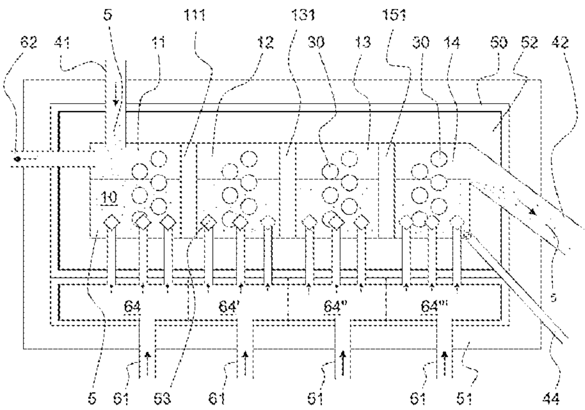
(57) Tiivistelmä - Sammandrag - Abstract

Lämmönvaihtimessa hyödynnetään kiinteitä partikkeleja (5), esimerkiksi hiekkapartikkeleja, joita lämmitetään uusiutuvan energian voimalaitoksen sähköllä. Kiinteät partikkelit (5) leijutetaan kaasulla staattisesta kiinteästä tilasta dynaamiseen nestemäiseen tilaan. Lämmönvaihtimessa on useita vierekkäisiä lämmönsiirtomoduuleja (11 – 18), jotka kukin on erotettu osittain moduuliseinällä (111, 121, 131, 141). Vierekkäisten lämmönsiirtomoduulien välisessä moduuliseinämässä (111, 121, 131, 141) on aukko moduulin seinämässä, jotta leijutetut kiinteät partikkelit (5) voivat kulkea viereiseen lämmönsiirtomoduuliin (11 - 18). Leijutetut kiinteät partikkelit (5) kulkevat vaakasuunnassa hiukkasten tuloaukosta (41) viereisten lämmönsiirtomoduulien (11-18) kautta ja mainitun aukon kautta viimeisen lämmönsiirtomoduulin hiukkasten ulostuloon (42).

A heat exchanger utilizes solid particles (5), for example sand particles, that 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 heat exchanger has multiple adjacent heat transfer modules (11 – 18), that are each partially separated by a module wall (111, 121, 131, 141). The module wall (111, 121, 131, 141) between adjacent heat transfer modules has an opening in the module wall 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 (41) via adjacent heat transfer (11 – 18) modules and through said opening to the particle outlet (42) of the last heat transfer module.



# A HEAT EXCHANGER 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.

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 heat transfer. Sand particles may agglomerate or clump together over time, affecting the fluidization process and disturbing 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 heat exchanger 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 heat exchanger utilizes solid particles, for example sand particles, that are heated by the electric power from the energy power plant. The solid particles are fluidized by gas from a static solid-like state to a dynamic fluid-like state.

The heat exchanger has multiple adjacent heat transfer modules, that 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 cool particles and exit through the outlet of the last heat transfer module as heated solid particles. The fluidization airflow may be recirculated to recover the heat for used on other processes of the energy storage system.

The heating process is continuous and effective, top portion of the fluidized solid particles travels laterally towards the outlet via each module. Temperatures may be controlled throughout the heat exchanger system.

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 heat exchanger as disclosed herein can be designed with modular configurations, allowing for scalability based on energy storage requirements.

The modular configurations enable discharging solid particles from the heat exchanger at different phases. The solid particles become hotter while travelling through multiple heat transfer modules – controllable particle outlets at various places along the heat transfer modules may be used to various purposes. For example, short periods of cheap or negatively priced electric energy may be captured more efficiently. Different outlet temperatures may be used, as an example, for distillation, district heating or other purposes that require lower temperatures than the full target temperature of the heat storage system. As one example, the excess electric energy may be available only for a short time period, therefore the heat storage system may select the best usage for smaller peak energy.

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 heat exchanger.

The heater elements may be quick to react in receiving available electric power. For example, the excess electric energy may be quickly directed to resistors. The solid particle movement may start few seconds after the resistors have been deployed to further dissipate the thermal energy into the storage. The energy storage system may be used to balance transients of the electric grid.

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 heat exchangers.

## 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 side view of one exemplary embodiment of a heat exchanger in a support position;

FIG. 2 illustrates schematically a top view of one exemplary embodiment of a heat exchanger in a support position;

FIG. 3a illustrates schematically a top view of one exemplary embodiment of the heat transfer module arrangement;

FIG. 3b illustrates schematically a top view of one exemplary embodiment of the heat transfer module arrangement;

FIG. 4a illustrates schematically a top view of one exemplary embodiment of the heat transfer module arrangement;

FIG. 4b illustrates schematically a top view of one exemplary embodiment of the heat transfer module arrangement;

FIG. 5 illustrates schematically a top view of one exemplary embodiment of the heat transfer module arrangement; and

FIG. 6 illustrates schematically a flowchart of a method for heating solid particles.

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

## 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 heat exchanger 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 heat exchanger.

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 electric 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 electric energy to thermal energy. Later, the thermal energy may be converted into electric 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 working fluid through a bed of sand. The electric heating element may be resistive, inductive, arced or any other means that convert electric 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 microns, 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 one embodiment, the system components are configured to fit inside a cargo container.

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. As the working fluid passes through the hot 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 steam

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rotates a turbine generator that converts the thermal energy into electric energy. Examples of the working fluid are air, gas or water.

FIG. 1 illustrates schematically a side view of one exemplary embodiment of the heat exchanger. The heat exchanger comprises multiple adjacent heat transfer modules 11, 12, 13, 14. The number of adjacent heat transfer modules 11, 12, 13, 14 is four in the example of FIG.1, but the number is not limited to four or any other number. The following exemplary embodiments show multiple arrangements of heat transfer modules, numbered between 11 – 18.

The heat storage system may comprise multiple heat exchangers. In one embodiment, multiple heat exchangers are arranged sequentially. In one embodiment, multiple heat exchangers are arranged in parallel.

In FIG. 1, each heat transfer module 11, 12, 13, 14 comprises a particle chamber 10 for fluidizable solid particles 5. A first heat transfer module 11 comprises a particle inlet 41 for receiving solid particles 5, such as sand. In the present example the particle inlet 41 is on the ceiling of the first heat transfer module 11, where the solid particles 5 may fall into the heat exchanger. In one embodiment, the solid particle flow is controlled by gravity and air flow. Alternatively, the inlet 41 is positioned at the wall. In one embodiment, the path to the inlet 41 is inclined. In one embodiment, the flow to the inlet 41 is controlled by the inclination angle. In one embodiment, the flow to the inlet 41 is controlled by a valve. In one embodiment, the flow to the inlet 41 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.

The last heat transfer module 14 comprises a particle outlet 42 for the solid particles 5, from where the solid particles 5 may travel into storage phase. Different phases of the heat storage system may be stacked vertically or placed laterally.

One embodiment of the heat exchanger comprises a particle draining outlet 44. The particle draining outlet 44 is controllable, as it may be used for emptying the

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heat exchanger from solid particles 5. The particle draining outlet 44 is in one embodiment selectable to be fully open, fully closed or in mixed position. In the present example the particle draining outlet is arranged to the last transfer module 14. In one embodiment, all heat transfer modules 11, 12, 13, 14 comprise the particle draining outlet 44, 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. The particle draining outlet 44 may reside at the bottom of any heat transfer module.

A heater element 30 provides thermal energy to solid particles 5 in the particle chamber 10. In this example, each heat transfer module 11, 12, 13, 14 comprises multiple heater elements 30. The heater elements 30 are in this example electric heater elements, resistors, that convert electric energy into thermal energy. In one embodiment, the heater elements 30 comprise tubes that carry a hot working fluid through the particle chamber 10. In one embodiment, the heater elements 30 are positioned below the surface of the bed of solid particles 5.

In one example, the heater elements 30 heat the solid particles 5 of natural sand to a maximum temperature range between 1400 °C and 1600 °C. In one example, the heater elements 30 heat the solid particles 5 of aluminium oxide to a maximum temperature of 2200 °C. In one example the solid particles 5 are heated to a temperature range between 800 °C and 1200 °C.

The modular arrangement enables recycling the heater elements 30 to different positions in the heat exchanger. For example, fresh heater elements 30 may be used in the last heat transfer module 11 during the first stint of its lifetime and reused at previous stages of the following heat transfer modules 12 – 18. The heater elements 30 may be different in terms of power, surface temperature, durability, controllability, price or efficiency. The fluidized solid particles 5 may be heated only within selected temperature range in a single heat transfer module 11 – 18, and the optimized heater exchanger may comprise optimized heater element 30 configuration.

A 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. In a bubbling fluidized system, 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. Increasing the air flow would cause the solid particles 5 to travel along the air flow. 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.

In one embodiment, the wall construction of the heat exchanger comprises a plate wall 50. The plate wall 50 is surrounded by insulation layer 51 that maintains the thermal energy inside the heat exchanger. Inside the plate wall 50 is a refractory wall 52, made of refractory material. Refractory materials are chemically and physically stable at high temperatures. In one embodiment, the refractory wall 52 is made of ceramic material, such as ceramic bricks. In one embodiment, the plate wall 50 is made of plate steel.

Adjacent heat transfer modules 11, 12, 13, 14 are partially separated by module walls 111, 121, 131, 141, 151 and partially connected by openings 112, 122, 132, 142, 152. FIG. 2 illustrates schematically a top view of one exemplary embodiment of the heat exchanger, where the partial separation of the module walls 111, 121, 131, 141, 151 is illustrated. The fluidized solid particles 5 travel horizontally from the particle inlet 41 via adjacent heat transfer modules 11, 12, 13, 14 and through said opening 112, 122, 132, 142, 152 to the particle outlet 42. As shown in FIG. 2, the openings 112, 122, 132, 142, 152 are alternated on opposite sides for each heat transfer module 11, 12, 13, 14. As the particle outlet 42 is the lowest release spot in the space for the solid particles 5, that causes flow to the solid particles 5, travelling in a zig-zag pattern in this example. The particle outlet 42 defines the height from which the solid particles 5 are removed from the last heat transfer module 14. As the fluidized solid particles 5 behave like the liquid, the surface portion of the bed of solid particles 5 travels out of the last heat transfer module 14. This arrangement evens the temperature of the bed of solid particles 5 inside the heat exchanger and makes controlling the temperatures easier.

In one embodiment, the opening 112, 122, 132, 142, 152 in the module wall 111, 121, 131, 141, 151 between adjacent heat transfer modules 11, 12, 13, 14 comprises a vertical section extending from a top portion of the module wall to a lower portion of the module wall, as illustrated in FIG. 2. In one embodiment, at least one of the openings 112, 122, 132, 142, 152 does not extend to the floor of the heat transfer module 11, 12, 13, 14; 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, 12, 13, 14, while the upper solid particles 5 may travel to the next transfer module. The height of the threshold may vary between each opening 112, 122, 132, 142, 152. 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, 12, 13, 14.

Heat transfer module arrangements may be different. In one embodiment, the openings 112, 122, 132, 142, 152 in adjacent walls of the module wall 111, 121, 131, 141, 151 comprise a vertical section at different distances from a common corner. FIG. 3a illustrates schematically a top view of exemplary embodiments of the heat transfer module arrangement, where three adjacent heat transfer modules 11, 12, 13 share a corner 19. FIG. 3b illustrates schematically another exemplary arrangement of heat transfer modules 11, 12, 13. Various alternatives or embodiments may follow the outer structure of the heat exchanger or available space in the heat storage system.

FIG. 4a illustrates schematically a side view of one exemplary embodiment of the heat transfer module arrangement, having curved module walls 111, 121, 131, or where at least portion of the module wall is curved. In one embodiment, for the adjacent heat transfer modules 11 - 13 the module walls 111, 121, 131 are curved. This arrangement may mitigate the wear that rapidly moving solid particle may cause to the module walls 111, 121, 131. The heat transfer module may comprise four walls, wherein at least one of those walls may be curved.

FIG. 4b illustrates schematically another embodiment, where the heat exchanger structure is donut-shaped, and the walls of consecutive heat transfer modules 11 – 18 are curved. In the illustrated example the partially open walls 111, 121, 131, … 171 are straight while the outer and inner walls of the heat transfer module 11 – 18 are curved. In this example the particle inlet 42 is on the inner wall, solid particles 5 travelling from a middle portion of the donut-shaped structure and the particle outlet 41 being on the outer wall. In one embodiment, the heat exchanger is arranged on a silo-shaped structure, where the storage may reside below the heat exchanger. The discharging phase, a discharging device may reside below the particle storage. The solid particles may be moved pneumatically with an airflow, by gravitation, or by a conveyor to the discharging phase.

In one embodiment, the openings 112, 122, 132, 142, 152 in three consecutive module walls 111, 121, 131, 141, 151 are noncollinear, i.e. they do not share a common straight visual line. From one heat transfer module is no line of sight to the second consecutive heat transfer module. In one embodiment, the module walls 111, 121, 131, 141, 151 between adjacent heat transfer modules are staggered to opposite sides. In one embodiment, at least two consecutive module walls 111, 121, 131, 141, 151 between adjacent heat transfer modules are on the same side.

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, 12, 13, 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 – 18 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. 1. 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 first heat transfer module 11, 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 transfer module 11 – 18. 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 fluidizing gas flows out of the heat exchanger via a fluidization outlet 62. In one embodiment, the fluidization outlet 62 is arranged at the first heat transfer module 11. In one embodiment, the fluidization outlet 62 is at the wall of the first heat transfer module 11. In one embodiment, the fluidization outlet 62 is at the ceiling of the first heat transfer module 11. In one embodiment, the fluidization system is arranged to function as a counter current heat exchanger system. The fluidizing gas gets hot during its flow through the heat exchanger. In one embodiment, the fluidization outlet 62 leads the fluidization gas to preheating solid particles 5, before the solid particles enter the heat exchanger. 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.

The solid particles 5 may be guided close to the heater elements 30 for better heating. In one embodiment, the heat transfer module comprises multiple heater elements 30 and the heater elements 30 are staggered, or inline, in relation to the travel direction of the fluidized solid particles 5. The solid particles 5 travel in curved route from the particle inlet 41 to the particle outlet 42, increasing the retention time along the path of the solid particles 5. Staggered placement of heater elements 30, as illustrated in FIG. 1, increases the density of the heater elements 30 along the path. Heater elements 30 may be mounted on the ceiling of the particle chamber 10 or on any wall or floor of the particle chamber 10.

FIG. 5 illustrates schematically a top view of one exemplary embodiment having multiple intermediate particle outlets 43. In one embodiment, the heat exchanger comprises multiple intermediate particle outlets 43, that may be placed on different heat transfer modules 11 - 15. The solid particles 5 travel different routes when exiting different intermediate particle outlets 43. At least one of the heat transfer modules 11 – 15 comprise the intermediate particle outlet 43 for the solid particles 5. Said intermediate particle outlets 43 are controllable, so the flow to each particle outlet 42 is selectable to be fully open, fully closed or in mixed position. Solid particles 5 are heated to different temperature ranges. Leaving one intermediate particle outlet 43 open causes selecting temperature range of solid particles 5 travelling out of the heat exchanger. The selected temperature range may be useful in optimizing the heating cycle during heating ramp-up process; or different flows having different temperatures may be utilized to different purposes. Examples of different purposes are ramp-up heating, storing different temperatures to different particle storages or using the low-temperature particle flow to district heating or other distinct processes. The intermediate particle outlet 43 can be at any side wall of any heat transfer module 11 - 16. As the intermediate particle outlet 43 is controllable, they may be arranged near the surface of the fluidized solid particles 5, or near the floor of the heat transfer modules 11 – 15.

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 heat exchanger, wherein the intermediate particle outlet 43 may positioned during the design phase near those spots.

FIG. 6 illustrates schematically a flowchart of a method for heating solid particles in the heat exchanger described hereinbefore. In step 600 the method comprises receiving solid particles 5 into the heat exchanger through a particle inlet 41 for a first heat transfer module 11. Step 610 comprises heating solid particles 5 in the particle chamber 10; and step 620 comprises fluidizing the solid particles 5. In step 630 the solid particles 5 are fluidized, causing the solid particles 5 to travel horizontally from the particle inlet 41 through adjacent heat transfer modules 11, 12, 13, 14 and to the particle outlet 42. In this context, travelling horizontally refers to a mass of particles, as any single particle may travel random path from the particle in let 41 to the particle outlet 42.

A heat exchanger for an energy storage system is disclosed herein. The heat exchanger comprises multiple adjacent heat transfer modules. Each heat transfer module comprises: a particle chamber for fluidizable solid particles; a heater element for providing thermal energy to solid particles in the particle chamber; a fluidization system for fluidizing the solid particles; and a first heat transfer module comprising a particle inlet for receiving solid particles into the heat exchanger. 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, wherein the fluidized solid particles travel horizontally from the particle inlet via adjacent heat transfer modules and through said opening to the particle outlet. In one embodiment, the opening in the module wall between adjacent heat transfer modules comprises a vertical section extending from a top portion of the module wall to a lower portion of the module wall; or the openings in adjacent walls of the module wall comprise a vertical section at different distances from a common corner. In one embodiment, in adjacent heat transfer modules the module walls are curved. In one embodiment, openings in three consecutive module walls are noncollinear. 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 heat exchanger comprises a fluidization outlet leading the fluidization gas to preheating solid particles. In one embodiment, the fluidization outlet is at the first heat transfer module. In one embodiment, the heat transfer module comprises multiple heater elements and the heater elements are staggered, or inline, in relation to the travel direction of the fluidized solid particles. In one embodiment, at least two heat transfer modules comprise the particle outlet for the solid particles and said particle outlets are controllable, wherein said heat transfer modules have solid particles heated to different temperature ranges; and leaving one particle outlet open causes selecting temperature range of solid particles travelling out of the heat exchanger. In one embodiment, at least two of the heater elements are different in terms of power, surface temperature, durability, controllability, life cycle or efficiency.

Alternatively, or in addition, a method for heating solid particles by a heat exchanger is disclosed herein. The heat exchanger comprises multiple adjacent heat transfer modules; and the heat transfer module comprises a particle chamber for fluidizable solid particles. The method comprises receiving solid particles into the heat exchanger through a particle inlet for a first heat transfer module; heating solid particles in the particle chamber; and fluidizing the solid particles. 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, wherein the method further comprises fluidizing solid particles cause the particles to travel horizontally from the particle inlet through adjacent heat transfer modules and through said opening to the particle outlet. In one embodiment, openings in three consecutive module walls are noncollinear and the fluidized solid particles travelling a curved horizontal route from the particle inlet to the particle outlet. In one embodiment, the fluidization system comprises at least one fluidizing

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chamber below the heat transfer modules; and the method comprises receiving fluidizing gas though a fluidization inlet into the fluidizing chamber; and leading the fluidizing gas from the fluidizing chamber to each heat transfer module by at least one fluidizing nozzle. In one embodiment, the method comprises leading the fluidization gas to preheating solid particles. In one embodiment, the heat transfer module comprises multiple heater elements and the heater elements are staggered, or inline, in relation to the travelling direction of the fluidized solid particles. In one embodiment, at least two heat transfer modules comprise the particle outlet for the solid particles and said particle outlets are controllable, heating solid particles in said heat transfer modules to different temperature ranges; and selecting temperature range of solid particles travelling out of the heat exchanger by selecting one particle outlet to be open during the fluidization.

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 heat exchanger 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 heater element (30) for providing thermal energy to solid particles (5) in the particle chamber (10);
a fluidization system for fluidizing the solid particles (5); and
a first heat transfer module (11) comprising a particle inlet (41) for receiving solid particles (5) into the heat exchanger;
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 (111, 121, 131, …) and partially connected by an opening (112, 122, 132, ...) in the module wall (111, 121, 131, …); and
a last heat transfer module (14) comprises a particle outlet (42) for the solid particles (5), wherein the fluidized solid particles (5) travel horizontally from the particle inlet (41) via adjacent heat transfer modules (11 - 18) and through said opening (112, 122, 132, ...) to the particle outlet (42).

2. A heat exchanger according to claim 1, c h a r a c t e r i z e d in that the opening (112, 122, 132, ...) in the module wall (111, 121, 131, …) between adjacent heat transfer modules (11 - 18) comprises a vertical section extending from a top portion of the module wall (111, 121, 131, …) to a lower portion of the module wall (111, 121, 131, …); or the openings (112, 122, 132, ...) in adjacent walls of the module wall (111, 121, 131, …) comprise a vertical section at different distances from a common corner.

3. A heat exchanger according to claim 1 or claim 2, c h a r a c t e r i z e d in that in adjacent heat transfer modules (11 - 18) the module walls (111, 121, 131, …) are curved.

4. A heat exchanger according to any of the claims 1 to 3, c h a r a c t e r i z e d in that openings (112, 122, 132, ...) in three consecutive module walls (111, 121, 131, …) are noncollinear.

5. A heat exchanger according to any of the claims 1 to 4, 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) below the particle chambers (10), a fluidization inlet (61) for receiving fluidizing gas into the fluidizing chamber (64) and at least one fluidizing nozzle (63) leading the fluidizing gas from the fluidizing chamber (64) to each particle chamber (10).

6. A heat exchanger according to any of the claims 1 to 5, 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).

7. A heat exchanger according to claim 6, c h a r a c t e r i z e d in that the fluidization outlet (62) is at the first heat transfer module (11).

8. A heat exchanger according to any of the claims 1 to 7, c h a r a c t e r i z e d in that the heat transfer module comprises multiple heater elements (30) and the heater elements (30) are staggered, or inline, in relation to the travel direction of the fluidized solid particles (5).

9. A heat exchanger according to any of the claims 1 to 8, c h a r a c t e r i z e d in that at least two heat transfer modules (11 - 18) comprise the particle outlet (42) for the solid particles (5) and said particle outlets (42) are controllable, wherein said heat transfer modules (11 - 18) have solid particles (5) heated to different temperature ranges; and leaving one particle outlet (42) open causes selecting temperature range of solid particles (5) travelling out of the heat exchanger.

10. A heat exchanger according to any of the claims 1 to 9, c h a r a c t e r i z e d in that at least two of the heater elements (30) are

different in terms of power, surface temperature, durability, controllability, life cycle or efficiency.

11. A method for heating solid particles (5) by a heat exchanger, wherein the heat exchanger comprises multiple adjacent heat transfer modules (11 - 18); and the heat transfer module comprises a particle chamber (10) for fluidizable solid particles (5), wherein the method comprises:
receiving solid particles (5) into the heat exchanger through a particle inlet (41) for a first heat transfer module (11);
heating solid particles (5) in the particle chamber (10); and
fluidizing the solid particles (5),
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 (111, 121, 131, …) and partially connected by an opening (112, 122, 132, ...) in the module wall (111, 121, 131, …); and
a last heat transfer module comprises a particle outlet (42) for the solid particles (5), wherein the method comprises:
fluidizing solid particles (5) cause the particles (5) to travel horizontally from the particle inlet (41) through adjacent heat transfer modules (11 - 18) and through said opening (112, 122, 132, ...) to the particle outlet (42).

12. A method according to claim 11, c h a r a c t e r i z e d in that openings (112, 122, 132, ...) in three consecutive module wall (111, 121, 131, …) s are noncollinear and the fluidized solid particles (5) travelling a curved horizontal route from the particle inlet (41) to the particle outlet (42).

13. A method according to claim 11 or claim 12, 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) below the heat transfer modules (11 - 18);
receiving fluidizing gas though a fluidization inlet (61) into the fluidizing chamber (64); and
leading the fluidizing gas from the fluidizing chamber (64) to each heat transfer module by at least one fluidizing nozzle (63).

14. A method according to any of the claims 11 to 13, c h a r a c t e r i z e d by leading the fluidization gas to preheating solid particles (5).

15. A method according to any of the claims 11 to 14, c h a r a c t e r i z e d in that the heat transfer module comprises multiple heater elements (30) and the heater elements (30) are staggered, or inline, in relation to the travelling direction of the fluidized solid particles (5).

16. A method according to any of the claims 11 to 15, c h a r a c t e r i z e d by that at least two heat transfer modules (11 - 18) comprise the particle outlet (42) for the solid particles (5) and said particle outlets (42) are controllable, heating solid particles (5) in said heat transfer modules (11 - 18) to different temperature ranges; and selecting temperature range of solid particles (5) travelling out of the heat exchanger by selecting one particle outlet (42) to be open during the fluidization.

# VAATIMUKSET

1. Lämmönvaihdin energian varastointijärjestelmää varten, johon kuuluu: useita vierekkäisiä lämmönsiirtomoduuleja (11 - 18), joissa jokainen lämmönsiirtomoduuli (11 - 18) käsittää: partikkelikammion (10) leijutettaville kiinteille partikkeleille (5); lämmityselementin (30) lämpöenergian tuottamiseksi kiinteille partikkeleille (5) partikkelikammiossa (10); leijutusjärjestelmän kiinteiden partikkelien leijuttamiseksi (5); ja ensimmäisen lämmönsiirtomoduulin (11), joka käsittää partikkelien sisääntulon (41) kiinteiden partikkelien (5) vastaanottamiseksi lämmönvaihtimeen;
t u n n e t t u siitä, että:
vierekkäiset lämmönsiirtomoduulit (11 - 18) on osittain erotettu moduuliseinällä (111, 121, 131, …) ja osittain yhdistetty aukolla (112, 122, 132, ...) moduulin seinämässä (111, 121) , 131, …); ja viimeinen lämmönsiirtomoduuli (14) käsittää partikkelien poistoaukon (42) kiinteitä partikkeleja (5) varten, jolloin leijutetut kiinteät partikkelit (5) kulkevat vaakasuunnassa partikkelien tuloaukosta (41) vierekkäisten lämmönsiirtomoduulien (11 - 18) kautta ja mainitun aukon (112, 122, 132, ...) kautta partikkelien poistoaukkoon (42).

2. Patenttivaatimuksen 1 mukainen lämmönvaihdin, t u n n e t t u siitä, että aukko (112, 122, 132, ...) moduulin seinämässä (111, 121, 131, …) vierekkäisten lämmönsiirtomoduulien (11 - 18) välillä käsittää pystysuoran osan, joka ulottuu moduulin seinän yläosasta (111, 121, 131, …) moduulin seinän alaosaan (111, 121, 131, …); tai moduuliseinän (111, 121, 131, …) vierekkäisten seinien aukot (112, 122, 132, ...) käsittävät pystysuoran osan eri etäisyyksillä yhteisestä kulmasta.

3. Patenttivaatimuksen 1 tai 2 mukainen lämmönvaihdin, t u n n e t t u siitä, että vierekkäisissä lämmönsiirtomoduuleissa (11 - 18) moduulin seinämät (111, 121, 131, …) ovat kaarevia.

4. Jonkin patenttivaatimuksista 1 - 3 mukainen lämmönvaihdin, t u n n e t t u siitä, että aukot (112, 122, 132, ...) kolmessa peräkkäisessä moduuliseinämässä (111, 121, 131, ...) ovat ei-kollineaarisia.

5. Jonkin patenttivaatimuksen 1 - 4 mukainen lämmönvaihdin, t u n n e t t u siitä, että leijutusjärjestelmä käsittää ainakin yhden leijutuskammion (64) partikkelikammioiden (10) alapuolella, leijutustulon (61) leijutuskaasun vastaanottamiseksi leijutuskammioon (64) ja vähintään yhden leijutussuuttimen (63), joka johtaa leijutuskaasun leijutuskammiosta (64) jokaiseen partikkelikammioon (10).

6. Jonkin patenttivaatimuksista 1 - 5 mukainen lämmönvaihdin, t u n n e t t u siitä, että se käsittää leijutusaukon (62), joka johtaa leijutuskaasun esikuumentuviin kiinteisiin partikkeleihin (5).

7. Patenttivaatimuksen 6 mukainen lämmönvaihdin, t u n n e t t u siitä, että leijutusaukko (62) on ensimmäisessä lämmönsiirtomoduulissa (11).

8. Jonkin patenttivaatimuksista 1 - 7 mukainen lämmönvaihdin, t u n n e t t u siitä, että lämmönsiirtomoduuli käsittää useita lämmityselementtejä (30) ja lämmityselementit (30) ovat porrastettuja tai rivissä, suhteessa leijutettujen kiinteiden partikkelien (5) kulkusuuntaan.

9. Jonkin patenttivaatimuksista 1 - 8 mukainen lämmönvaihdin, t u n n e t t u siitä, että ainakin kaksi lämmönsiirtomoduulia (11 - 18) käsittävät partikkelien poistoaukon (42) kiinteille partikkeleille (5) ja mainitut partikkelien poistoaukot (42) ovat säädettävissä, jolloin mainituissa lämmönsiirtomoduuleissa (11 - 18) on kiinteitä partikkeleja (5), jotka on kuumennettu eri lämpötila-alueille; ja yhden partikkelien poistoaukon (42) jättäminen auki saa aikaan lämmönvaihtimesta ulos kulkevien kiinteiden partikkelien (5) lämpötila-alueen valitsemisen.

10. Jonkin patenttivaatimuksista 1 - 9 mukainen lämmönvaihdin, t u n n e t t u siitä, että ainakin kaksi lämmityselementeistä (30) ovat erilaisia tehon, pintalämpötilan, kestävyyden, ohjattavuuden, elinkaaren tai hyötysuhteen suhteen.

11. Menetelmä kiinteiden partikkelien (5) lämmittämiseksi lämmönvaihtimella, jossa lämmönvaihdin käsittää useita vierekkäisiä lämmönsiirtomoduuleja (11 - 18); ja lämmönsiirtomoduuli käsittää partikkelikammion (10) leijutettaville kiinteille partikkeleille (5), jossa menetelmään kuuluu, että:
vastaanotetaan kiinteitä partikkeleja (5) lämmönvaihtimeen ensimmäisen lämmönsiirtomoduulin (11) partikkelien sisääntulon (41) kautta;
kuumennetaan kiinteitä partikkeleja (5) partikkelikammiossa (10); ja leijutetaan kiinteitä partikkeleita (5),
t u n n e t t u siitä, että:
vierekkäiset lämmönsiirtomoduulit (11 - 18) on osittain erotettu moduuliseinällä (111, 121, 131, ...) ja osittain yhdistetty aukolla (112, 122, 132, ...) moduulin seinämässä (111, 121) , 131, ...); ja
viimeinen lämmönsiirtomoduuli käsittää partikkelien poistoaukon (42) kiinteitä partikkeleja (5) varten, jolloin menetelmä käsittää:
kiinteiden partikkelien (5) leijuttaminen aiheuttaa partikkelit (5) kulkemaan vaakasuunnassa partikkelien sisääntuloaukosta (41) vierekkäisten lämmönsiirtomoduulien (11 - 18) kautta ja mainitun aukon (112, 122, 132, ...) kautta partikkelien ulostuloon (42).

12. Patenttivaatimuksen 11 mukainen menetelmä, t u n n e t t u siitä, että aukot (112, 122, 132, ...) kolmessa peräkkäisessä moduuliseinämässä (111, 121, 131, ...) ovat ei-kollineaarisia ja leijutetut kiinteät partikkelit (5) kulkevat kaarevaa vaakasuoraa reittiä partikkelien sisääntuloaukosta (41) partikkelien poistoaukkoon (42).

13. Patenttivaatimuksen 11 tai 12 mukainen menetelmä, t u n n e t t u siitä, että leijutusjärjestelmä käsittää ainakin yhden leijutuskammion (64) lämmönsiirtomoduulien (11 - 18) alapuolella;

vastaanottamaan leijutuskaasua leijutustulon (61) kautta leijutuskammioon (64); ja
johtamaan leijutuskaasu leijutuskammiosta (64) kuhunkin lämmönsiirtomoduuliin ainakin yhdellä leijutussuuttimella (63).

14. Jonkin patenttivaatimuksista 11 - 13 mukainen menetelmä, t u n n e t t u siitä, että johdetaan leijutuskaasu esikuumennettaviin kiinteisiin partikkeleihin (5).

15. Jonkin patenttivaatimuksista 11 - 14 mukainen menetelmä, t u n n e t t u siitä, että lämmönsiirtomoduuli käsittää useita lämmityselementtejä (30) ja lämmityselementit (30) on porrastettu, tai linjassa, suhteessa leijutettujen kiinteiden partikkeleiden (5) kulkusuuntaan nähden.

16. Jonkin patenttivaatimuksista 11 - 15 mukainen menetelmä, t u n n e t t u siitä, että ainakin kaksi lämmönsiirtomoduulia (11 - 18) käsittää partikkelien poistoaukon (42) kiinteitä partikkeleja (5) varten ja mainitut partikkelien poistoaukot (42) ovat säädettäviä, kuumentaen kiinteät partikkelit (5) mainituissa lämmönsiirtomoduuleissa (11 - 18) eri lämpötila-alueille; ja valitaan lämmönvaihtimesta ulos kulkevien kiinteiden partikkelien (5) lämpötila-alue valitsemalla yksi partikkelien poistoaukko (42) avoimeksi leijutuksen aikana.

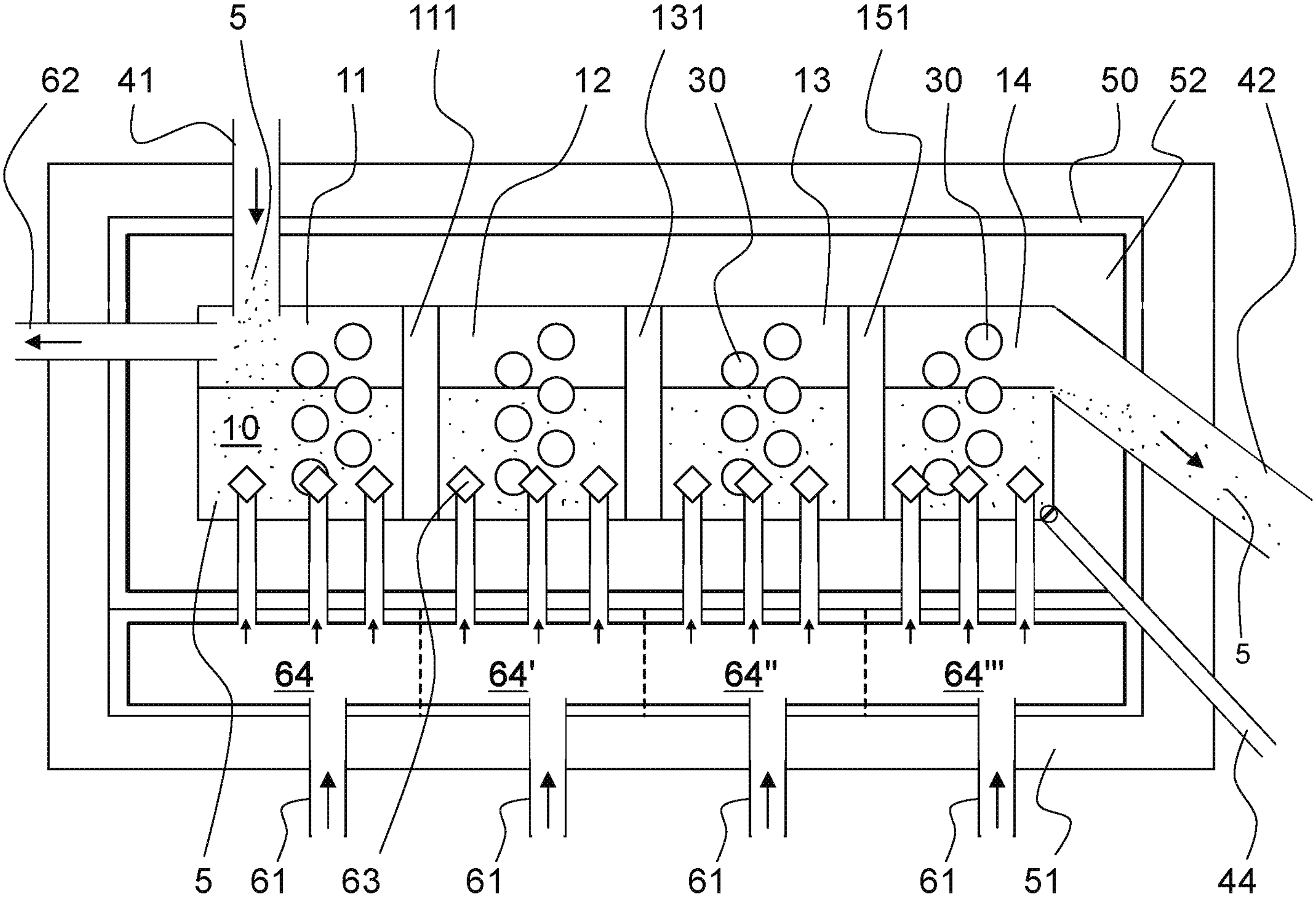
5
111
131
151
62
41
11
12
30
13
30
14
50
52
42
10
5
64
64'
64''
64'''
5
61
63
61
61
61
51
44

Fig. 1

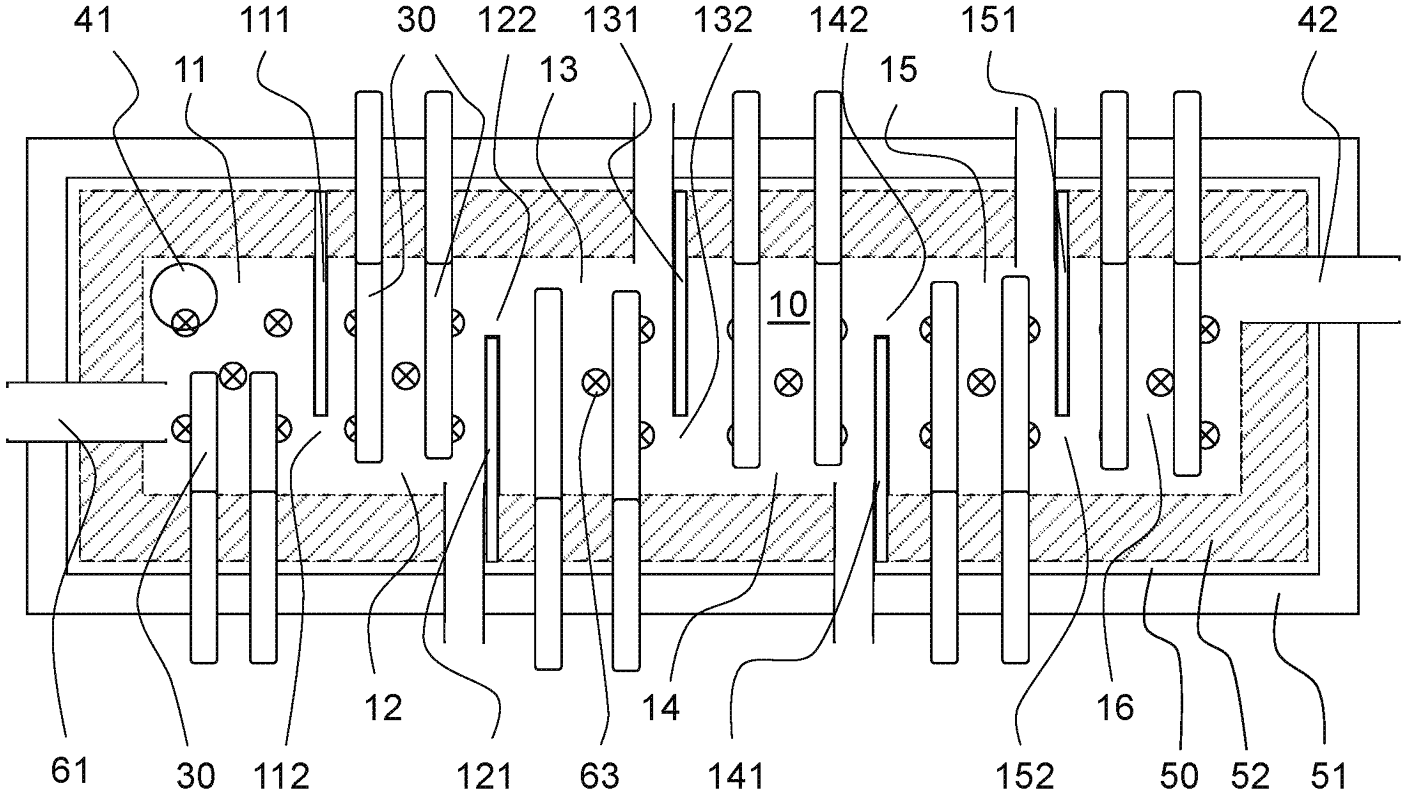
41
111
30
122
131
132
142
151
42
11
13
15
10
61
30
112
12
121
63
14
141
152
16
50
52
51

Fig. 2

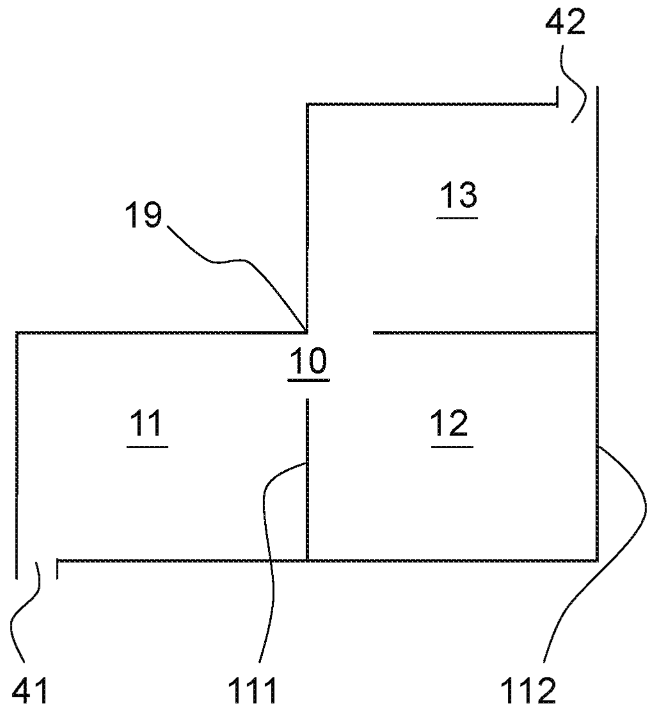


Fig. 3a

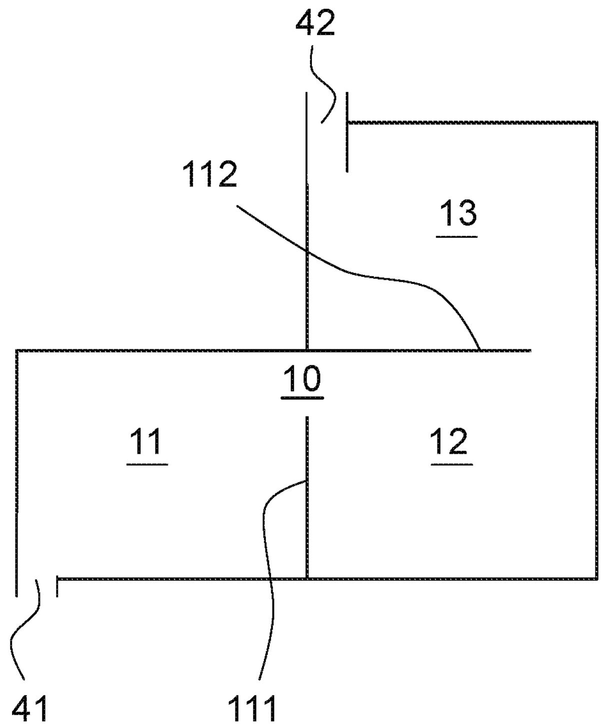


Fig. 3b

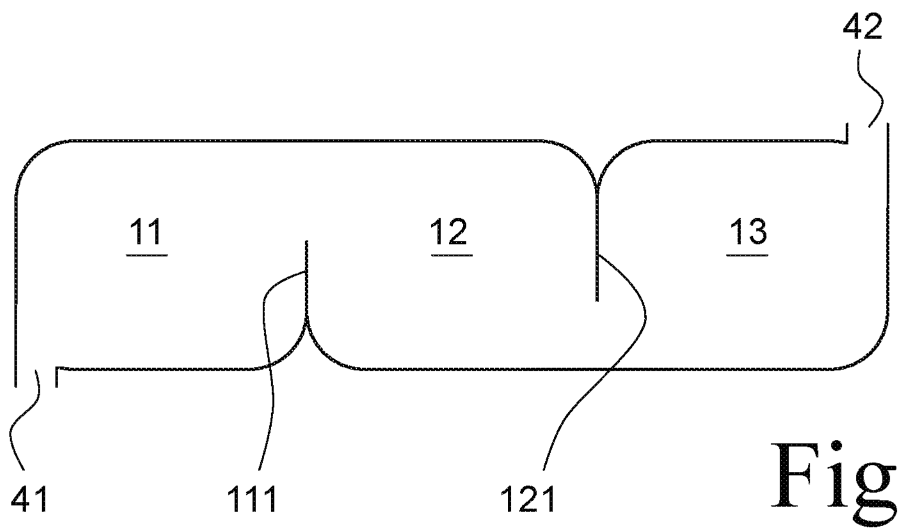
42
11
12
13
41
111
121

Fig. 4a

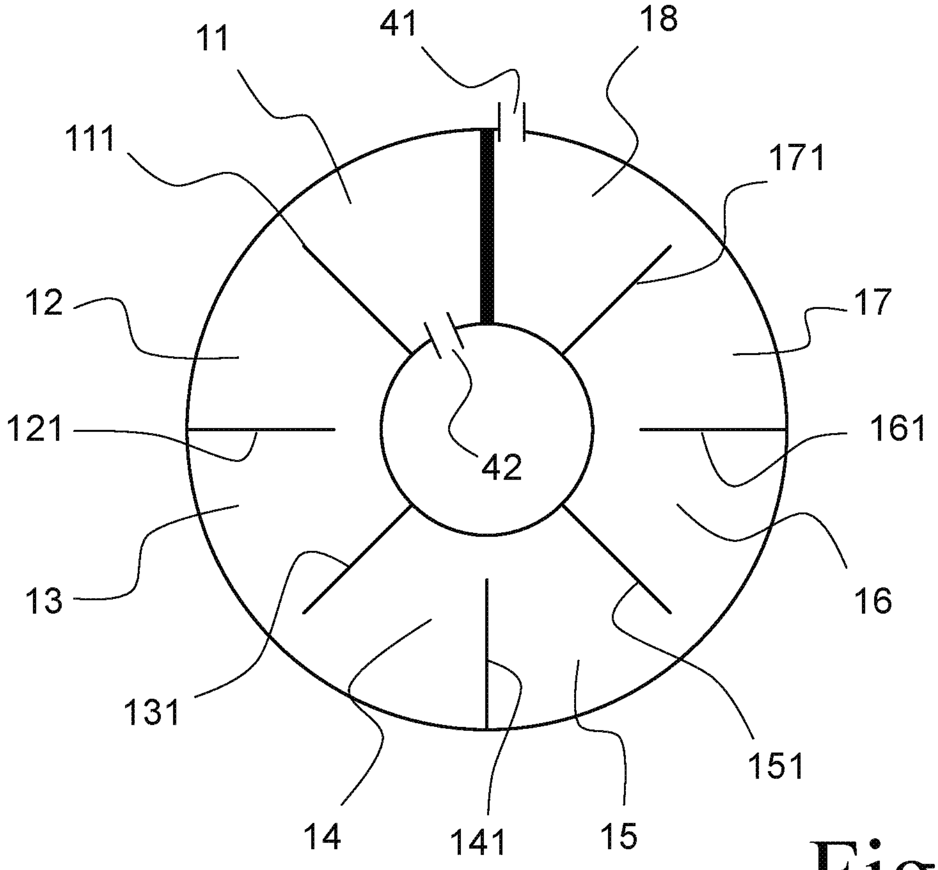
11
41
18
111
171
12
17
121
161
42
13
16
131
151
14
141
15

Fig. 4b

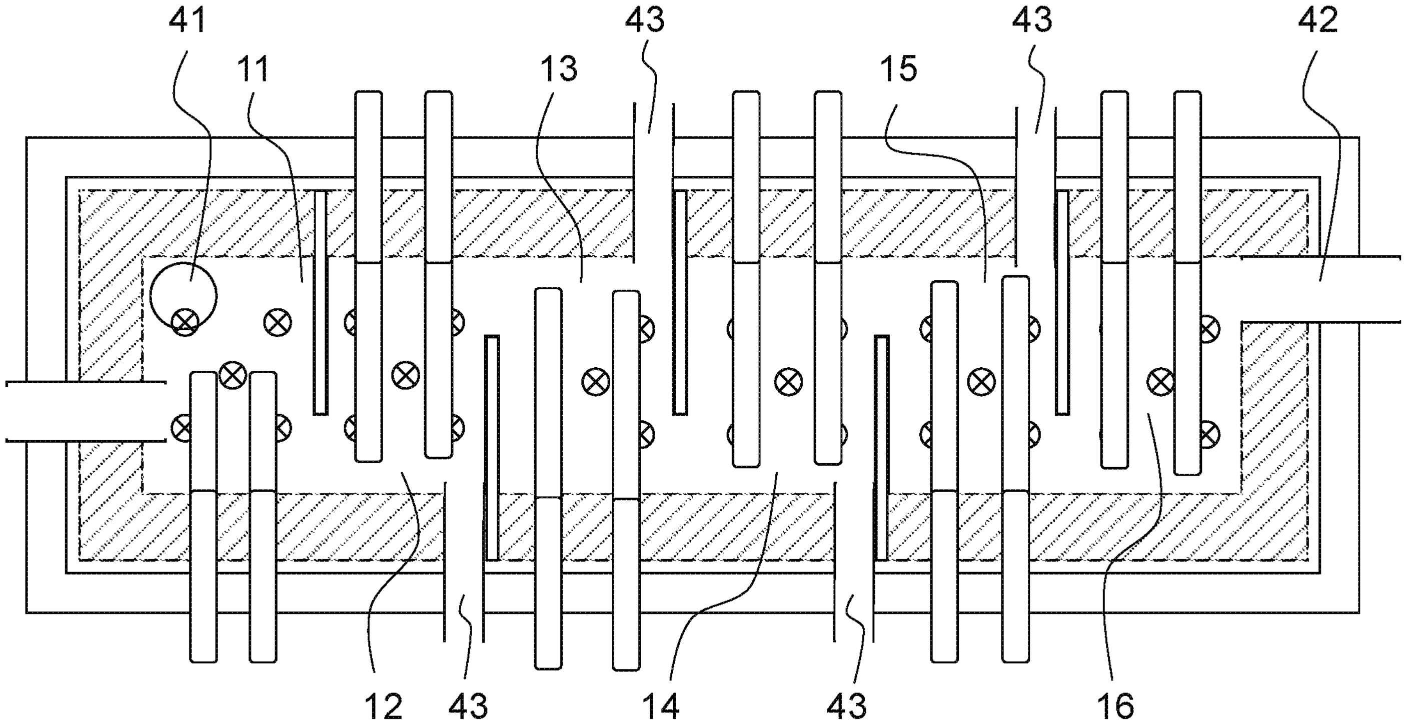


Fig. 5

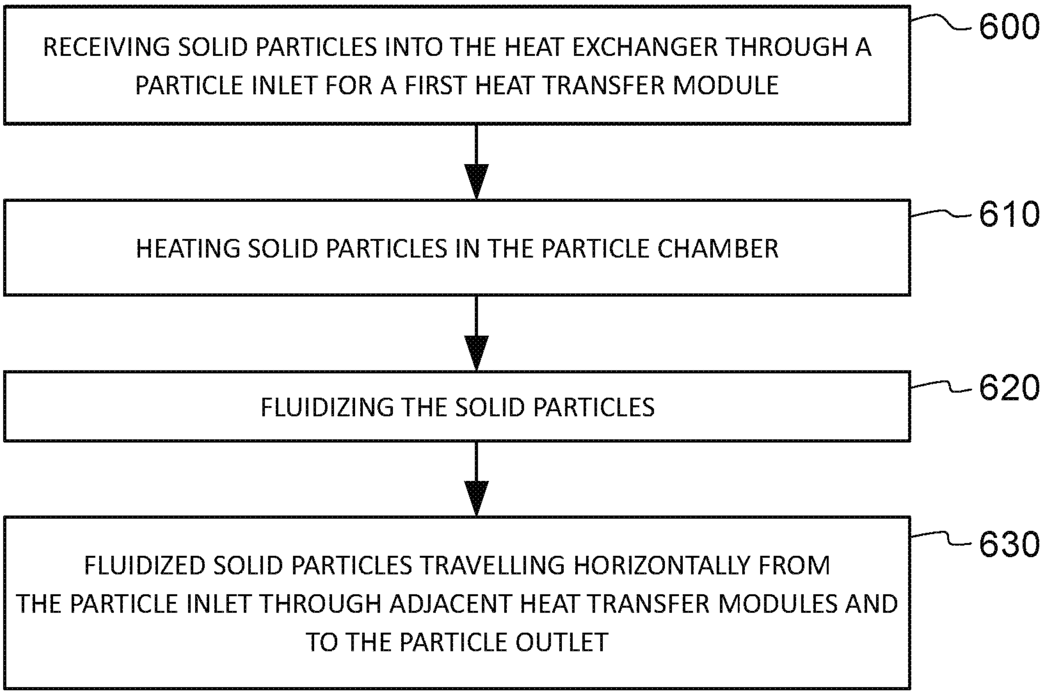
RECEIVING SOLID PARTICLES INTO THE HEAT EXCHANGER THROUGH A PARTICLE INLET FOR A FIRST HEAT TRANSFER MODULE
600
HEATING SOLID PARTICLES IN THE PARTICLE CHAMBER
610
FLUIDIZING THE SOLID PARTICLES
620
FLUIDIZED SOLID PARTICLES TRAVELLING HORIZONTALLY FROM THE PARTICLE INLET THROUGH ADJACENT HEAT TRANSFER MODULES AND TO THE PARTICLE OUTLET
630

Fig. 6