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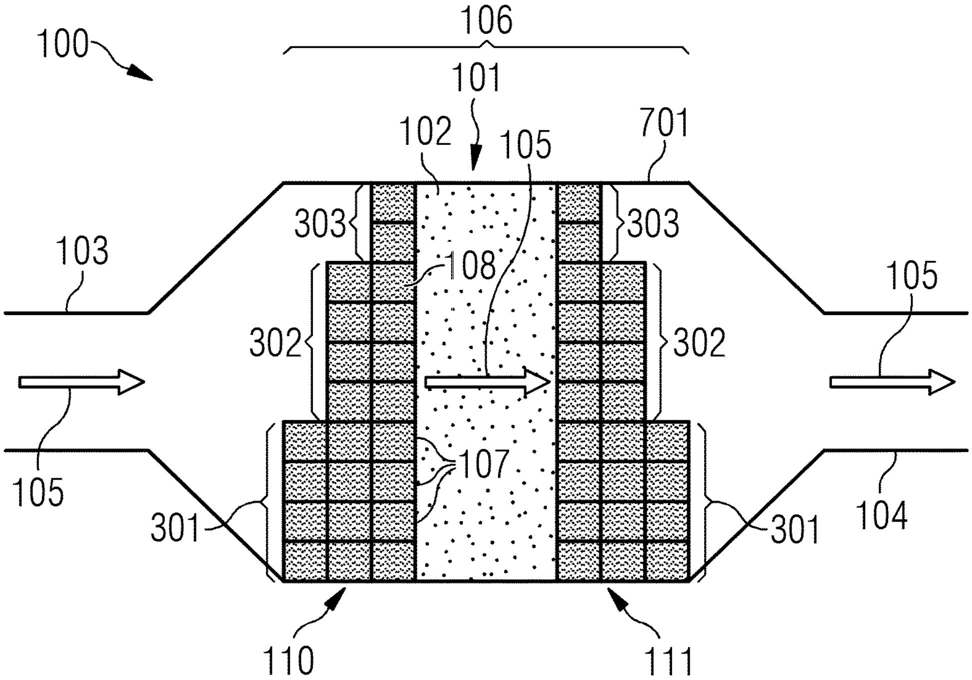
(54) THERMAL ENERGY STORAGE DEVICE

(57) A thermal energy storage device (100) is provided. The thermal energy storage device comprises a chamber (101) including storage material (102), which is configured to store thermal energy, and two or more ports (103, 104) configured to pass a flow (105) of heat transfer medium. The storage material is configured to exchange thermal energy with the heat transfer medium. The thermal energy storage device further comprises a cage structure (106) comprising one or more cages (107) that provide a boundary (110) between one of the ports and at least part of the storage material, wherein the cage structure comprises a filling material (108). Further, the cage structure is configured to be passable by the heat transfer medium.

FIG 4



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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a thermal energy storage device and a method for assembling such a thermal energy storage device.

BACKGROUND

[0002] As the amount of energy that is produced from renewable sources is increasing, situations may occur in which the energy output from such energy sources is higher than the demand. Excess energy is then stored, for example in a storage device that is charged by thermal energy converted from electrical energy. Such thermal energy storage device may also store residual or waste heat from a conventional heat cycle, for example waste heat from an industrial process or the like. Thermal energy storage devices are known that employ a storage material in the form of sand, rocks or other solids which take up and release thermal energy via a respective heat transfer medium passing through the thermal energy storage device.

[0003] Such solid materials require a support structure to keep the storage material in place and allow the heat transfer medium (e.g. air) to pass through the storage device. The materials available for manufacturing such support structures are limited due to the high operating temperature of such storage device which can exceed 750°C. Materials, for example metals, have to be chosen which withstand high temperatures and maintain acceptable values in load capacity. Since such support structures are exposed to high thermal and high mechanic stresses, for example due to forces resulting from thermal expansion of the storage material, material-intensive high temperature steel grates may be used in order to retain the storage material. Due to limited creep stability over the heat storage lifetime, the design of steel grates applicable in thermal energy storage devices is challenging and results in high costs for material and manufacturing processes. Furthermore, manufacturing of the steel grates is a burden to the environment as for example carbon dioxide emissions arise during steel production.

SUMMARY

[0004] Accordingly, there is the need to mitigate at least some of the drawbacks mentioned above and to improve the retaining of the storage material in a thermal storage device.

[0005] This need is met by the features of the independent claims. The dependent claims describe embodiments of the invention.

[0006] According to an embodiment of the invention, a thermal energy storage device is provided. The thermal energy storage device comprises a chamber including storage material, which is configured to store thermal energy, and two or more ports configured to pass a flow of heat transfer medium. The storage material is configured to exchange thermal energy with the heat transfer medium. The thermal energy storage device further comprises a cage structure comprising one or more cages that provide a boundary between one of the ports and at least part of the storage material, wherein the cage structure comprises a filling material in the one or more cages. Further, the cage structure is configured to be passable by the heat transfer medium.

[0007] Using a cage structure that provides a boundary in order to retain the storage material may save resources, balance stresses, and improve the system parameters of the thermal energy storage device. The filling material, for example stones, gravel, sand or soil, reduces the required amount of high-temperature steel and thus saves material and costs. Other examples for the filling material are rocks, bricks, lava stone, granite, basalt and/or ceramics, gravel, rubble and/or grit. The filling material in the cages contributes to the self-weight of the cage structure and thus to a high strength and rigidity. The device has thus an improved capability of taking up thermal/mechanic stresses, and particularly mechanical stresses can be directed to ground. The filling material can also be used to store thermal energy, so that the implementation of such a cage structure improves the energy capacity. Furthermore, the structure of the filling material can be chosen to reduce the flow resistance of the barrier to be passed by the heat transfer medium, and accordingly, may reduce pressure losses. Therefore, the energy density of the thermal energy storage device may be increased and the energy required to convey the heat transfer medium may be decreased.

[0008] The heat transfer medium may for example be a fluid, in particular a gas, such as air, that is passed through the storage material of the thermal energy storage device to deposit heat in the storage device (i.e. to charge the storage device) or to extract heat from the storage device (i.e. to discharge the storage device). The heat transfer medium is transportable through the storage device. The pressure of the heat transfer medium is preferably less than 2 bar or less than 1.5 bar, e.g. about atmospheric pressure.

[0009] The two or more ports are for example an entry and an exit point, through which the heat transfer medium can enter and leave the chamber which includes the storage material. The flow direction and thus the function of the ports may be reversed when changing between charging and discharging, or it may stay the same.

[0010] The cage structure and in particular the one or more cages may at least partially be filled or completely be filled with the filling material. In some implementations, all cages of the cage structure are filled with the same filling material, while in other implementations, the cage structure may be filled with filling material composed by a first and at least a second filling material. Different cages of the cage structure may thus be filled with a different filling material. The first and second filling material may also form a filling material mixture. This way, system parameters of the thermal energy storage device can be set, which are associated with the amount and composition of filling material in the cage structure. For example, the flow of the heat transfer medium can be influenced in a predetermined way.

[0011] The cage may be configured to bundle the filling material in such a way that the filling material does not drop out. The filling material may in particular have a (average) grain size that is larger than the gaps in the grid of the cage structure.

[0012] In an embodiment, the cage structure is a wire cage structure, the one or more cages may for example be wire baskets. Preferably the cage structure, in particular the one or more cages, are provided as one or more gabions.

[0013] Such wire cage structure can comprise wires enclosing the filling material. The cage may be made with wires spaced closely together to prevent the filling material or portions thereof from slipping through the gaps between them. The wires may be connected to each other, for example welded or clamped together at uniformly distributed points, in order to form a geometric body, for example a hexahedron.

[0014] The cage structure, and thus the cages, may be formed from at least one of mesh, bars or wires. A combination of these elements may be used, such as mesh enforced by bars.

[0015] The cage structure is preferably made of steel, in particular high temperature steel. Steel is a material which is highly resistant against thermal and mechanical stresses.

[0016] The wires may be preferably stiff like bars, yet they may also be flexible like ropes. The bars may comprise a cross-sectional area of less than 2500 mm^2, less than 900 mm^2 or 400 mm^2 or even less than 25 mm^2. The wires may comprise a cross-sectional area of less than 100 mm^2, less than 25 mm^2 or even less than 10 mm^2. The mesh may comprise strings, and the strings may comprise a cross-sectional area of less than 100 mm^2, less than 25 mm^2 or even less than 10 mm^2. In some implementations, the cages may comprise a finer mesh, e.g. with a pore size of less than 4 mm^2 or less than 1 mm^2, which can be useful when using a filling material of finer granularity, e.g. sand or soil.

[0017] Further, the cage structure may comprise a mesh comprising a coarsely dimensioned grid. Preferably, the mesh may comprise gaps of an area greater than 0.5 cm^2, greater than 1 cm^2, greater than 10 cm^2, greater than 25 cm^2 or even greater than 100 cm^2. Such a broad-meshed cage structure is less material-intensive and reduces the manufacturing effort.

[0018] The cages may have the shape of a polyhedron, e.g. a hexahedron, preferably of a rectangular cuboid. Each individual cage may have a geometric volume of at least 0.01 m^3, or at least 0.1 m^3 or at least 0.5 m^3, or at least 1 m^3. An individual cage may for example have a dimension of at least 0.5 m x 0.5 m x 0.5 m. In some implementations, the cages may have the shape of a cube. Each cage may comprise at least four sidewalls and a bottom wall. It may further comprise an upper wall, or it may comprise an open upper side (which is for example closed when stacking cages). It should be clear that each side of the cage may be considered as an open upper side. It should be further clear that a first cage may comprise more than one open side if each open side is closed by a respective second cage, wherein one of the second cages is positioned next to the first cage on each open side.

[0019] Such a shape simplifies the erection of the cage structure, as single cages can be combined easily. Further, the self-weight of the cages increases the stability of the thermal energy storage device and is capable to take up high forces. For example, cages enclosing the filling material can take up forces related to thermal expansion of the filling material and, hence, reduce or limit the forces that need to be taken up by the enclosure or housing of the storage device.

[0020] In an embodiment, the filling material comprises or consists of a granular material having a structure selected such that a flow resistance for the heat transfer medium passing the filling material is lower than a flow resistance for the heat transfer medium passing the storage material. The granular material may for example have a grain size corresponding to one or a combination of pebble gravel (e.g. 4-64mm), in particular fine gravel, medium gravel, coarse gravel, or very coarse gravel, or cobble (>64mm), which are defined grain sizes (e.g. Wentworth classes on the Wentworth scale).

[0021] Further, the filling material of at least a part of the cage structure may be different from the storage material. In particular, the filling material of at least some cages may have a larger grain size than the storage material. Preferably, this may be the case for one or more cages of the cage structure that provide the boundary to one of the ports.

[0022] For example, the filling material is composed of a granular material, e.g. stones, having a grain size larger than that of the storage material. Accordingly, the heat transfer medium can pass the bigger gaps of the filling material more easily. Such more coarse grained filling material (at least in the cages providing the boundary) therefore reduces pressure losses.

[0023] Further, the filling material of at least a part of the cage structure may have a similar structure and/or composition as the storage material. In particular, this may be the case for part of the cage structure (i.e. for respective cages) that does not provide a boundary to the ports. In some implementations, all of the filling material of the cage structure may have a similar structure and/or composition as the storage material.

[0024] If the filling material corresponds at least partly to the storage material, for example in its type, the filling material extends the capability of the thermal energy storage device to store thermal energy. Accordingly, the filling material may contribute to the energy storing capacity thereof.

[0025] In an embodiment, the cage structure comprises or consists of plural individual cages, each cage comprising the filling material.

[0026] The plural individual cages may comprise cages for which the structure and/or composition of the filling material is different than for other individual cages of said plural cages.

[0027] The plural individual cages may further comprise cages for which the shape or the elements (e.g. mesh, wires, bars), from which the cage structure is formed, is different than for other individual cages of said plurality of cages. Such an individual design of cages allows high flexibility regarding the physical configuration of the thermal energy storage device.

[0028] The plural individual cages may include cages that are stacked on top of each other and/or cages that are arranged next to each other in contact with each other. Preferably, the boundary may include plural individual cages that are stacked and arranged next to each other, e.g. it may correspond to a wall made up of stacked individual cages.

[0029] This combination of modular individual cages ('units') allows erecting the cage structure in accordance with arbitrary geometric shapes within the chamber of the energy storage device. Self-weight of such plural individual cages stacked/next to each other increases the stability of the whole device. Horizontal forces, for example induced by the thermal expansion of the storage material, are taken up and directed to ground. Accordingly, forces acting on the walls of the chamber can be eliminated or at least be reduced.

[0030] The plural individual cages may be mechanically connected by connecting elements or may be welded together. Connecting elements for connecting two neighboring cages together may include one of or a combination of a clamp, e.g. C-shaped clamp, a spiral, a welded connection, ties, and welded taps/loops. It may also be possible that no connecting elements are necessary and that the plurality of individual cages are sufficiently mechanically connected by frictional forces, in particular by frictional forces due to the self-weight of the individual cages and the irregular surface structure of the cages or by frictional forces due to the irregular surface structure of the cages in a horizontal direction. For example, irregular surfaces can arise if the filling material, e.g. stones, protrudes partly from the cages. Due to filling material protruding from a cage, the mating surfaces of two individual cages stacked or placed next to each other are interlocked, thus connecting both cages with each other.

[0031] At least a portion of said storage material may be provided as filling material in said cage structure. In some implementations, all of the storage material can be provided as filling material in said cage structure. Accordingly, the storage material does not exert horizontal forces on the walls of the storage device, as it is fully confined in the respective cages, each cage bearing the horizontal forces exerted by its filling material.

[0032] According to an embodiment, the one or more cages that provide the boundary to the port are configured such that the boundary has a tapered structure that is wider at a bottom of the boundary and narrower at the top of the boundary in a direction perpendicular to the boundary. The tapered structure of the boundary is preferably obtained by arranging a larger number of cages at the bottom of the boundary and a smaller number of cages at the top of the boundary in the direction perpendicular to the boundary. As an alternative, the tapered structure of the boundary can be obtained by arranging one or more cages having a tapered shape, in particular a trapezoid shape, in the boundary.

[0033] The boundary may be provided by two or more cages of similar size and shape. The boundary may alternatively be provided by two or more cages of different size and shape.

[0034] The boundary may have a port facing side, wherein the port facing side is the side of the boundary that faces the port, and a storage material facing side, wherein the storage material facing side is the side of the boundary that faces the storage material. The boundary may be configured such that the storage material facing side and/or the port facing side is inclined. In an exemplary implementation, the boundary may be supported on an inclined plane (e.g. foundation). By such arrangement, the boundary may for example have a structure of constant width but is still inclined. Such shaped boundary ensures a high resistance and stability against forces in the lower portion of the thermal energy storage device, where the stresses are higher.

[0035] In another embodiment, the cage structure is configured to form a wall structure around the storage material that partly or fully confines the storage material in horizontal direction. Preferably, the cage structure extends along substantially vertical walls of the chamber so as to provide separation between the walls of the chamber and the heat storage material, in particular to separate all vertical walls of the chamber that bear horizontal loads due to the storage material from the storage material.

[0036] Confining the storage material in horizontal direction, which is comparable to a 'belt' or 'ring' surrounding the storage material in horizontal direction, allows a better distribution of forces directed outwards and therefore further increases the mechanic stability of the storage device. It further allows the use of thinner walls, and thus less concrete, as the walls have to bear only little or no horizontal forces .

[0037] In an embodiment, one port to which the one or more cages provide a boundary is a first port, and the cage structure comprises one or more cages that provide a further boundary between a second port of the two or more ports and at least part of the storage material. The storage material may thus be sandwiched between the cages forming the two boundaries. It should be clear that the storage material may be provided between the boundaries either as bulk material, or may fully or partially be comprised in cages of the cage structure.

[0038] The energy storage device may be configured to store thermal energy at a temperature between 300 °C and 1000 °C, preferably between 500 °C and 1000 °C, more preferably between 600°C and 900°C in a charged state (in particular in a hot region of the device). For example, the temperature in the energy storage device may be between 650 and 800°C in the charged state. It should be clear that the temperature can be significantly lower if the storage device is discharged.

[0039] According to an embodiment of the invention, a method of assembling an energy storage device is provided. The method comprises providing a chamber having two or more ports configured to pass a flow of heat transfer medium, the chamber including storage material configured to store thermal energy. The storage material is configured to exchange thermal energy with the heat transfer medium. The method further comprises providing a cage structure in the chamber comprising one or more cages as boundary between one of the ports and at least part of the storage material, wherein the cage structure comprises a filling material in the one or more cages, and wherein the cage structure is configured to be passable by the heat transfer medium.

[0040] The method may further comprise providing the one or more cages and filling the one or more cages with the filling material. The method may further include transporting the one or more cages, prior to or after filling, into the chamber for providing the cage structure in the chamber.

[0041] The energy storage device assembled by the method may correspond to any of the configurations of the energy storage device disclosed hereinabove or further below.

[0042] It is to be understood that the features mentioned above and those yet to be explained below can be used not only in the respective combinations indicated, but also in other combinations or in isolation, without leaving the scope of the present invention. In particular, the features of the different aspects and embodiments of the invention can be combined with each other unless noted to the contrary.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] The foregoing and other features and advantages of the invention will become further apparent from the following detailed description read in conjunction with the accompanying drawings. In the drawings, like reference numerals refer to like elements.

Fig. 1 is a schematic drawing showing a sectional view of a thermal energy storage device according to an embodiment.

Fig. 2 is a schematic drawing illustrating a single cage comprised in a cage structure according to an embodiment.

Fig. 3 is a schematic drawing showing a sectional view of a thermal energy storage device according to an embodiment.

Fig. 4 is a schematic drawing showing a sectional view of a thermal energy storage device according to an embodiment.

Fig. 5 is a schematic drawing showing a sectional view of a thermal energy storage device according to an embodiment.

Fig. 6 is a schematic drawing showing a sectional view of a thermal energy storage device according to an embodiment.

Fig. 7 is a schematic drawing illustrating a segment of an outer part of a cage structure next to a chamber wall according to an embodiment.

Fig. 8 is a schematic drawing illustrating a segment of an outer part of a cage structure next to a chamber wall according to an embodiment.

Fig. 9 is a schematic drawing illustrating a segment of an outer part of a cage structure next to a chamber wall according to an embodiment.

Fig. 10 is a schematic flow diagram illustrating a method for assembling an energy storage device according to an embodiment.

DETAILED DESCRIPTION

[0044] In the following, embodiments of the invention will be described in detail with reference to the accompanying drawings. It is to be understood that the following description of the embodiments is given only for the purpose of illustration and is not to be taken in a limiting sense. It should be noted that the drawings are to be regarded as being schematic representations only, and elements in the drawings are not necessarily to scale with each other. Rather, the representation of the various elements is chosen such that their function and general purpose become apparent to a person skilled in the art. As used herein, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted.

[0045] Figure 1 shows a schematic drawing illustrating a section of a thermal energy storage device 100 according to an embodiment. The thermal energy storage device 100 comprises a chamber 101 with walls 701, which include lateral side walls not visible in the sectional view of figure 1. The chamber 101 includes storage material 102, which is configured to store thermal energy, and two or more ports 103, 104. The ports 103, 104 are configured to pass a flow 105 of heat transfer medium. The flow enters the thermal energy storage device 100 via port 103, which is for example an inlet, and leaves the storage 100 via port 104, which is for example an outlet. The energy storage device 100 is operable in a charging mode in which the heat transfer medium transfers thermal energy to the storage material, and in a discharging mode in which the storage material transfers thermal energy to the heat transfer medium. The direction of the flow 105 may be reversed during charging and discharging (with a respective reversal of the function of the ports 103, 104), or may be the same during charging and discharging. The storage material 102 may comprise, but is not limited to, solid granular material, e.g. soil, sand or stones. The heat storage material 102 may comprise or consist of rocks, bricks, stone, lava stone, granite, basalt and/or ceramics provided as bulk material. Preferably, the heat storage material comprises or consists of sand and/or stones, in particular gravel, rubble and/or grit. The heat storage device can thus be provided cost efficiently while being capable of storing large amounts of thermal energy.

[0046] The thermal energy storage device 100 further comprises a cage structure 106 comprising one or more cages 107 that provide boundaries 110, 111 between the ports 103, 104 and the storage material 102. A single cage 107 is exemplarily illustrated in figure 2 and explained in the description thereof. The cage structure 106 comprises a filling material 108 and is configured to be passable by the heat transfer medium. The filling material 108 may be, but is not limited to, solid granular material like soil, sand or stones. It is also possible that the filling material 108 is composed from different materials which may have different grain sizes. The grain size of the filling material 108 is chosen such that the storage material 102 is kept in place and cannot pass the cage structure. It is further chosen such that the flow 105 of heat transfer medium can pass through the cage structure comprising the filling material.

[0047] According to the shown embodiment, the cage structure 106, which represents boundary 110 and boundary 111, is provided by a stack of cages 107. Both, left and right stack of cages 107 form the cage structure 106. In figure 1, the left portion of the cage structure 106 provides boundary 110 between port 103 and storage material 102 and the right portion of the cage structure 106 provides boundary 111 between the storage material 102 and the port 104. The boundaries 110, 111 ensure that in case of thermal expansion of the storage material 102, the storage material 102 is kept in place and is not shifted towards port 103 or port 104. Since figure 1 (and also figures 3-6) is a 2D view of a section through the thermal energy storage device, it should be clear that the cage structure 106, and accordingly boundaries 110, 111, also extends in depth. As such, each boundary can be understood as a wall built from the cages 107, which covers the whole cross-sectional area (in depth) of chamber 101 and thus extends between vertical side walls of chamber 101 that are not visible as they lie before and behind the drawing plane. In the depth direction perpendicular to the drawing plane, the individual cages may span the width of the storage device, or plural cages can be placed next to each other to span the width (i.e. plural neighboring stacks can be provided).

[0048] The cages 107 shown in figure 1 have similar or identical dimensions and thus form walls (boundaries) of approximately constant thickness. However, it is also possible that cage structure 106 comprises cages 107 which are dimensioned differently. The bounding surfaces of cage structure 106 may thus not be plane but have a more complex shape. Further, it is possible that cage structure 106, in particular one of the boundaries 110, 111 is built from a single cage 107. Figure 1 shows the stack of cages 107 erected straight upwards. It is also possible to erect a stack in a slant way, for example by positioning the stack on a slant ground plane or foundation. The cages 107 may be mechanically connected by connecting elements, such as clamps, ties, spirals and the like or may be welded together. It is also possible that no connecting elements are necessary and that the plurality of individual cages are sufficiently mechanically connected by frictional forces. The walls built from cages 107 may be connected to the walls 701 of the chamber 101 (in particular to the lateral walls not visible in figure 1) in order to provide further stability. The filled cage structure 106 has a high self-weight contributing to a high stability, strength and rigidity of the structure. High mechanical stresses can thus be taken up and directed to ground. Further, the filling material 108 may increase the energy storage capacity and energy density of the thermal energy storage device 100.

[0049] Figure 2 is a schematic drawing illustrating a single cage 107, for example a gabion, as it may be comprised in the cage structure 106 of any of the disclosed embodiments. The filling material 108 is schematically indicated on the front side of cage 107. It can be seen that cage 107 is fully filled with filling material 108. However, in certain situations, a cage 107 may also be partially filled or not filled. The cage 107 may comprise a single material, e.g. rocks, sand or soil, but may also comprise a mixture of materials. The filling material may slightly protrude from the cage 107, e.g. pieces of rock may stick out. In the embodiment shown, the cage 107 is formed as a rectangular cuboid built by a grid structure made from wires 201. It is also possible to form other geometric shapes. The wires 201 are spaced so closely together that the filling material or portions thereof cannot slip through the openings between them. The wires may be connected to each other, for example welded or clamped together at uniformly distributed points, in order to form a desired geometric body. The wires may be flexible like strings but are preferably stiff like bars. The wires 201 as shown in figure 2 form a cage having six closed sides enclosing the filling material. In some embodiments, the cage 107 may also comprise open sides. For example, the cage 107 may comprise a closed bottom side, four closed lateral sides and an open top side. It should be clear that in general, it would also be possible that a side of the cage is left open and closed by an adjacent cage. Further, the cage 107 can be connected to a second cage via a mechanical connection (for example by connecting the wires 201 to the second cage by means of a connecting element), which can also be a frictional connection as cage 107 and the second cage are in contact with each other.

[0050] Figures 3 and 4 are schematic drawings each illustrating a section of the thermal energy storage device 100 according to an embodiment. Since the load on the boundaries 110, 111 of the thermal energy storage device 100 is higher in the lower portion 301 and decreases upwards, figures 3 and 4 illustrate boundaries 110, 111 which are designed wider in the lower portion 301 and become narrower in the middle portion 302 and narrowest in the upper portion 303. Such a tapered structure of each of the boundaries 110, 111 is obtained by arranging in the direction perpendicular to the boundaries 110, 111 a larger number of cages 107 in the bottom portion 301, a smaller number of cages 107 in the middle portion 302 and the smallest number of cages 107 in the upper portion 303 of boundaries 110, 111. Cages 107 shown in figures 3 and 4 are identically or at least similarly dimensioned and arranged such that one side of each boundary 110, 111 is approximately a vertical plane and the other side of each boundary 110, 111 has a stepped shape forming a slant. According to the embodiment shown in figure 3, the side including the stepped slant is the storage material facing side and the side directed straight upwards is the port facing side. According to the embodiment shown in figure 4, the side including the stepped slant is the port facing side and the side directed straight upwards is the storage material facing side. It should be clear that cages 107 may be arranged in order to obtain other desired structures or shapes of the boundaries 110, 111.

[0051] Figure 5 corresponds to figures 3 and 4 in that the lower portion 301 of the boundaries 110, 111 of the cage structure 106 is wider than the upper portion 303, which creates boundaries 110, 111 having a tapered structure. However, the shown embodiment comprises a cage structure 106 that is composed of differently sized or dimensioned cages 107, for example of cages 501 having a tapered shape. Thereby, a rather smooth trapezoid shape is created which does not comprise steps as for example shown in figures 3 (storage material facing side) and 4 (port facing side). Further, in the shown embodiment of the thermal energy storage device 100, the storage material facing side is vertical, but in other implementations, both the storage material facing side and the port facing side of each boundary 110, 111 can be inclined.

[0052] Figure 6 is a schematic drawing illustrating a section of the thermal energy storage device 100 according to an embodiment. Cage structure 106 encloses all of the storage material 102 and the filling material 108. Both are distributed over plural individual cages 107, which form a structured chamber 601. The characteristics of the filling material 108 can be similar or identical to that of the storage material 102. However, it may also differ. Since all of the material 102, 108 to be passed by flow 105 is enclosed by individual cages 107, the flow 105 can be influenced or predetermined by the fillings of the cages 107. For example, the flow 105 passing chamber 101 can be influenced to follow a path through the single cages 107 in a predetermined way such that the energy exchange between the heat transfer medium and the storage material 102 is improved. This way, the energy density and efficiency of the thermal energy storage system can be increased. Further, each cage 107 compensates as a single independent unit the forces resulting from the thermal expansion or self-weight of the portion of filling material 108 it encloses. Thus, horizontal forces due to thermal expansion may be compensated or at least significantly reduced. It should be clear that also in the cage structure of figure 6, some cages, for example inner cages, can be filled with the storage material 102 while other cages, e.g. the ones forming the boundaries 110, 111, can be filled with a different filling material 108 that is, e.g., coarser to allow a better flow of the heat transfer medium through the boundaries.

[0053] Figure 7 is a schematic diagram illustrating a segment of an outer part of the cage structure 106 next to the chamber wall 701 according to an embodiment. It is noted that figures 7, 8 and 9 illustrate only a segment of the cage structure 106, they in particular show a portion of the cage structure 106 positioned in a corner of the thermal energy storage device. The cage structure includes further cages not visible in these figures. Also, only one layer of the cage structure is arranged at the vertical walls 701 of the energy storage device of this embodiment; further layers may certainly be present. The cage structure 106 follows the wall 701 of the chamber 101 and surrounds the storage material 102 in a horizontal direction. Thus, the cage structure 106 confines the storage material 102 in a horizontal direction comparable to a 'belt' or a 'ring', and forms a ring structure 702. Further, the ring structure 702 may be configured such that forces can be directed or can flow through the ring. For example, cages 107 comprised in the ring structure 702 can be mechanically coupled together for this purpose. In doing so, forces directed outwards from the interior of the thermal energy storage device are distributed to the whole ring structure and compensated. The ring structure 702 thus increases the stability of the cage structure 106.

[0054] Figures 8 and 9 are schematic drawings each illustrating a segment of an outer part of the cage structure 106 next to the chamber wall 701 based on the embodiment shown in figure 7. However, for the same reasons outlined above in the description of figures 3-5, a trapezoid shape of the cage structure 106 providing boundaries 110, 111 is formed. In figure 8, the cage structure 106, which forms the ring structure 702, has outer vertical surfaces (the surfaces facing the port side and wall 701), while the storage material facing side forms a stepped slant. In figure 9, an embodiment of the cage structure 106 forming ring structure 702 is shown, in which the port facing sides and the sides facing side walls 701 form a stepped slant, while the storage material facing side is directed straight upwards, i.e. is a vertical plane.

[0055] Figure 10 shows a flow diagram illustrating an embodiment of a method 1000 of assembling an energy storage device as described hereinabove. The sequence of the steps S1001-S1005 is not fixed to the shown order. The method comprises a first step S1001 of providing a chamber having two or more ports configured to pass a flow of heat transfer medium. One or more cages are provided in step S1002. The providing of one or more cages may also include steps necessary for manufacturing the one or more cages. In the next step S1003, the cages are filled with a filling material. In the following step S1004, a cage structure comprising one or more cages as boundary between one of the ports and at least part of the storage material, which is provided in step S1005, is formed in the chamber of the storage device. The cage structure is configured such that it is passable by the heat transfer medium. Providing the cage structure in step S1004 may include an erecting of the one and more cages (stacking/placing next to each other and connecting) in order to compose the cage structure, and implementing the cage structure into the chamber. The cage structure may be erected inside the chamber or may be erected outside the chamber and afterwards transported into the chamber. Transporting single cages, the cage structure, or parts thereof may be performed by means of a crane which conveys the single cages, the cage structure or parts thereof into the chamber, for example through the upper side (roof side) of the thermal energy storage device. The step S1003 of filling of the one or more cages may also be performed after erecting and implementing the cages into the chamber. In this case, the cage structure is filled with the filling material during or after erecting (e.g., cages may be filled layer by layer). As a further step S1005, filling the part of the chamber which is confined by the boundary provided by the cage structure with the storage material is performed. It is performed such that the heat transfer medium is allowed to flow through the boundaries and the storage material to exchange thermal energy with the storage material comprised in the chamber.

[0056] While specific embodiments are disclosed herein, various changes and modifications can be made without departing from the scope of the invention. The present embodiments are to be considered in all respects as illustrative and nonrestrictive, and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.

Claims

1. A thermal energy storage device (100) comprising:

   a chamber (101) including storage material (102) configured to store thermal energy,
   two or more ports (103, 104) configured to pass a flow (105) of heat transfer medium, the storage material being configured to exchange thermal energy with the heat transfer medium, and
   a cage structure (106) comprising one or more cages (107) that provide a boundary (110) between one of the ports and at least part of the storage material, wherein the cage structure comprises a filling material (108) in the one or more cages, and wherein the cage structure is configured to be passable by the heat transfer medium.

2. The thermal energy storage device (100) according to claim 1, wherein the one or more cages (107) are wire baskets and/or gabions.

3. The thermal energy storage device (100) according to claim 1 or 2, wherein the one or more cages (107) are formed from at least one of mesh, bars or wires.

4. The thermal energy storage device (100) according to any of the preceding claims, wherein the one or more cages (107) have the shape of a hexahedron, preferably of a rectangular cuboid.

5. The thermal energy storage device (100) according to any of the preceding claims, wherein the filling material (108) comprises or consists of a granular material having a structure selected such that a flow resistance for the heat transfer medium passing the filling material is lower than a flow resistance for the heat transfer medium passing the storage material.

6. The thermal energy storage device (100) according to any of the preceding claims, wherein the filling material (108) of at least a part of the cage structure (106) is different from the storage material (102).

7. The thermal energy storage device (100) according to any of the preceding claims, wherein the filling material (108) of at least a part of the cage structure (106) has a similar structure and/or composition as the storage material (102).

8. The thermal energy storage device (100) according to any of the preceding claims, wherein the cage structure (106) comprises or consists of plural individual cages (107), each cage comprising the filling material (108).

9. The thermal energy storage device (100) according

to claim 8, wherein the plural individual cages (107) comprise cages for which the structure and/or composition of the filling material (108) is different than for other individual cages of said plural cages.

10. The thermal energy storage device (100) according to claim 8 or 9, wherein the plural individual cages (107) include individual cages that are stacked on top of each other and/or include individual cages that are arranged next to each other in contact with each other.

11. The thermal energy storage device (100) according to any of the preceding claims, wherein at least a portion of said storage material (102) is provided as filling material (108) in said cage structure (106), wherein preferably, all of the storage material is provided as filling material in said cage structure.

12. The thermal energy storage device (100) according to any of the preceding claims, wherein the one or more cages (107) that provide the boundary (110) to the port (103) are configured such that the boundary has a tapered structure that is wider at a bottom of the boundary and narrower at the top of the boundary in a direction perpendicular to the boundary, wherein preferably, the tapered structure of the boundary is obtained by arranging, in the direction perpendicular to the boundary, a larger number of cages at the bottom of the boundary and a smaller number of cages at the top of the boundary, or by arranging one or more cages having a tapered shape, in particular a trapezoid shape, in the boundary.

13. The thermal energy storage device (100) according to any of the preceding claims, wherein the cage structure (106) is configured to form a wall structure around the storage material (102) that partially or fully confines the storage material in horizontal direction.

14. The thermal energy storage device (100) according to any of the preceding claims, wherein the one port to which the one or more cages provide a boundary (110) is a first port (103), and wherein the cage structure comprises one or more cages that provide a boundary (111) between a second port (104) of the two or more ports and at least part of the storage material (102).

15. A method of assembling an energy storage device, comprising:

providing (S1001) a chamber having two or more ports configured to pass a flow of heat transfer medium and including storage material, the storage material being configured to store thermal energy and to exchange thermal energy with the heat transfer medium, and

providing (S1002) a cage structure comprising one or more cages as boundary between one of the ports and at least part of the storage material, wherein the cage structure comprises a filling material in the one or more cages, and wherein the cage structure is configured to be passable by the heat transfer medium.

FIG 1

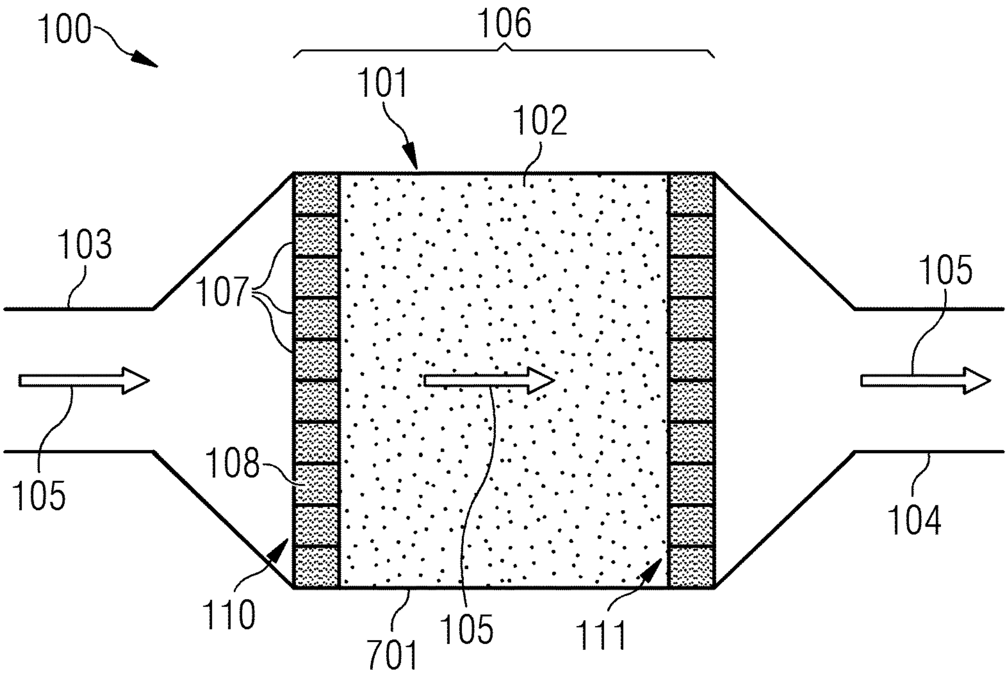

100
106
101
102
103
107
105
108
105
104
110
701
105
111

FIG 2

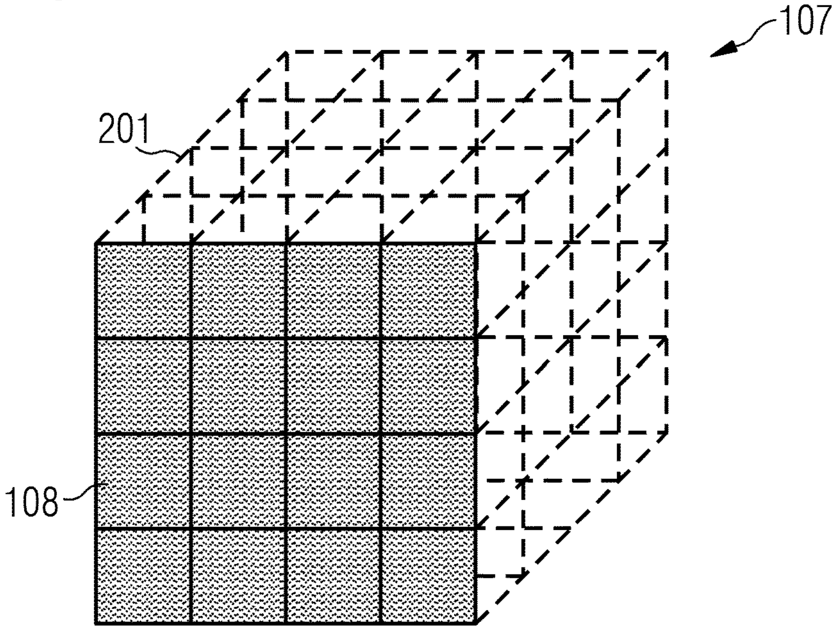
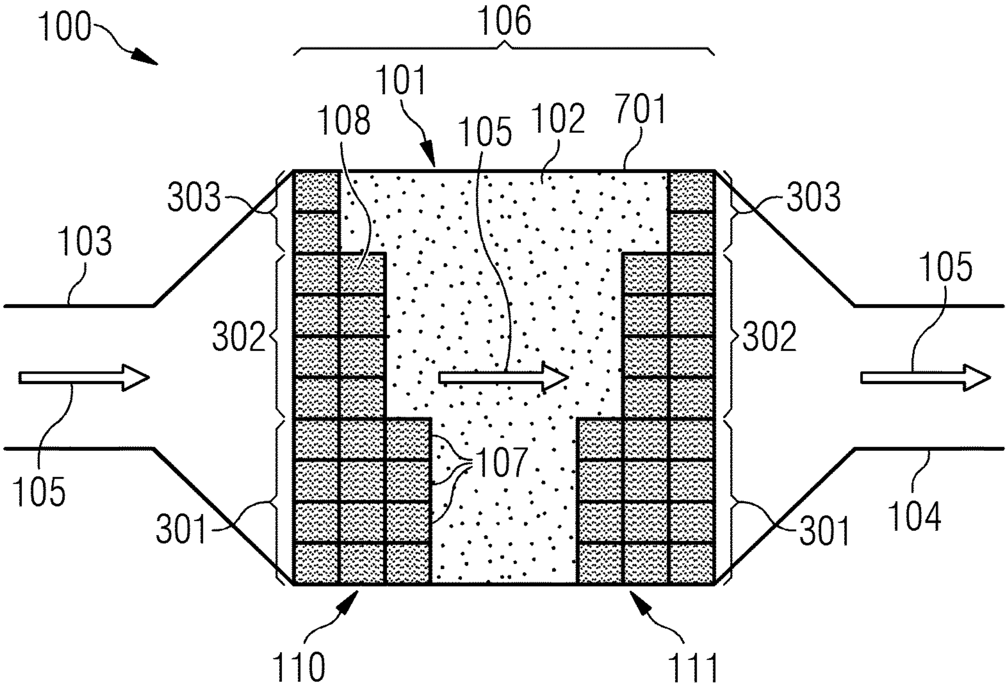

107
201
108

FIG 3


100
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701
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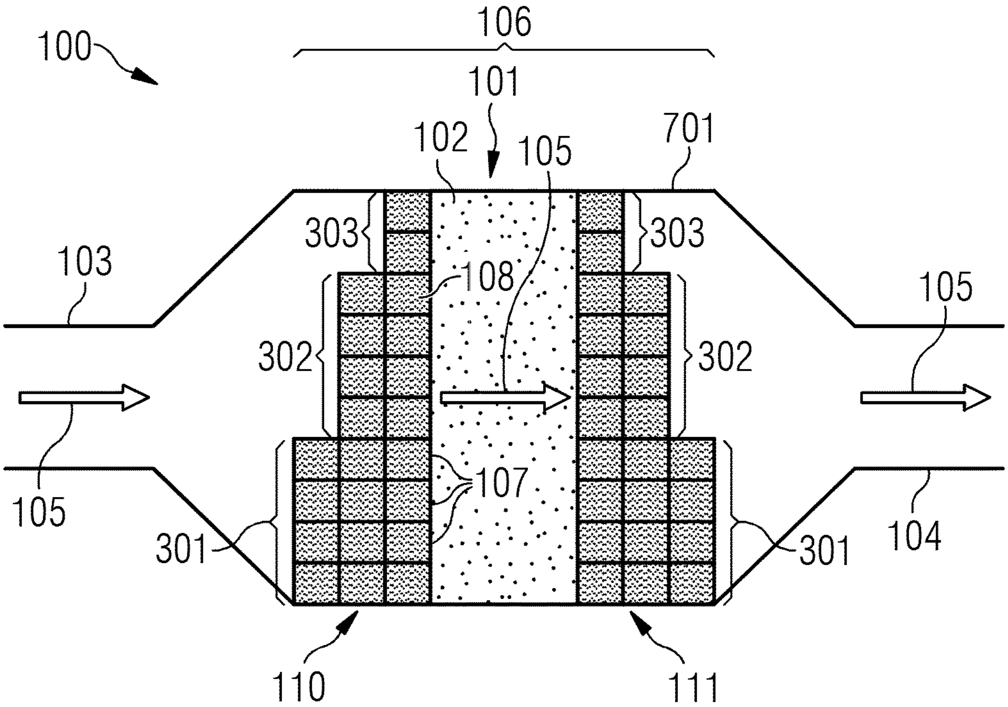
110
111

FIG 4


100
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701
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302
302
107
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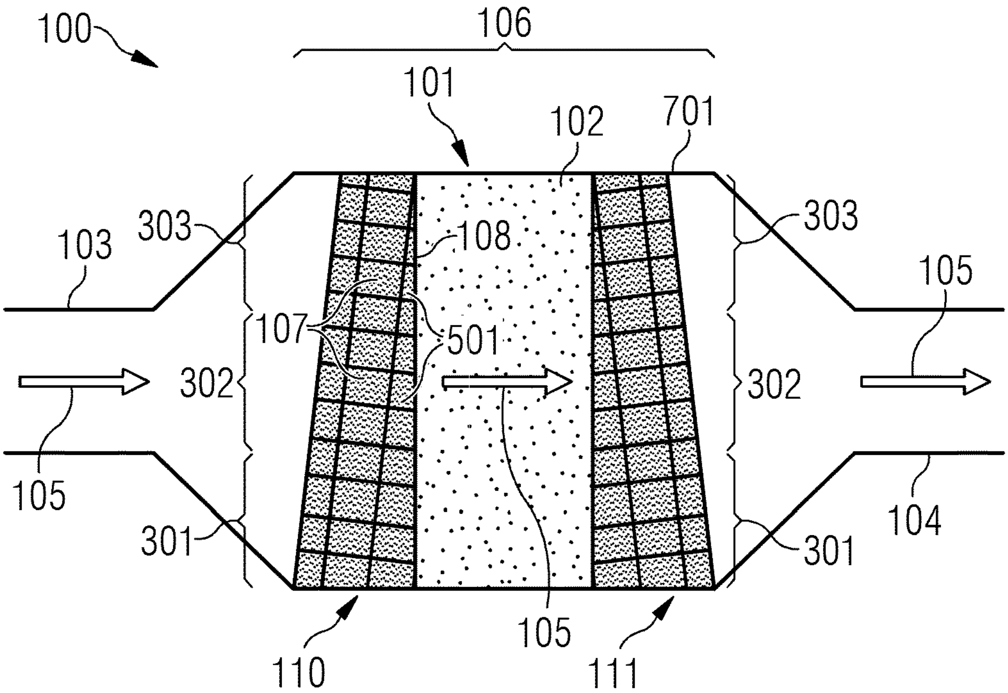
104
301
301
110
111

FIG 5


100
106
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102
701
103
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108
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107
501
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302
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301
104
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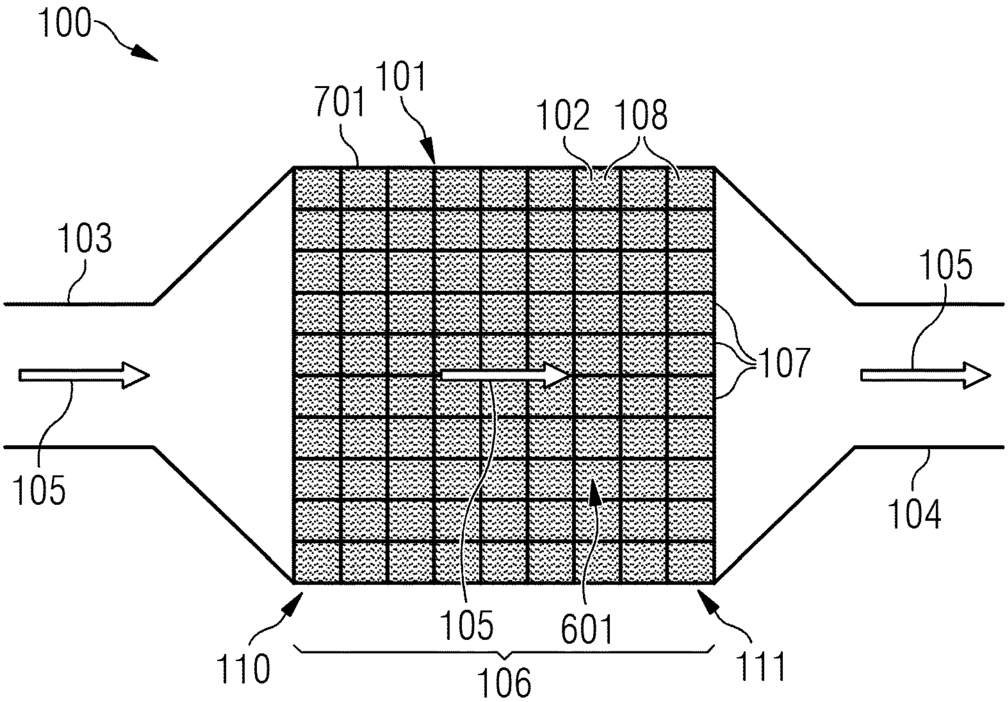
105
110
111

FIG 6


100
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101
102
108
103
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107
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104
105
601
110
111
106

FIG 7

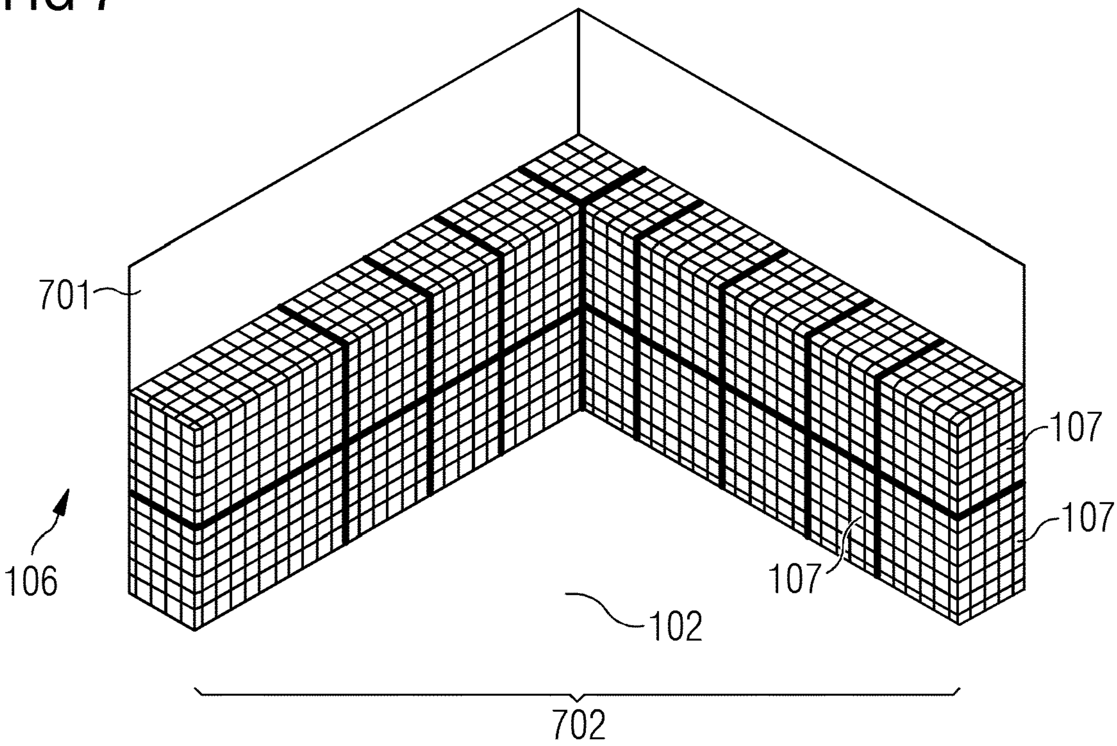


FIG 8

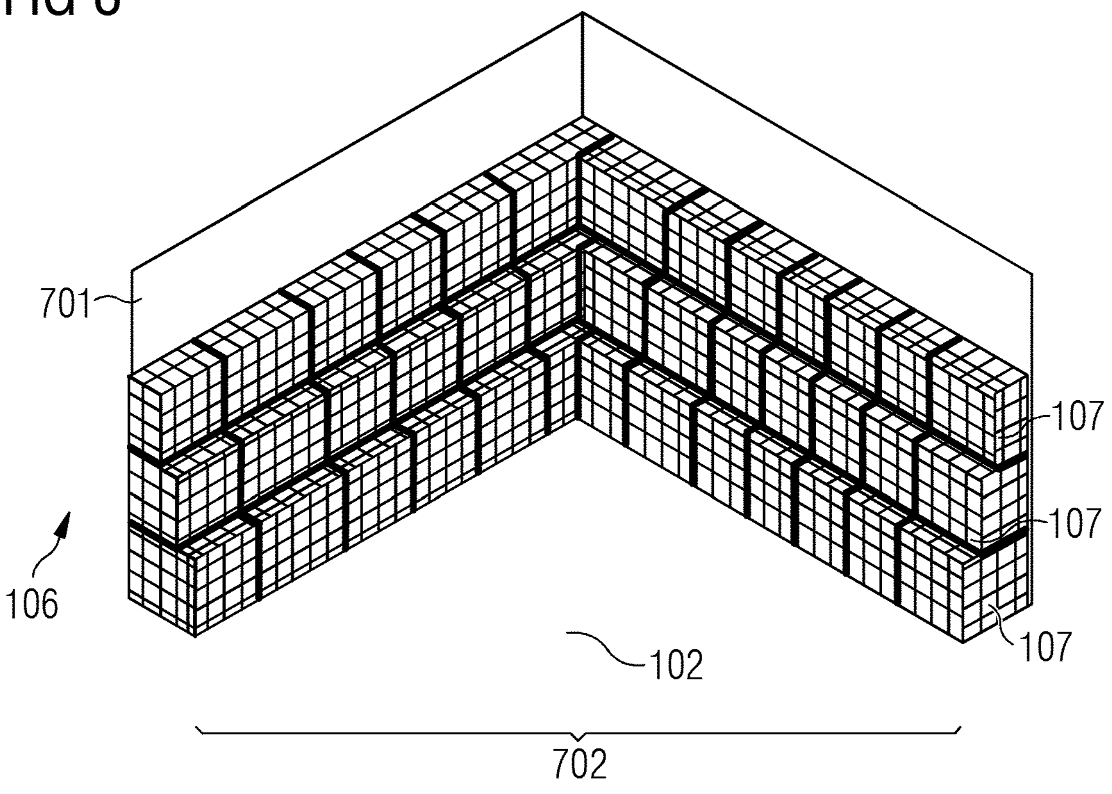


FIG 9

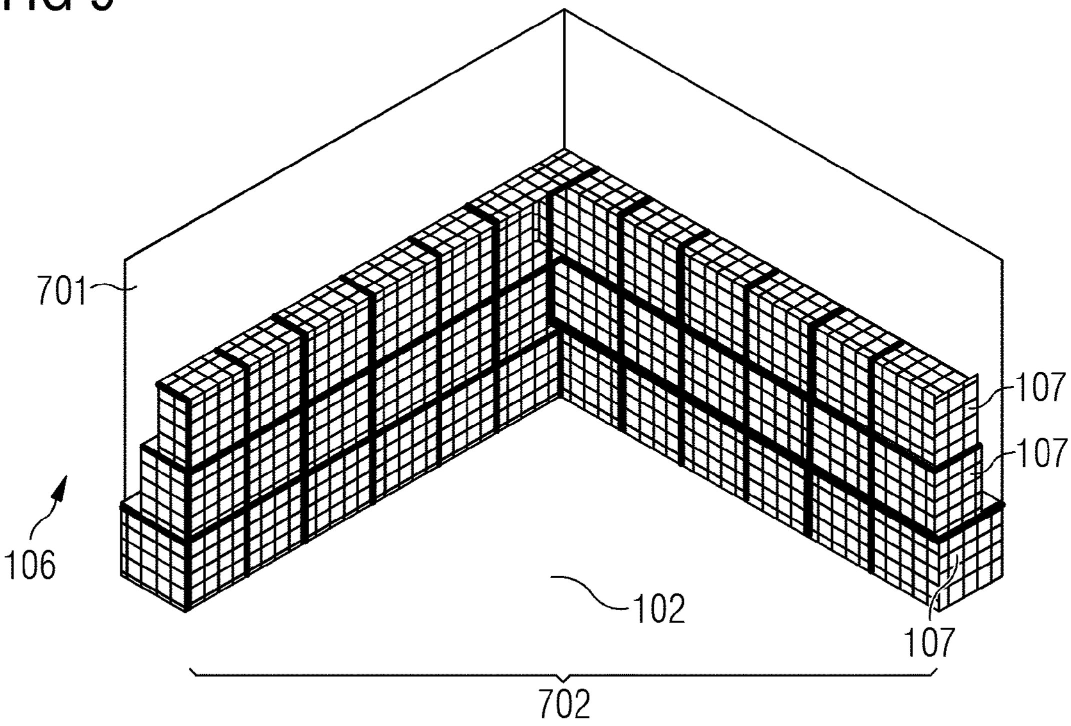
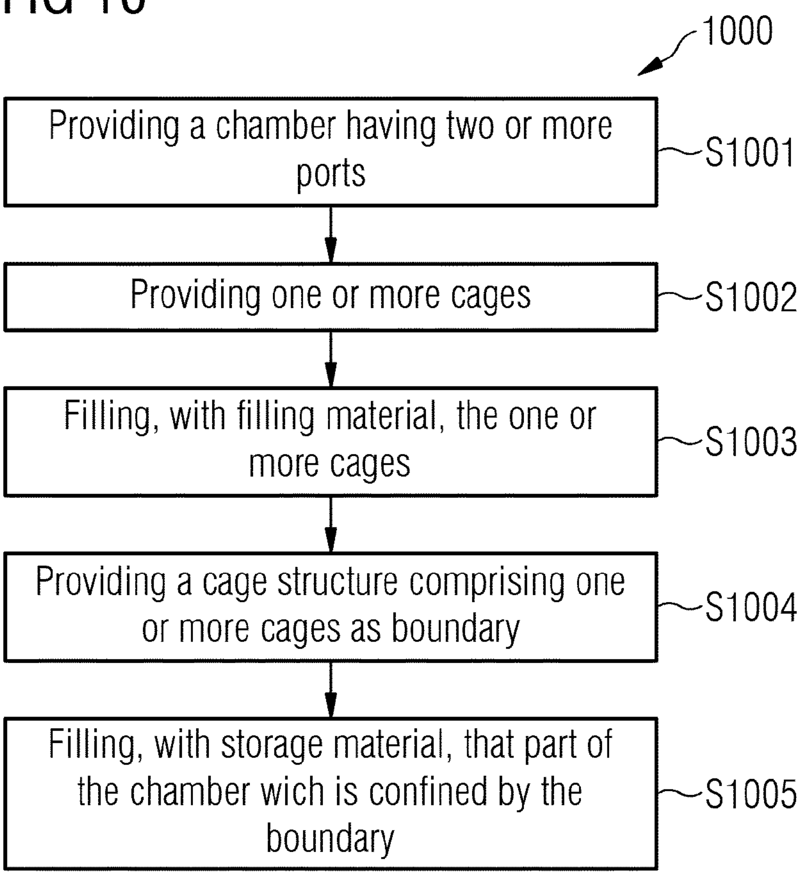

701
106
102
107
107
107
702

FIG 10


1000
Providing a chamber having two or more ports
S1001
Providing one or more cages
S1002
Filling, with filling material, the one or more cages
S1003
Providing a cage structure comprising one or more cages as boundary
S1004
Filling, with storage material, that part of the chamber wich is confined by the boundary
S1005

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EUROPEAN SEARCH REPORT

Application Number
EP 21 16 5979

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Place of search	Date of completion of the search	Examiner
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