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(54) **APPARATUS FOR HEAT EXCHANGE BETWEEN A GRANULAR MATERIAL AND A FLUID, AND RELATED PROCESS FOR ENERGY STORAGE**

(57) The present invention relates to an apparatus for the heat exchange between a granular material and a fluid, comprising a container (2) having a sidewall (3) extending between a lower branch chamber (10) and an upper branch chamber (11) and containing a predetermined quantity of granular material intended to be heated to high or very high temperatures, a main duct (6) extended axially and substantially centrally within the container (2) between the chambers (10, 11) for the circulation of fluid from the upper branch chamber (11) to the lower branch chamber (10) and peripheral ducts (7) positioned around the main duct (6) communicating with the main duct (6) through the chambers (10, 11) for the circulation of fluid from the lower branch chamber (10) to the upper branch chamber (11). The apparatus also has valve means (12) configured to move between a closed position, where circulation between the upper branch chamber (11) and the main duct (6) is interrupted, to an open position, where circulation from the upper branch chamber (11) to the main duct (6) is permitted, resistance means (14) configured to heat the fluid, and ventilation means (13) configured to control the direction of fluid circulation.

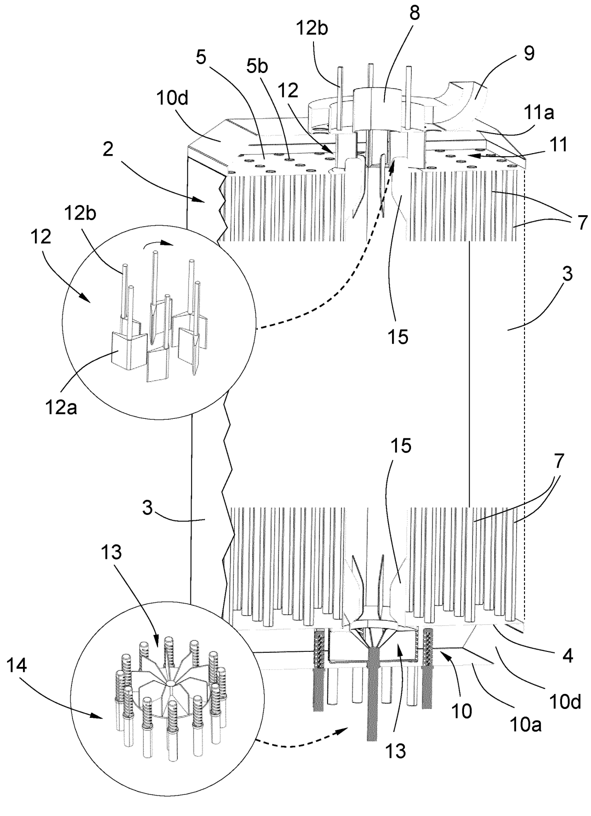

Fig. 7

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Description

Technical Field

[0001] The present invention concerns an apparatus for the heat exchange between a granular material and a fluid. More specifically, the invention concerns an apparatus for the heat exchange suitable for the storage of thermal energy thanks to the heating of the granular material stored inside a container and suitable for transforming the heat thus produced into mechanical or electrical energy for industrial, commercial and/or domestic use.

Background Art

[0002] A solution for the preheating of granule material in silos or containers is described in publication EP 4105184 A2 on behalf of the same Inventor. This publication describes an apparatus for the heat exchange intended for the preheating of sand which can subsequently be used in glass furnaces.

Description of the Invention

[0003] The Applicant has become aware of the need to develop apparatus for the heat exchange that allows both energy storage in an optimized and simplified manner and effective transfer of thermal energy from a granular material to a fluid.

[0004] The Applicant has therefore realized that by creating optimized heat exchange paths for the continuous passage of air, it is possible to guarantee very high operational efficiencies, long-term reliability, ease of use and maintenance, as well as obtaining economically advantageous investments and extremely satisfactory economic balances.

[0005] In detail, the apparatus is made to possess a high thermal conductivity with a structural capacity such as to compensate for temperature variations while minimizing the amount of maintenance required.

[0006] In addition, the Applicant found that the apparatus of the invention provides mechanically optimized fluid dynamic paths such as to improve the structural capabilities of the apparatus and allow it to be easily transported by road avoiding complicated in-situ constructions.

[0007] The Applicant has therefore developed apparatus and the related process that allows a fluid to be circulated along a well-defined path in order to accumulate thermal energy through a recharge phase and to withdraw the thermal energy accumulated in a discharge phase to transform it into mechanical or electrical energy or to be used as a primary energy source. Basically, during the recharge phase, the fluid gives heat to the granular material, while during the discharge phase, the granular material gives heat to the fluid.

[0008] The apparatus of the invention has shown its maximum competitiveness over long charging times (e.g. by a combined use of thermal and electrical energy in a one-to-two ratio, i.e. 1/3 electrical and 2/3 thermal). With energy reuse times of about six months, i.e. proceeding with the accumulation of energy in the summer period (charging phase) and then returning it in the winter (discharge phase), the overall energy efficiency, as well as the energy and economic balance, is exceptionally high. Even with shorter energy reuse times, such as two/three-week charge/discharge cycles, this solution remains highly competitive.

[0009] By virtue of the foregoing considerations, the main purpose of the present invention refers to an apparatus for the heat exchange according to claim 1. Another object of the present invention relates to a process for the production of energy through the heat exchange between a granular material and a fluid according to claim 11.

Brief Description of the Drawings

[0010] Further characteristics and advantages of the apparatus and method according to the present invention will result from the description below of preferred embodiments thereof, given by way of an indicative yet non-limiting example, with reference to the attached figures, wherein:

- Figure 1 is a front view of an embodiment of the apparatus for the heat exchange of the invention in which the ducts inside the container are visible;
- Figures 2 and 3 are side perspective views of the apparatus in Figure 1 oriented horizontally;
- Figures 4a and 4b are side perspective views of the apparatus in figures 2 and 3 with the container visible;
- Figure 5 is a view of the apparatus in Figure 4B showing the insulation panels in transparency;
- Figure 6 is a perspective view in horizontal section of the apparatus in figure 1;
- Figure 7 is a vertical perspective view of the apparatus in figure 1 with enlargements of the valves, ventilation means and resistance means;
- Figure 8 is a top-down view of the apparatus in Figure 1;
- Figure 9 is a cross-sectional overhead view of the upper branch chamber of the apparatus detailing the drilled

passages around the inlet duct;

- Figure 10 is a cross-sectional view of the upper branch chamber of Figure 1 where the top plate and valve means are visible in detail;
- Figures 11 and 12 are perspective cross-sectional views of the horizontally oriented apparatus showing the fluid paths in the different charge/discharge phases;
- Figures 13a and 13b are seen in section of the valve means, respectively, in the closed and open position;
- Figures 14 and 15 are perspective views of forms of construction of ventilation means;
- Figure 16 is a perspective view of a further embodiment of the invention apparatus showing the ducts inside the container;
- Figure 17 is a detailed perspective view of the lower branch chamber of the apparatus in Figure 16 showing the inside of the branch ducts.

Embodiments of the Invention

[0011] With reference to said figures, 1 is globally referred to an apparatus for the heat exchange in accordance with the present invention.

[0012] In the following description and claims, the term "granular material", by way of example, means granular material such as sand (such as, for example, silicon dioxide (S_iO_2) in the form of quartz) or other particulate material with a diameter between approximately 0.074 and 4.75 millimeters suitable for heating to high or very high temperatures. However, the use of different particulate materials suitable for the same purpose is not excluded.

[0013] As will be appreciated below, the granular material (e.g. sand) is stored inside a container 2 and is intended to be heated to high or very high temperatures through a non-direct heat exchange with a fluid, e.g. hot air. In the remainder of this description and in the following claims, high temperatures are defined as temperatures between 150°C and 650°C, while very high temperatures are defined as temperatures between 650°C and 1000°C. The apparatus 1 of the invention is configured to operate between 150°C and 1000°C, preferably 950°C.

[0014] The term "fluid" is intended to describe, preferably, air or air mixtures in general, which may commonly include nitrogen, oxygen, argon and/or carbon dioxide (CO2). Preferably, the fluid circulating in apparatus 1 is only air.

[0015] As shown in figures 4a and 4b, the apparatus 1 comprises a container 2 for the storage of a granular material (e.g. silica sand) bounded by a sidewall 3, a lower branch chamber 10 and an upper branch chamber 11.

[0016] The container 2 extends mainly along a longitudinal X-X direction and has an overall parallelepiped shape, preferably cuboid, with chambers 10, 11 substantially square. It is not excluded, however, that the container 2 may have a different shape, for example cylindrical with chambers 10, 11 circular.

[0017] In detail, the apparatus 1 is equipped with a main duct 6, preferably tubular in shape, acting as a central manifold, extended axially inside container 2 for the passage of air. In essence, as will be explained later in the description, the granular material stores heat during a charging phase, and releases heat during a discharge phase. Preferably, the main duct 6 is extended vertically between the two plates 4,5.

[0018] For the purposes of this discussion, the terms "upper", "lower", "vertical" and "horizontal", used with reference to apparatus 1, are intended to refer to the conditions of normal use of apparatus 1, i.e. as shown in figure 1. However, the use of the apparatus horizontally, i.e. with the main duct extended horizontally, for example if underground, is not excluded.

[0019] As can be seen from the attached figures, the main duct 6 is centrally interposed between the lower branch chamber 10 and the upper branch chamber 11 trough respective central openings/holes 4a, 5a centrally formed in the plates 4, 5.

[0020] The apparatus 1 is also equipped with peripheral ducts 7 arranged around the main duct 6.

[0021] Preferably, the main duct 6 and the peripheral ducts 7 are preferably tubular in shape.

[0022] The apparatus 1 has an air inlet duct 8 communicating with the main duct 6 and an outlet duct 9 communicating with the upper branch chamber 11.

[0023] The main duct 6, the peripheral ducts 7 and the branch chambers 10, 11 are in communication with each other allowing a high distribution of thermal energy inside the container 2. As will be explained in more detail later in the following description, the mechanical and fluid interconnection of the main duct 6, the peripheral ducts 6 and the branch chambers 10, 11 allows the apparatus 1 to maintain high structural stability and, at the same time, high levels of thermal conductivity.

[0024] As shown in the example in Figures 11 and 12, the main duct 6 is configured to allow air to circulate from the upper branch chamber 11 to the lower branch chamber 10 (dotted white arrows in figures 11 and 12) while the peripheral ducts 7 are configured to allow air to circulate from the lower branch chamber 10 to the upper branch chamber 11 (white arrows in figures 11 and 12). Air can be circulated in a closed path. For this purpose, the apparatus may include valves (not shown) at inlet duct 8 and/or outlet duct 9 to interrupt/allow air to enter/exit from/to the outside. In this context, the inlet duct 8 and the outlet duct 9 can be connected to a heat exchanger (not shown). Pressure switches can also be provided to control the pressure inside the container 2.

[0025] As anticipated, the apparatus 1 includes a lower branch chamber 10 and an upper branch chamber 11 fluid-dynamically connected to each other through the main duct 6 and the peripheral ducts 7.

[0026] The lower branch chamber 10 is configured to receive air from the main duct 6 and distribute it to the peripheral ducts 7 (black arrows shown in figures 11 and 12).

[0027] The upper branch chamber 11, on the other hand, is configured to receive air from the peripheral ducts 7 and, depending on the charging/discharging phase, to reintroduce it into the main duct 6 or distribute it outwards (dotted black arrows shown in figures 11 and 12).

[0028] As shown in figures 7 and 9, the upper branch chamber 11 is made from two pairs of walls 11d connected to a base plate 5 and an upper surface 11a facing parallel to define a predetermined internal volume of the chamber. The lower branch chamber 10 has a geometric configuration very similar to the lower branch chamber 10.

[0029] In accordance with a embodiment, the walls 11d are convergent so that chambers 10, 11 are preferably trapezoidal in shape. It is not excluded, however, that the 10d walls are oriented parallel to form a regular parallelepiped.

[0030] As shown, the top plate 5 serves as the base for the upper branch chamber 11 and the bottom plate 4 serves as the upper surface for the lower branch chamber 10.

[0031] Preferably, each chamber 10, 11 has significantly less height than its length or width.

[0032] As shown in the example in Figure 9, the upper surface 11a of the upper branch chamber 11 has a central perforated passage 11b connecting to the inlet duct 8. Preferably, the outlet duct 9 is connected to the upper branch chamber 11 by means of circular perforated passages 11c arranged circularly around the central hole 11b.

[0033] As shown in the examples in figures 10, 11 and 12, in each plate 4, 5 there is respectively a through hole 4a, 5a arranged centrally for the connection of the main duct 6. Around each central hole 4a, 5a are made peripheral holes 4b, 5b for the connection of the peripheral ducts 7. This configuration ensures fluid dynamic continuity between the branch chambers 10, 11. Essentially, the main duct 6 and the peripheral ducts 7 are interposed between plates 4, 5 and connected to the respective holes 4a, 5a, 4b, 5b for form-coupling. Preferably, the main duct 6 and the peripheral ducts 7 are connected to the plates 4, 5 by welding.

[0034] In use, plates 4 and 5 face each other so as to form a pair of parallel and opposing flat surfaces.

[0035] In detail, the peripheral holes 4b, 5b are of equal diameter and follow a regular lattice distribution. Preferably, the peripheral holes 4b, 5b are arranged in horizontal and vertical rows that are equally spaced and parallel.

[0036] Preferably, each central hole 4a, 5a has a larger diameter than the peripheral holes 4b, 5b which is substantially corresponding to the diameter of the main duct 6. Similarly, the peripheral holes 4b, 5b have a diameter substantially corresponding to the diameter of the peripheral ducts 7.

[0037] Advantageously, the peripheral ducts 7 are, as a whole, equally distributed within container 2 and oriented parallel to each other. The peripheral ducts 7 are oriented, in use, preferably parallel to the main duct 6, thus increasing the rigidity of the container 2. The location and quantity of peripheral ducts 7 can vary creating a higher heat exchange efficiency with the granular material. Such a configuration makes it possible to create a self-supporting and highly thermally conductive structure, allowing it to withstand any mechanical stress caused by the different thermal expansions of the granular material and the container 2.

[0038] Looking at the example shown in figure 6, it can be seen that the peripheral ducts 7 are distributed equidistant in an 8x8 matrix. In detail, the first three rows and the last between rows each have eight peripheral ducts 7 aligned along a respective axis. The two central rows have six peripheral ducts 7 aligned along a respective axis and distributed three by three on opposite sides with respect to the central holes 4a, 5a.

[0039] In the preferred embodiment, the number of peripheral ducts 7 is equal to sixty. However, a different number of peripheral ducts 7 as well as a different distribution such as, for example, circular, sinusoidal, irregular, etc., is not excluded, depending on the amount of thermal energy to be stored, the heat exchange to be carried out and according to the operating temperatures of the apparatus 1. In addition, it is possible to have peripheral ducts 7 with different diameters, for example with peripheral ducts 7 distributed outwards with a larger diameter, while peripheral ducts 7 closer to the main duct 6 with a smaller diameter, or vice versa. As a result, plates 4, 5 will have holes 4a, 5a, 4b, 5b in diameter substantially corresponding to the diameter of ducts 6, 7. Preferably, the ratio of the diameter of the main duct 6 to the diameter of each peripheral duct 7 is about 7:1. For example, peripheral ducts 7 may have a diameter (external) of 60 mm while the central duct may have a diameter (external) of 400 mm.

[0040] In use, the main duct 6 and the peripheral ducts 7 extend, preferably, vertically and parallel to each other.

[0041] In accordance with a design form, peripheral ducts 7 can be seamlessly connected to branch chambers 10, 11 by welding processes.

[0042] In one embodiment, valve means 12 may be arranged between the inlet duct 7 and the main duct 6 to interrupt/allow air to circulate from the upper branch chamber 11 to the main duct 6.

[0043] In detail, valve means 12 are configured to move between a closed position (figure 13a), in which circulation between the upper branch chamber 11 and the main duct 6 is interrupted, to an open position (figure 13b), in which circulation from the upper branch chamber 11 to the main duct 6 is allowed.

[0044] As shown in the enlargement of figure 7, valve means 12 comprise a plurality of bulkheads 12a arranged around the central hole 5a of the top plate 5.

[0045] Each bulkhead 12a extends along the X-X direction and has a height substantially corresponding to the height of the upper branch chamber 11. Each bulkhead 12a is preferably concave in shape (similar to a boomerang) with convexity facing the central hole 5a. Each bulkhead 12a has a respective shaft 12b keyed into it. Shafts 12b are constrained to the top plate 5 and the top surface 11a of the top branch chamber 11 in order to be able to rotate axially.

[0046] The shafts 12b are connected to handling apparatus (not shown) which imparts rotational motion to bulkheads 12a to close around the central hole 5a. The width of each bulkhead 12a is such that, in the closed position, the valve means 12 together create a ring-like surface around the central hole 5a which acts as a connection between the inlet duct 8 and the main duct 6, ensuring fluid dynamic continuity. When opened, the 12a bulkheads rotate at a predetermined angle and move away from each other, allowing air to pass through.

[0047] The lower branch chamber 10 includes ventilation means 13, preferably located at the central hole 4a of the lower plate 4, to increase the air conductivity coefficient in the ducts. In addition, ventilation means 13 allow air to be forced to circulate from the main duct 6 to the peripheral ducts 7. In essence, the air flows, in succession:

- from the main duct 6 to the lower branch chamber 10,
- from the lower branch chamber 10 to the peripheral ducts 7,
- from the peripheral ducts 7 to the upper branch chamber 11,
- from the upper branch chamber 11 to the main duct 6 and so on.

[0048] It is not excluded, however, that the air path is carried out in reverse according to specific construction requirements.

[0049] The ventilation means 13 shall comprise a rotating shaft 13a on which an impeller 13b equipped with a plurality of blades 13c and at least two 13d discs is keyed. The impeller 13b can be rotated around its own axis of rotation coaxial with the axis of extension of the main duct 6.

[0050] The rotating shaft 13a is connected to handling apparatus regulated by appropriate control means (not shown), such as an electronic controller, a plc, etc.

[0051] Each blade 13c is connected to at least one disk 13d by means of, preferably, interlocking connection. The interlocking connection between the blades 13c and the discs 13d is made in such a way as to increase its effectiveness under the effect of the centrifugal force acting on the impeller 13b during operation. In the embodiment of the example in figure 14, the ventilation means 13 consist of parts connected to each other exclusively by interlocking connection. These interlocking connections make it possible to create ventilation means 13 without classic assembly elements such as rivets, rivets and/or welds.

[0052] In the form of the example in figure 15, ventilation means 13 can be made up of parts connected to each other by interlocking and/or welding.

[0053] Advantageously, the blades 13c are substantially flat, each radially developed with a surface parallel to the axis of rotation. In addition, the blades 13c have a mainly symmetrical shape (with respect to a plane perpendicular to the axis of rotation).

[0054] The blades 13c have the portion close to the shaft 13a narrower than the portion furthest from the shaft 13a. The closely spaced portions are partially enclosed between the two facing and parallel 13d discs.

[0055] In the embodiment of the example in figure 14, the blades 13c basically have a dovetail profile. In the embodiment of the example in figure 15, the blades 13c have a substantially trapezoidal profile.

[0056] Advantageously, this configuration allows the ventilation means 13 to be able to work even at temperatures close to 1000° C thanks to the fact that the flat profile of the blades 13c allows linear expansion, guaranteeing the typical heads of centrifugal impellers. The ventilation means 13 of the invention are thus able to develop higher heads than a classic axial fan, allowing large masses of hot air to be transferred.

[0057] Preferably, the blades 13c are nine (or twelve) symmetrically arranged and equally spaced. However, a greater or lesser number of blades is not excluded depending on the heat exchange needs and the operating temperatures of the apparatus 1.

[0058] Preferably, the ventilation means 13 are configured to operate, in the recharging/discharging steps at a working speed between 600 and 1500 rpm, preferably 1000 rpm.

[0059] As illustrated, the lower branch chamber 10 also serves as a support for resistance means 14. The resistance means 14 may comprise one or more electrical resistors 14a configured to heat the air passing through the lower branch chamber 10 and, consequently, heat the granular material stored in container 2.

[0060] In detail, each electrical resistors 14a is preferably fixed to the lower surface 10a of the lower branch chamber 10 with the possibility of electrical connection by means of appropriate connectors 14b arranged outside the lower branch chamber 10. In this way, each electrical resistor 14a can be easily supplied from outside the container 2 by connecting the 14b connectors to a special energy source, preferably renewable.

[0061] Preferably, each electrical resistor 14a has a tubular shape that extends for a predetermined length inside the lower branch chamber 10 avoiding any direct contact with the sand.

[0062] Preferably, the resistors 14a extend along the longitudinal direction X-X and are distributed around the ventilation means 13.

[0063] Each resistor 14a preferably has a height substantially corresponding to the height of the lower branch chamber 10.

[0064] As shown in the example of Figure 7, at the end portions of the main duct 6 it is possible to have one or more fins 15 arranged in a radial pattern configured to control the aerodynamic load of the air flow inside the duct 6. Each fin 15 has a substantially trapezoidal shape with a development plane mainly extended along X-X for a stretch of predetermined length and partially extended radially from the wall of the central duct 6 towards the center. Preferably, the fins 15 are six symmetrically arranged and equally spaced. However, a greater or lesser number of fins is not excluded depending on the heat exchange needs and the operating temperatures of the apparatus 1.

[0065] In an embodiment, the apparatus 1 can include a plurality of insulating panels 16 (figure 5) that can be joined together and distributed around the container 2 to increase the thermal insulation of the apparatus. In correspondence with the upper branch chamber 11, the insulating panels 16 are shaped to size to be able to access the inlet ducts 8 and outlet 9.

[0066] The apparatus 1 of the invention may include control means (not illustrated) configured to control the operation of the various elements of the apparatus itself, in particular, valve means 12, ventilation means 13 and resistance means 14, pressure switches, and so on.

[0067] In detail, in the recharge phase (figure 11), the control means close the valve means 12 and activate the ventilation means 13 and the resistance means 14 for a predetermined time. In the discharge phase (figure 12), the control means open the valve means 12 and activate the ventilation means 13 and the resistance means 14 for a predetermined time. In a mixed modulation phase, the control means can sequentially activate/deactivate the valve means 12 and/or the resistance means 14 while the ventilation means 13 can still be active but at speeds lower than the working speed.

[0068] In accordance with the shape of figures 16 and 17, the branch chambers 10, 11 are preferably circular in shape and have branched branch ducts 17, 18. In addition, each duct 6, 7 may have one or more through holes evenly distributed along its length, creating junction points for the insertion of ducts 19 which act as additional heat exchange elements with the sand stored inside container 2. The median ducts 19 can be seamlessly associated with the peripheral ducts 7 and/or the main duct 6 by welding process. It is certainly also possible to make shape couplings by interposing mechanical connectors (not shown). The median ducts 19 are oriented, in use, preferably perpendicular to the peripheral ducts 7. With reference to figure 17 showing the lower branch chamber 4, at least one first branch duct 17 and at least one second branch duct 18 are arranged on the internal surface of the lower branch chamber 4. These branch ducts 17, 18 extend radially around the central hole 4a for a predetermined length. Even more preferably, branch ducts 17, 18 are located in diametrically opposite positions and, in use, are extended horizontally. In this embodiment, the air inlet duct 8 is arranged on the surface opposite the inner surface of the upper branch chamber 11. The upper branch chamber 11 is very similar in shape to the lower branch chamber 10 and also has a plurality of branch ducts that extend radially around the main duct 6 and are located in diametrically opposite positions. In this embodiment, the air outlet duct 9 is positioned on the surface opposite the inner surface of the lower branch chamber 10.

[0069] As shown in figures 16 and 17, each branch 17, 18 (in the following description, for ease of reading, the term "branches" can be used to indicate branch ducts) has a branched configuration that expands in order to cover as much surface as possible of the branch chambers 10, 11 and can include first-order branches, second-order, third-order, and so on. In detail, each branch has a main branch and peripheral branches that are articulated starting from specific positions from the main branch. Such a configuration allows the air to be distributed inside container 2, increasing the heat exchange surface between the sand and the air. In the illustrated example of figure 17, each electrical resistor 14a is housed inside a respective peripheral conduit 7 ensuring its isolation from the granular material and preventing any potential damage to the resistors themselves. Preferably, each electrical resistor 14a has a tubular shape that extends for predetermined length within the respective peripheral conduit 7 and has a diameter smaller than the diameter of the peripheral conduits 7. The peripheral ducts 7 are arranged around the main duct 6 and interconnect between branches 17, 18. The peripheral ducts 7 can be seamlessly connected to branches 17, 18 by welding. It is also possible to make shape couplings by interposing connectors (not shown). Each peripheral duct 7 has one or more through holes evenly distributed along the length of the main duct 6 and/or peripheral ducts 7, advantageously creating junction points for the insertion of the median ducts 19. Additional fins 20 can be associated with the peripheral ducts 7 to increase the heat exchange surface.

[0070] According to a preferred embodiment, ducts 6, 7, 19, container 2, branch chambers 10, 11, plates 4, 5 are made of metal material.

[0071] The process of energy production is described below in accordance with the invention using an apparatus 1 as described above.

[0072] A first initial step involves placing a predetermined amount of granular material, preferably silica sand, inside container 2. It has been identified that to achieve a barely sufficient heat exchange, container 2 must be filled with sand for at least 30% of its volume. For optimal heat exchange, the sand should occupy 80% to 99% of the container's volume, preferably about 95%.

[0073] A subsequent step involves carrying out a recharge phase in which the sand is heated to a temperature between

150°C and 1000°C, preferably 950°C. Heating is carried out by activating the electric resistors 14a, preferably powered by a renewable energy production system. The activation of the resistors 14a allows the circulating air inside ducts 6, 7 and chambers 10, 11 to be heated to a temperature between 150°C and 1000°C, preferably 950°C. The recharging step also involves activating the ventilation means 13 for a predetermined period of time.

[0074] It should be specified that unlike other fluids, air can reach very high temperatures in the order of 800/1000°C. The activation of the ventilation means 13 allows the direction of air circulation to be controlled in order to optimise the heat exchange between the air and the sand. Since sand has a low thermal conductivity, the numerous contact surfaces created by ducts 6, 7 described above allow for effective heat exchange.

[0075] As will be explained in detail in the following descriptive part of the tests carried out, the charging time can last from a few days up to even a semester and more depending on the size of the container. In this recharge period, the sand receives heat from the air circulating in the ducts and chambers heat that is stored to be returned during the discharge phase. Given the low thermal conductivity of sand, the heating times are generally long but, proportionally, so are the cooling times.

[0076] At the end of the charging phase, the discharge phase begins where the sand transfers heat to the air in the ducts and chambers. The discharge phase also involves sending the flow of hot air leaving the outlet duct, by means of appropriate circuits (not illustrated), to machines/plants for the transformation of thermal energy into mechanical, electrical, etc., such as steam engines or air machines (Rankine, Stirling, etc.). It is also possible to directly use the outgoing hot air flow as a primary energy source, for example to use it in dryers, district heating, etc.

[0077] The process of the invention provides that the apparatus 1 described above can be electrically connected to a plant for the production of electricity, preferably renewable, and that the flow of air leaving and entering the ducts can be fluid-dynamically connected to a plant for the transformation of thermal energy into mechanical and electrical energy or that the flow of hot air leaving is used as primary energy in other processes Industrial.

[0078] The charging phase requires that apparatus 1, and in particular the resistors 14a, is therefore, preferably, powered by, for example, photovoltaic panels. An operation that follows the daily cycle of activity of the photovoltaic panels allows a more balanced supply of electricity. The flow of air, through the ventilation means 13, is controlled by means of appropriate electronic control means. In this way, the energy required for the operation of the apparatus can be kept proportional to the daily trend and allow the transfer of energy from the resistors 14a to the sand with only the necessary amount of air. During the night, or in any case when the resistors 14a are not activated, the ventilation means 13 may preferably be deactivated. The air flow can therefore be active during charging and discharging to maintain low electrical current absorption. In view of the above, the invention offers excellent energy density values, close to lithium-ion batteries: with sand storage temperatures of the order of 750°C, the energy density value is about 210 Wh/kg (335 Wh/dmc). This means that in 3 cubic meters it is possible to store 1 thermal MWh, in a structure much cheaper than any other storage system available at the time of filing the present invention.

[0079] The apparatus 1 shows its maximum competitiveness over long charging times and a combined use of thermal and electrical energy in a ratio of one to two, i.e. 1/3 electrical and 2/3 thermal. With reuse times of the stored energy of around six months, i.e., proceeding with the accumulation of energy (charging phase) in the summer, and then returning it in the winter (discharge phase), energy efficiency is decidedly advantageous.

[0080] With shorter reuse times (discharge phase), the apparatus 1 of the invention showed extremely satisfactory efficiencies. The investment costs were estimated to be ten times lower than the costs of a lithium-ion battery system.

[0081] In the tests conducted by the Applicant, the subsequent calculations were carried out on a container 2 as described above and having the following dimensions:

Outer diameter = 11 m
Height = 45 m
Gross volume = 4,274.33 cubic meters

[0082] Subtracting the volume occupied by the reticular structure, a storage volume V for sand of about 3,996 cubic meters is obtained.

[0083] The specific heat of the sand was identified over several operating temperatures:

at 0 °C = 0.17 Kcal/°C kg
at 350 °C = 0.28 Kcal/°C kg
at 700 °C = 0.40 Kcal/°C kg

[0084] Considering that 1 Wh is equal to about 0.860 Kcal, a specific heat value is obtained expressed as follows:

at 0 °C = 0.20 Wh/°C kg
at 350 °C = 0.33 Wh/°C kg

at 700 °C = 0.47 Wh/°C kg

[0085] Considering a sand recharge phase carried out at a temperature between 150°C and 750°C, for the subsequent calculations it was considered prudent to use a specific heat value Cs of the sand equal to 0.35 Wh/°C kg.

[0086] This led to the calculation of the energy density of the sand, which is equal to the specific heat multiplied by the temperature differential of the sand in operation:

T.max = 750 °C
T.min =150 °C
ΔT = 600 °C

[0087] Knowing the density ρ of the sand which is equal to 1,600 kg/mc, it was therefore possible to calculate the energy density D on volume:

$$\text{Energy Density DE} = \Delta T \cdot Cs \cdot \rho = 334{,}940 \text{ Wh/mc} \simeq 335 \text{ kWh/mc}$$

[0088] From the energy density value DE of the sand, equal to about 335 kWh/mc, it is therefore possible to obtain how much volume of sand is necessary to develop 1000 kWh of thermal energy ET at the aforementioned temperature with the following proportion:

$$\text{DE} : 1 \text{ mc} = 1000 \text{ kWh} : \text{ET}$$

$$\text{ET} = 1000 / 335 = 2{,}985 \text{ cubic meters}$$

[0089] The Applicant has therefore come to determine that the apparatus of the invention is capable of realizing 1000 kWh (1 MWh) of thermal energy in about 3 cubic meters of sand on a temperature differential ΔT equal to about 600 °C. To know the amount of energy that all the sand in container 2 can exchange with the airflow inside the silo center pipe (enthalpy ΔH°), the following formula can be used:

$$\Delta H^\circ = \text{ET} \cdot \text{V} = 2.985 \cdot 3.996 = 1.338{,}66 \text{ MWh} \simeq 1.34 \cdot 106 \text{ kWh}$$

[0090] Assuming a silo charging time of 30 days (720 hours), the power to bring the sand to operating temperature is equal to:

$$\text{P} = \Delta H^\circ / \text{no. of hours} = 1.34 \cdot 106 \text{ kWh} / 720 = 1{,}859 \text{ kW}$$

[0091] Finally, assuming a reticular structure consisting of thirty peripheral ducts heated by respective resistances, the absorption of each resistance will be equal to:

$$\text{Single heating element power} = 1{,}859 \text{ kW} / 30 = 62 \text{ kW}$$

[0092] According to the invention, the apparatus 1 can be made in different sizes and heights depending on the thermal energy to be stored. The apparatus 1 can be configured to be transported on trailers or trucks. Generally, the container 2 can be built to have a storage capacity between 1 and 5000 m^3. For domestic applications, a container with a smaller sand storage capacity, for example, of about 9 m^3 may be sufficient to develop 3 MWh. Such apparatus could be made with a square base of 1.5 meters per side with a height of about 4 meters. If more power is needed, the size of the container can be increased or more apparatus can be built together in a modular configuration. The apparatus may have one or more coupling means (not shown) to be lifted from the truck and placed on the ground for installation.

[0093] In practice, it has been ascertained that the invention described achieves the proposed purposes and in particular the fact that the apparatus of the invention and the related process for the production of energy allows to obtain excellent heat exchange efficiencies between the granular material and the air. The apparatus is adaptable and can allow the recovery of abandoned silos or can be built from scratch. The apparatus is configured to operate at high or very high temperatures and is advantageously designed to be integrated with the use of renewable resources to power the electric heaters and ventilation means and to be connected to machines for the transformation of hot air leaving the apparatus into mechanical or electrical energy, such as steam or air machines. The simple construction and mechanics of this apparatus makes it cheaper and more competitive than other solutions on the market.

[0094] The type of structural combinations of the apparatus as well as of the process are potentially infinite and obviously a technician in the field, in order to meet contingent and specific needs, will be able to make numerous modifications and variations to the examples of realization described above, all of which are also contained in the scope of protection of the invention, as defined by the following claims.

Claims

1. Apparatus (1) for the heat exchange between a granular material and a fluid, comprising:

a container (2) having a side wall (3) extending between a lower branch chamber (10) and an upper branch chamber (11) and containing a predetermined quantity of granular material intended to be heated to high or very high temperatures,
a main duct (6) extended axially and substantially centrally within the container (2) between said chambers (10, 11) for the circulation of said fluid from the upper branch chamber (11) to the lower branch chamber (10);
peripheral ducts (7) positioned around the main duct (6) in fluid communicating with the main duct (6) through said chambers (10, 11) for the circulation of said fluid from the lower branch chamber (10) to the upper branch chamber (11),
valve means (12) configured to move between a closed position, in which circulation between the upper branch chamber (11) and the main duct (6) is interrupted, to an open position, in which circulation from the upper branch chamber (11) to the main duct (6) is permitted,
resistance means (14) configured to heat said fluid,
ventilation means (13) configured to control the direction of circulation of said fluid.

2. Apparatus (1) according to claim 1, wherein

said resistance means (14) are positioned inside the lower branch chamber (10) to heat said fluid during its passage through the lower branch chamber (10), said ventilation devices (13) are located inside that lower branch chamber (10), and
said valve means (12) are positioned inside said upper branch chamber (11).

3. Apparatus (1) according to any of the preceding claims, wherein said peripheral ducts (7) are equally distributed vertically along said container (2) and mechanically interconnected to said chambers (10, 11) so as to create a self-supporting structure.

4. Apparatus (1) according to any of the preceding claims, comprising an inlet duct (8) communicating with said main duct (6) for the inlet of said fluid and an outlet duct (9) communicating with said upper branch chamber (11) for the outlet of said fluid.

5. Apparatus (1) according to any of the preceding claims, including control means configured to control the operation of such valve means (12), said ventilation means (13) and such resistance means (14),

where, in a recharging phase, the control means close said valve means (12) and activate said ventilation means (13) and resistance means (14) for a predetermined time,
where, in a discharge phase, the control means open said valve means (12) and activate said ventilation means (13) and resistance means (14) for a predetermined time, and
where, in a mixed modulation phase, the control means activate/deactivate said valve means (12) and resistance means (14), and activate said ventilation means (13).

6. Apparatus (1) according to any of the preceding claims, in which, in said charging phase, the air flow travels, sequentially, through said main duct (6), said lower branch chamber (10), said peripheral ducts (7), said upper branch chamber (11), and so on,

in which, in that discharge phase, the air flow travels, sequentially, through said main duct (6), said lower branch chamber (10), said peripheral ducts (7), said upper branch chamber (11), said outlet duct (9),
and in which, in said mixed modulation phase, the air flow travels, sequentially, through said main duct (6), said lower branch chamber (10), said peripheral ducts (7), said upper branch chamber (11), and in which, from said upper branch chamber (11), part of the flow returns to said main duct (6) and part of the flow goes towards said outlet duct (9).

7. Apparatus (1) according to any of the preceding claims, in which said ventilation means (13) comprise a rotating shaft (13a) on which an impeller (13b) equipped with a plurality of blades (13c) is keyed and rotatable around its own axis of rotation coaxial with the axis of extension of the main duct (6).

8. Apparatus (1) according to any of the preceding claims, comprising a heat exchanger connected to said inlet duct (8) and to said outlet duct (9).

9. Apparatus (1) according to any of the preceding claims, in which said granular material is silica sand.

10. Apparatus (1) according to any of the preceding claims, in which said container (2) has a storage capacity between 1 m^3 and 5000 m^3.

11. Process for the production of energy through the heat exchange between a granular material and a fluid, comprising the steps of:

providing an apparatus (1) according to any of the preceding claims 1-10,
carrying out a charging phase in which
said granular material is heated to high or very high temperatures by said fluid for a predetermined time,
carrying out a discharge phase in which

said fluid is heated by said granular material, and
said heated fluid is sent at high or very high temperatures outside said apparatus.

12. A process according to the previous claim, in which said fluid is sent externally to a heat exchanger.

13. A process according to claim 11 or 12, in which said fluid is sent externally to a steam engine or an air engine.

14. Process according to any of the claims 11 to 13, in which said apparatus (1) has a granular material storage capacity of between 1 m^3 and 5000 m^3.

15. A kit for the production of energy through the heat exchange between a granular material and a fluid, comprising an apparatus (1) according to any of the claims 1 to 9 equipped with coupling means to be transported on trailers or trucks and installed in situ.

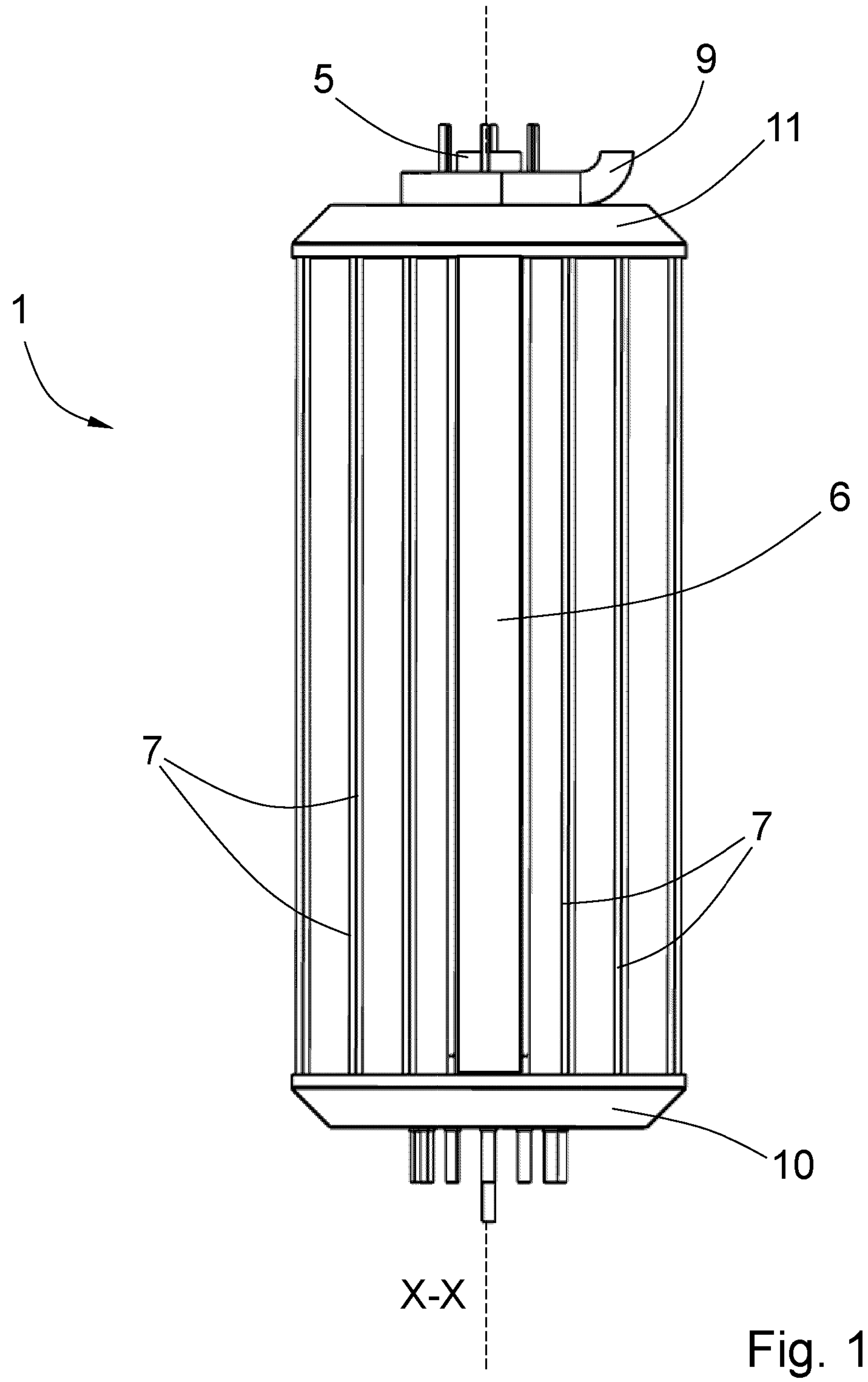


Fig. 1

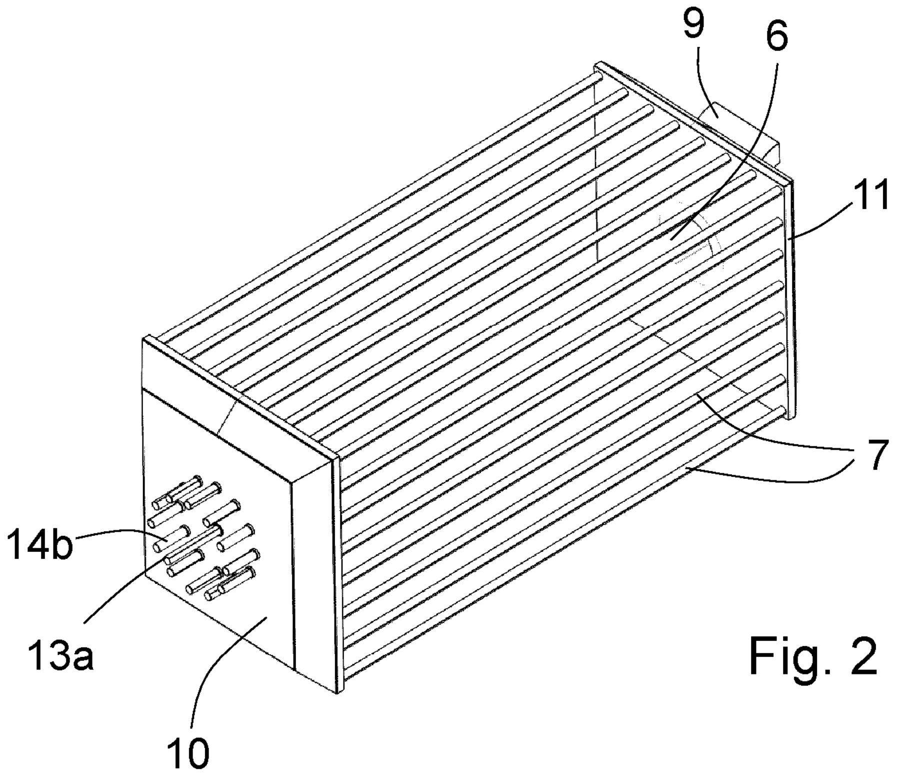


Fig. 2

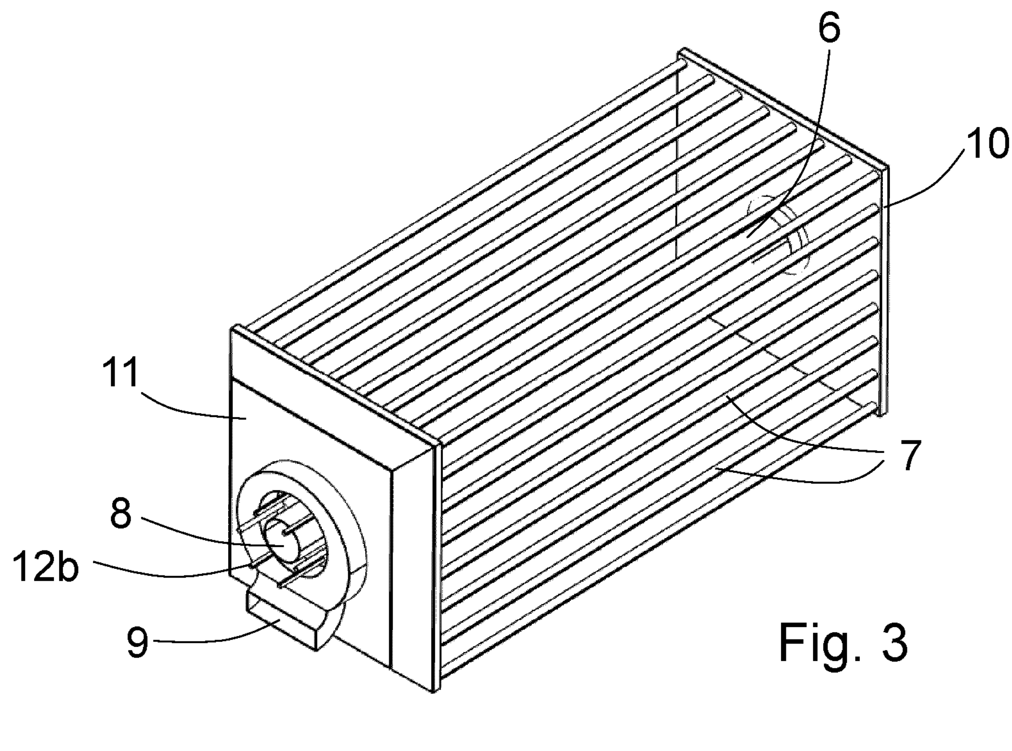


Fig. 3

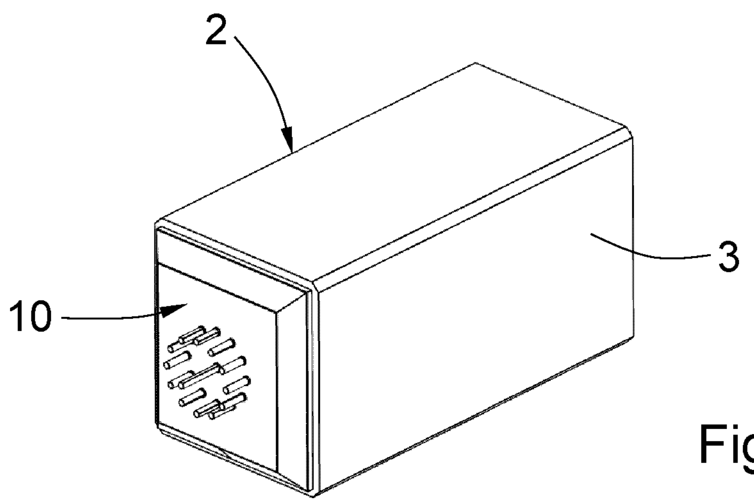


Fig. 4a

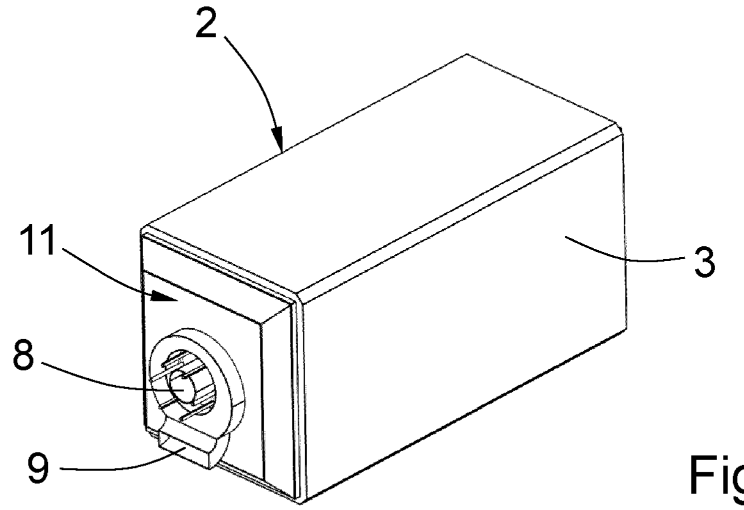


Fig. 4b

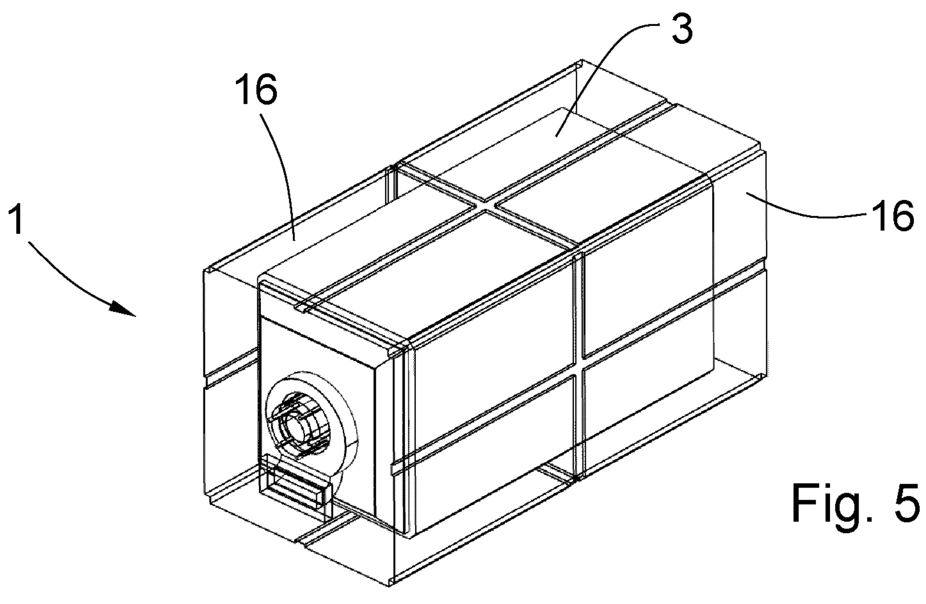


Fig. 5

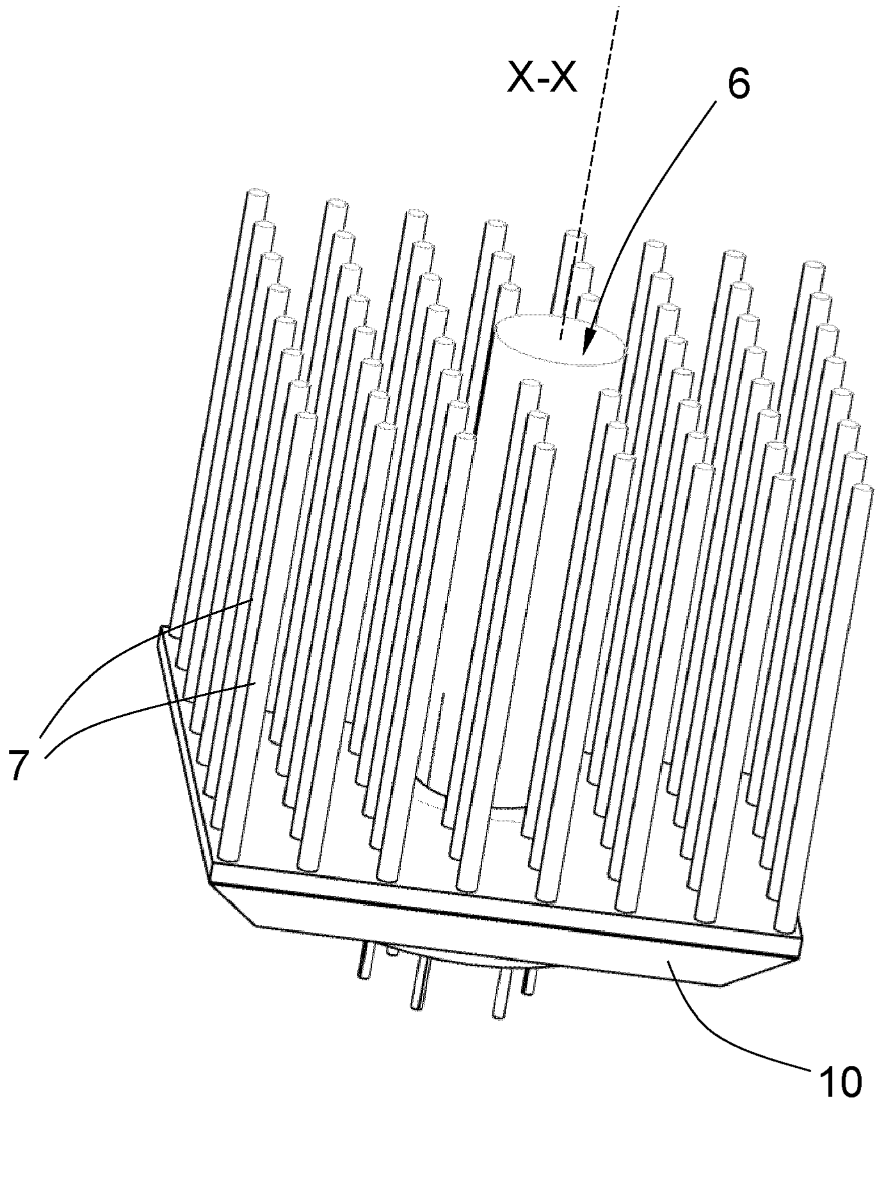
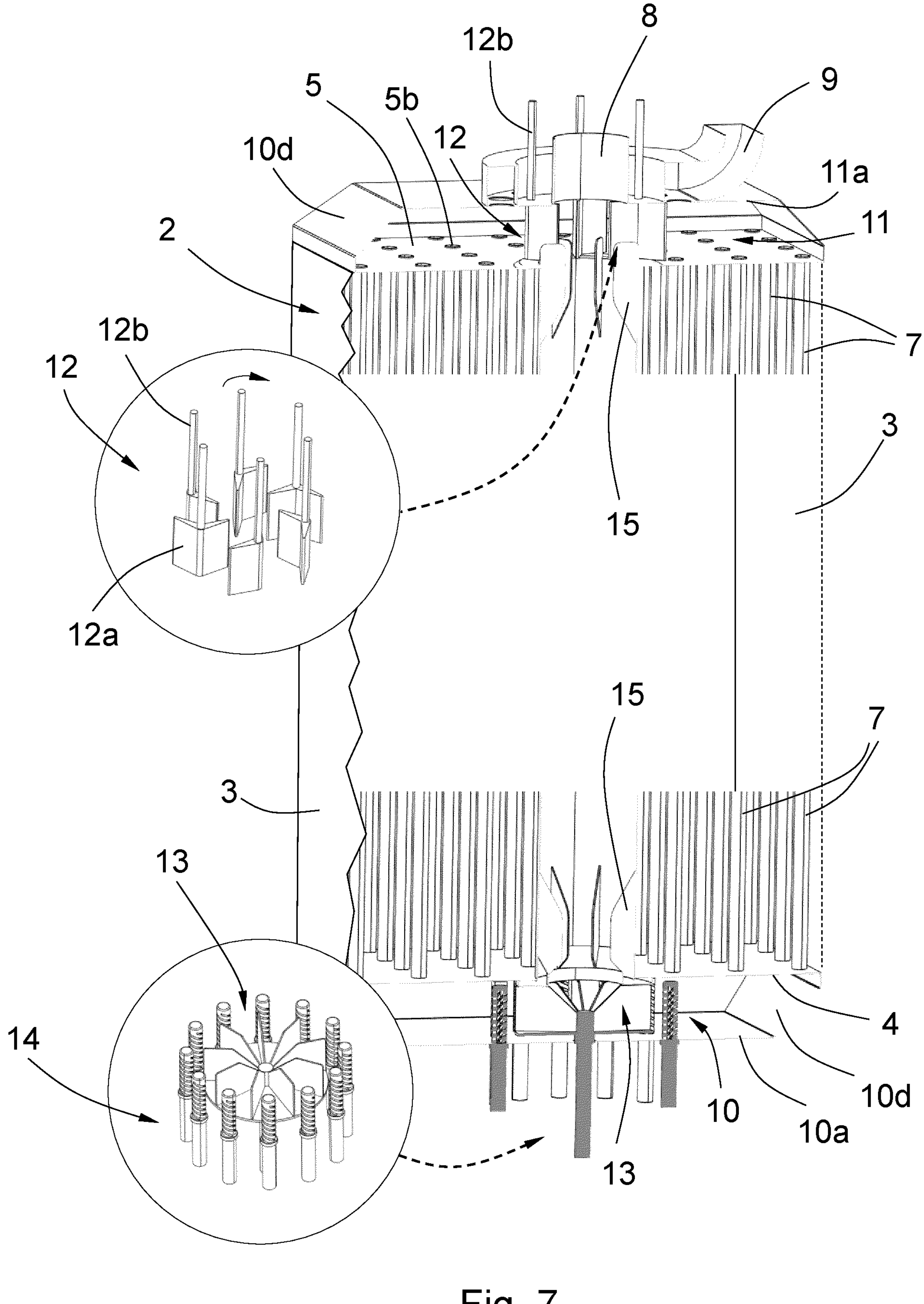


Fig. 6


8
12b
9
5
5b
12
11a
10d
11
2
7
12b
12
3
15
12a
15
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13
14
4
10d
10
10a
13

Fig. 7

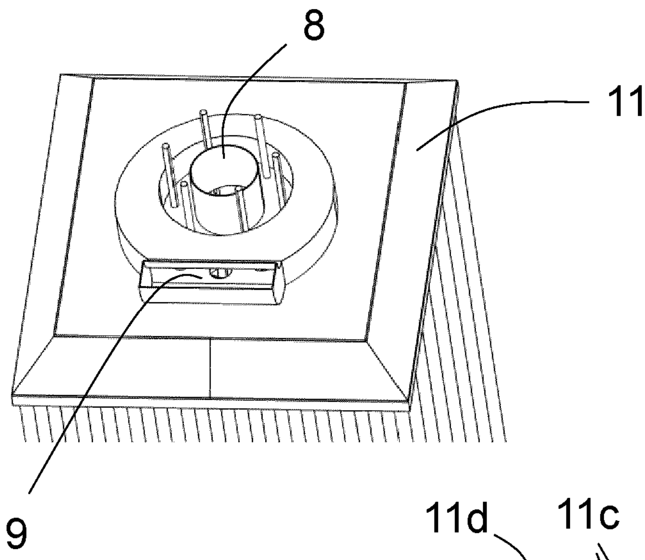
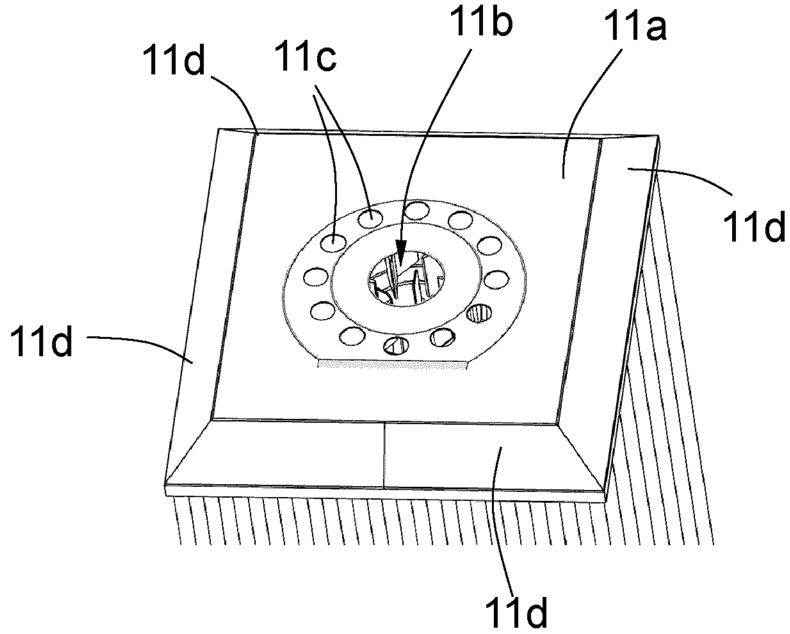


Fig. 8

Fig. 9



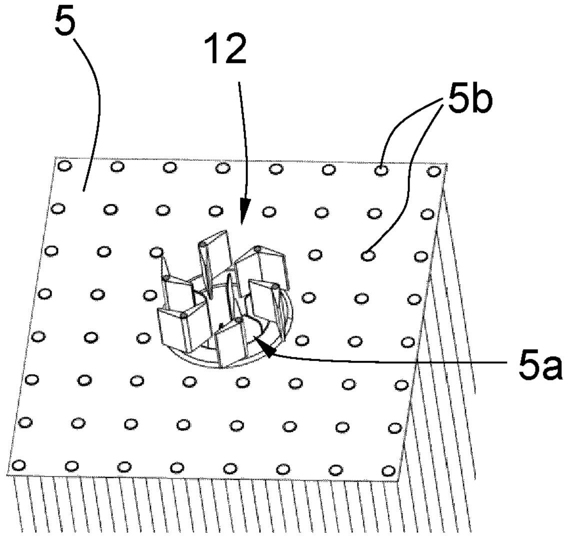


Fig. 10

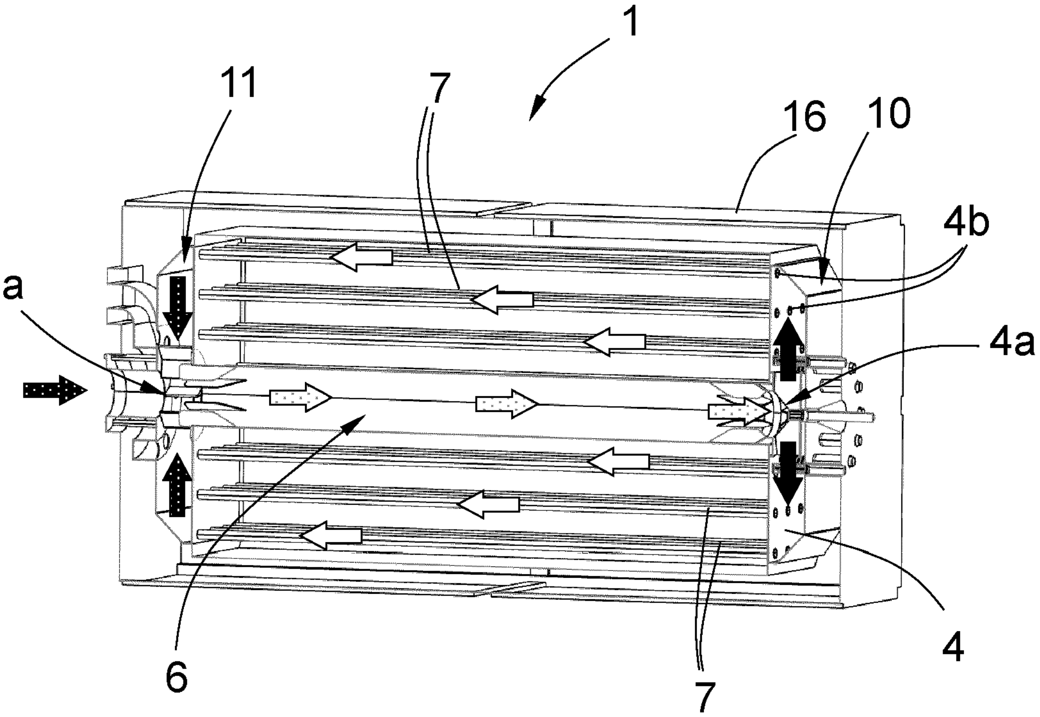


Fig. 11

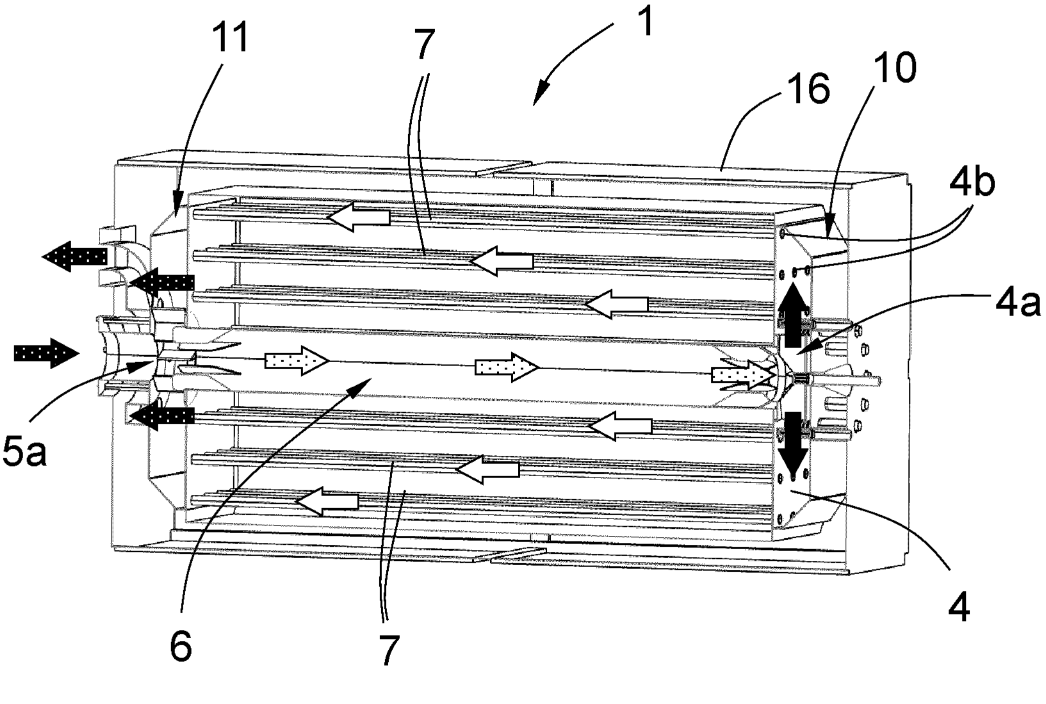


Fig. 12

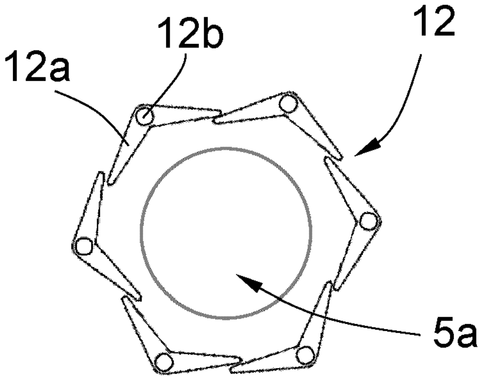


Fig. 13a

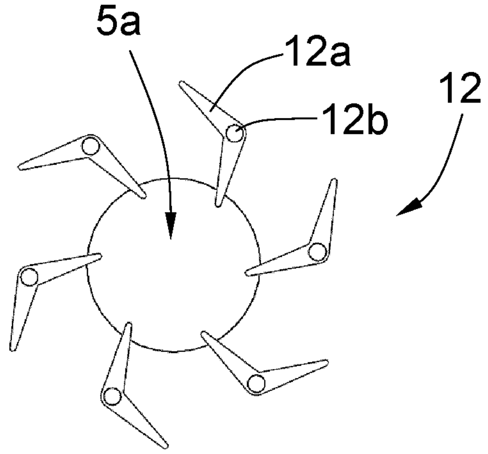


Fig. 13b

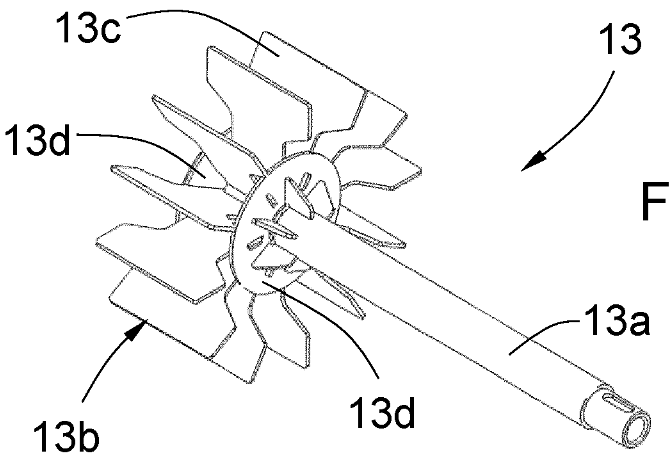


Fig. 14

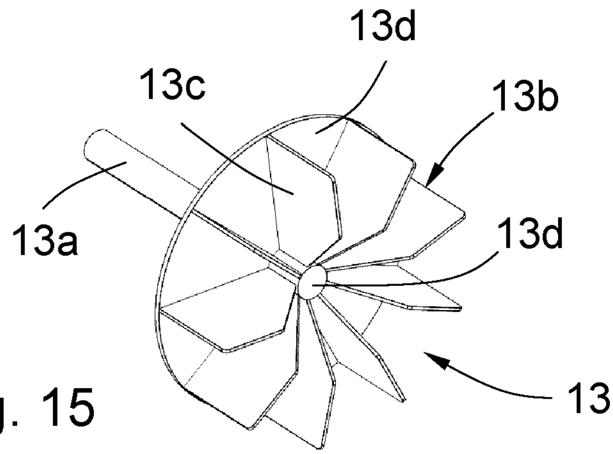


Fig. 15

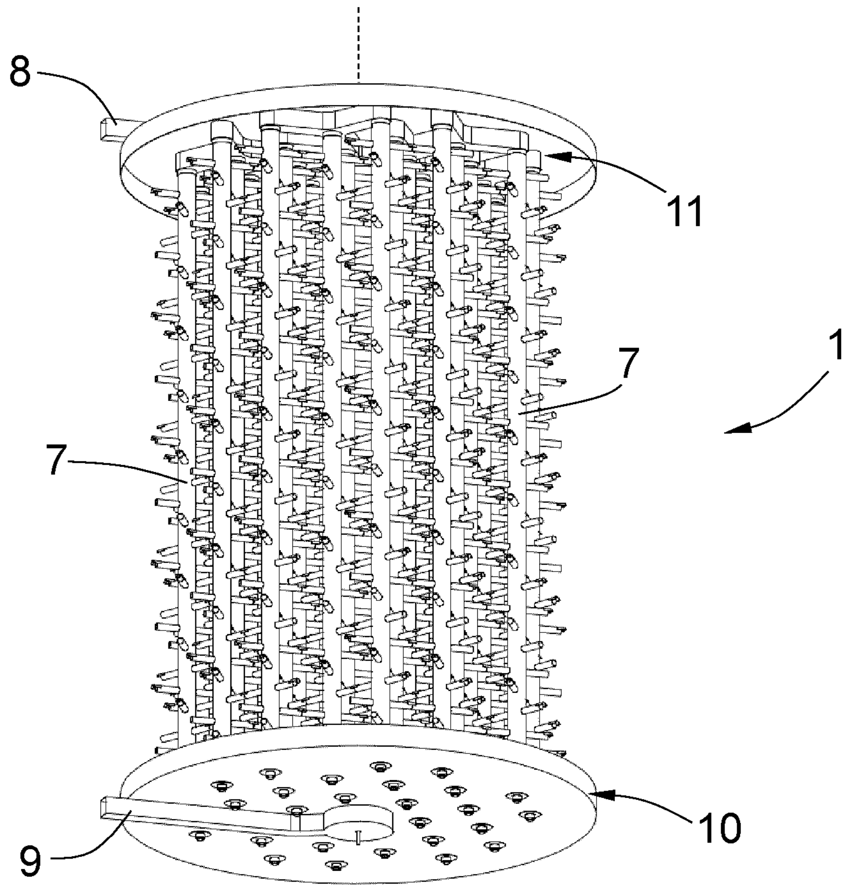


Fig. 16

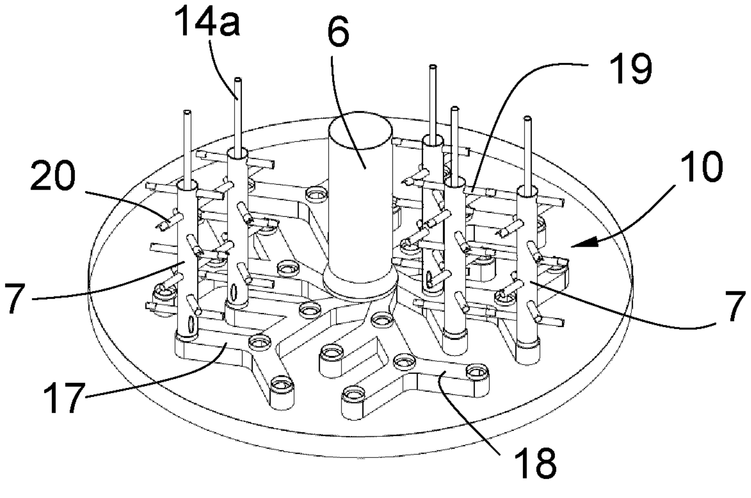


Fig. 17

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EUROPEAN SEARCH REPORT

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	28 February 2025	Martínez Rico, Celia

CATEGORY OF CITED DOCUMENTS

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