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(54) Benævnelse: **INDRETNING, ANLÆG OG FREMGANGSMÅDE TIL LAGRING OG OVERFØRSEL AF TERMISK ENERGI FRA SOLEN**

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DESCRIPTION

Field of the Invention

[0001] The present invention relates to a device, to a plant and to a method for the production of electric energy based upon exploitation of thermal energy of solar origin.

Background of the Invention

[0002] The use of the thermal potential of solar energy, possibly concentrated by heliostats, for the production of electric energy is known in the art. In particular, devices for the storage and transfer of said thermal energy based upon a bed of fluidizable solid particles exposed, directly or indirectly, to solar radiation are disclosed, e.g., in WO2013/150347A1 and WO2017/021832A1 to the same Applicant. These known configurations generally include heat exchangers, e.g. tube bundles, crossed by a working fluid and immersed in the bed of particles, so that steam to activate a turbine can be generated.

[0003] The above technology based upon a fluidizable bed of particles achieves a unique capacity of absorbing intensive and variable solar power fluxes and with intrinsic safety. At the same time, said solutions attain high thermal diffusivity in the storage medium, i.e. the fluidized particles, with operating temperatures higher than those presently achievable by other so-called "Concentrated Solar Power" (CSP) technologies.

[0004] Document US4316048A discloses a device for storage and transfer of thermal energy comprising a containment casing, a heat storage medium inside the casing and thermophotovoltaic cells.

[0005] Still, there is space for improving the efficiency and performance of said systems, particularly in conjunction with the total cost of electric energy production, also in view of the so-called *"grid parity".*

Summary of the Invention

[0006] The technical problem underlying the present invention is therefore to overcome the drawbacks mentioned above with reference to the known art by providing a device for the exploitation of thermal energy of solar origin to produce electric energy.

[0007] The above-mentioned problem is solved by a device according to claim 1 and a method according to claim 13.

[0008] Preferred features of the invention are the object of the dependent claims.

[0009] The invention provides a device for storage and transfer of thermal energy of solar origin based upon a solid storage means consisting of a bed of solid, fluidizable particles. Said bed of particles is thermally coupled to thermophotovoltaic (TPV) cells which produce electric energy.

[0010] The device of the invention allows high production efficiencies, low costs of investment and maintenance and high operational safety. In particular, the device has constructive simplicity, and, according to a preferred configuration, can be positioned on the ground, providing solar irradiation from above. In this latter configuration, irradiation from above can be carried out by reflective optical systems, for instance according to a so-called "beam down" configuration, or by mere positioning a mirror, or an equivalent means, at an altitude, e.g. on natural slopes or on dedicated elevated structures.

[0011] In addition, as said above the present invention employs the high temperature thermal power stored in the fluidizable bed in combination with thermophotovoltaic (TPV) technology, in particular TPV cells, to produce electricity from thermal radiation. In this way, the fluidized bed device collects and stores solar power as sensible heat of the bed solid particles. Such sensible heat, in turn, is converted directly into electricity, thanks to the TPV technology, for virtually round the clock power generation.

[0012] Preferably, the TPV means are exposed to thermal emitters, i.e. the fluidized bed particles, at high temperature, in particular ≥ 600°C and most preferably in a range of about 700-1000 °C.

[0013] The specific positioning and configuration of the TPV means within the fluidized bed device can be embodied in different ways. According to a first preferred configuration, the TPV cells are located immersed in the bed of hot particles, preferably protected by suitable layers, or shields, of high-temperature-resistant material, like ceramic or refractory walls.

[0014] According to a different preferred embodiment, the TPV means are embedded in the wall(s) of a casing housing the particle bed or at a lining layer thereof. In this latter configuration, thermal energy is conveyed to the TPV means by thermal conduction through the casing wall(s) and/or by radiation and/or convection.

[0015] According to a still another preferred configuration, the TPV means can be housed at a freeboard above the particle bed, eventually within a ceiling of the casing hosting such particle bed.

[0016] Compared to the already known technologies based upon storage and transfer of thermal energy of solar origin, the system of the invention is simpler, less expensive and more efficient. In particular, a system for steam generation is no more necessary in order to produce electricity. Accordingly, no heat exchangers immersed in the fluidized bed, steam pipe circuits interconnecting different modules together or steam turbines and associated equipment are necessary, with significant system simplification.

[0017] The above simplification allows building a modular system made of several accumulation and production devices, each based upon one or more fluidized bed of particles and respective TPV means associated therewith.

[0018] In addition, combination systems are also possible, wherein known heat exchangers based upon a working fluid are associated with the fluidized bed, in particular immersed therein, and exploited jointly with the TPV means.

[0019] In all the configurations mentioned above, additional TPV means can be arranged outside the solar receiver, for example on a secondary reflector of a beam-down system or at a preheater of the fluidization fluid or around the casing aperture.

[0020] Moreover, in any of the above configurations, additional power can be produced, during daytime, by a dedicated conventional photovoltaic system directly exposed to the solar radiation.

[0021] In all the above configurations, the energy for the auxiliary components of the system, in particular for the fluidized bed, can be produced, during daytime, by the TPV means.

[0022] The aforementioned polygenerative-type configuration, i.e. a configuration providing possible production of electric energy by associating the device to a turbine as well as by TPV means, allows maximizing efficiency.

[0023] In preferred arrangements, TPV means are used for producing electricity and heat exchangers (e.g. based upon tube bundles crossed by a processing fluid) for producing thermal power.

[0024] The device of the invention can be used both as module of a plant of any size and for so-called "stand-alone" applications, e.g. for desalination operations or to the service of small heat consumptions, to which it can confer high efficiency.

[0025] Other advantages, features and the operation steps of the present invention will be made apparent in the following detailed description of some embodiments thereof, given by way of example and not for limitative purposes.

<u>Brief Description of the Figures</u>

[0026] Reference will be made to the figures of the annexed drawings, wherein:

- Figure 1 shows a schematic representation, in longitudinal cross-section, of a first embodiment of a device for the storage and transfer of thermal energy of solar origin according to the invention, wherein TPV cells are arranged onto a device freeboard ceiling, in particular according to a vertical orientation and radial arrangement;

- Figures 2A and 2B show a schematic representation, according to a perspective view partially in longitudinal cross-section and a full perspective view, respectively, of the device of Figure 1;
- Figure 3 shows a schematic representation, in longitudinal cross-section, of a variant embodiment of a device for the storage and transfer of thermal energy of solar origin according to the invention, wherein TPV cells are arranged onto a device freeboard ceiling, in particular according to a horizontal orientation;
- Figure 4 shows a schematic representation, in longitudinal cross-section, of another embodiment of a device for the storage and transfer of thermal energy of solar origin according to the invention, wherein TPV cells are immersed in a fluidizable bed;
- Figure 5 shows a schematic representation, in longitudinal cross-section, of a further embodiment of a device for the storage and transfer of thermal energy of solar origin according to the invention, wherein TPV cells are arranged in a refractory lining of a casing housing a fluidizable bed.

Detailed Description of Preferred Embodiments of the Invention

[0027] Referring initially to Figures 1, 2A and 2B, a device according to a first preferred embodiment of the invention is globally denoted by 100. Device 100 is configured for storage and transfer of thermal energy associated with an incident solar radiation.

[0028] Device 100 comprises mainly a containment casing 102 and a bed of fluidizable solid particles, denoted by 103 and received inside casing 102.

[0029] In the present example, casing 102 has a substantially cylindrical geometry.

[0030] The containment casing 102 is thermally insulated so as to reduce to a minimum the dispersion of heat into the external environment, and is preferably made of metal.

[0031] Casing 102 may be totally closed with respect to the outside, in which case solar thermal energy is transmitted to bed of particles 103 by conduction through the casings walls. In an alternative configuration shown in the Figures, casing 102 may provide for one or more openings 250 allowing direct penetration of the solar radiation at its inside, so that the solid particles are irradiated directly from said radiation, without any shielding means interposed therebetween.

[0032] Device 100 also includes fluidization means 105 configured for inputting a fluidization gas, preferably air, into said bed 103 of fluidizable solid particles.

[0033] The fluidization gas is fed within the casing 102 to the bed 103 by feeding inlets 150 of air box type, known *per se* and schematically represented in the figures.

[0034] Preferably, at such inlets 150 it is provided a distribution means of the fluidization gas, apt to enable a uniform entry of the fluid and concomitantly ensure a support for the bed 103, contributing to realize the bottom of casing 102.

[0035] Bed of particles 103 is configured to be selectively moved by said fluidization gas for storing thermal energy received from the solar radiation. The fluidization of the bed of particles 103 ensures an effective and uniform heat exchange.

[0036] In variant embodiments, bed 103 can include several portions, eventually fluidizable one independently from the other.

[0037] Preferably, means for selectively varying the fluidization gas speed and/or flow rate are also provided. In this way, adjusting the extent of heat exchange and transfer is possible. In particular, by changing the speed of the fluidization gas across the particle bed 103 it is possible to control and modify the overall thermal exchange coefficient between the fluidized bed and the exchange surface, with consequent flexibility in the adjustment of the amount of thermal power transferred.

[0038] The choice of material for the particles of bed 103 privileges poor aptitude for abrasion and fragmentation, in response to the need to minimize the phenomenon of bed particles elutration so as to limit the production and transportation of fines in the fluidization air, particularly for those configurations providing for an "open" casing 102. Based on these considerations, a preferred configuration favors the use, for bed particles, of granular material inert to oxidation, like, e.g., silicon carbide or quartz. Preferably, the particles have a regular shape, preferably spherical. Preferably, the particles have a size of the order of 50 to 500 microns (greater dimension or diameter), and such that said size is preferably native, that is not resulting from the aggregation of smaller particles.

[0039] According to the invention, device 100 comprises a plurality of thermophotovoltaic (TPV) cells, each denoted by 104 and configured to transform thermal energy of said fluidizable solid particles into electric energy.

[0040] In the present embodiment, said TPV cells are arranged at a freeboard ceiling 110 of casing 102. In particular, TPV cells 104 are arranged in groups, each group being mounted upon a common support 140. In this way, thermophotovoltaic modules are obtained, each formed by a support 140 and by the associated TPV cells 104. In the example considered, each support 140 is fixed at a terminal portion thereof at ceiling 110 and projects inside casing 102. In this configuration, the TPV cells may be in contact with, or lapped by, the particles of bed 103.

[0041] Preferably, each support 140 extends according to a main development direction, in particular a longitudinal direction L in the present example, which, still according to the embodiment represented, is a substantially vertical direction.

[0042] As mentioned above, the overall configuration is such that thermal energy is transferred from the solar radiation to the particles of bed 103 and from said fluidizable solid particles to the TPV cells 104. In alternative configurations, solar radiation can also impinge directly upon the TPV cells or a subgroup thereof.

[0043] Device 100 may also include heat exchanging means 106, preferably one or more pipe bundles, crossed, in use, by a working fluid, and arranged within said casing 102 so as to be immersed in, or lapped by, said bed 103 of fluidizable solid particles.

[0044] Typically, the pipe bundles 106 are part of a heat exchanging circuit suitable for producing steam to be expanded in a turbine or for other thermal industrial uses, such as desalination. In particular, as said above, the working fluid is preferably water in a liquid state which receives thermal energy to become superheated steam. Said superheated steam, in pre-determined and selected conditions of temperature and pressure, may be then utilized to produce electric energy by expanding in the turbine associated with an electric energy generator.

[0045] Device 100 may also comprise additional TPV cells or modules 114 directly exposed to solar radiation.

[0046] Such additional TPV cells or modules 114 can be arranged outside casing 102, where high temperature areas are present, like around the casing aperture or on a reflector of solar radiation and/or at a fluidization gas preheater.

[0047] Figures 3 to 5 refer to further preferred embodiments of the device of the invention, which differ from the first embodiment described above only for the position of the TPV cells. Accordingly, such additional embodiments will be described only in conjunction with such difference and the same numerals already introduced will generally be used to denote the same, corresponding or similar parts.

[0048] In the device of Figure 3, globally denoted by 200, the TPV cells 104 of said plurality are associated with supports 140 analogous to the ones already introduced. In this case, supports 140 are arranged with a main development direction, in particular a transverse direction T, which, still according to the embodiment represented, is a substantially horizontal direction.

[0049] In the device of Figure 4, globally denoted by 300, the TPV cells 104 of said plurality are immersed, at least in part, within said bed 103 of fluidizable solid particles.

[0050] In the device of Figure 5, globally denoted by 400, the TPV cells 104 of said plurality are housed, at least in part, inside a refractory lining 402 of said casing 102, preferably at a lateral skirt thereof.

[0051] The device described above according to several embodiments and variants of the invention can be of a standalone type or be configured as part of an electric energy production plant, comprising one or more of such devices. In a preferred embodiment, the plant has a so-called "beam down" configuration, wherein said devices are irradiated from above by solar radiation.

[0052] The plant may include solar radiation captation means, in particular one or more heliostats and/or one or more reflectors.

[0053] Production of electric energy from the solar radiation by means of said device and/or plant provides exposing bed 103 of fluidizable solid particles, directly or indirectly, to the solar radiation so as to store thermal energy. The energy production method provides usage of said plurality of thermophotovoltaic cells 104, arranged immersed in said bed 103 or in the proximity thereof. As said above, the overall arrangement is such that thermal energy is transferred from the solar radiation to the fluidizable solid particles of said bed 103 and from said fluidizable solid particles to said thermophotovoltaic cells 104, the latter transforming thermal energy of said fluidizable solid particles into electric energy.

[0054] In said method, a step of storing thermal energy received from the solar radiation by said bed 103 and a step of transferring the thermal energy stored in said storing step to said thermophotovoltaic cells 104 can be activated one independently from the other. In particular, the storage step can be activated in daytime, and the transfer step in the daytime and/or nighttime.

[0055] The present invention has been hereto described with reference to preferred embodiments thereof. It is understood that other embodiments might exist, all falling within the scope of the same invention, as defined by the subject-matter of the claims hereinafter.

REFERENCES CITED IN THE DESCRIPTION

Cited references

Patent documents cited in the description

- WO2013150347A1 [0002]
- WO2017021832A1 [0002]
- US4316048A [0004]

Patentkrav

1. Indretning (100; 200; 300; 400) til lagring og overførsel af termisk energi associeret med en indfaldende solindstråling, hvilken indretning (1) omfatter:

▪ et indeslutningshus (102);

▪ et bed (103) af fluidiserbare faste partikler modtaget inden i nævnte hus (102);

▪ fluidiseringsorgan (105) konfigureret til at tilføre en fluidiseringsgas, fortrinsvis luft, til nævnte bed (103) af fluidiserbare faste partikler;

▪ en flerhed af termofotovoltaiske celler (104) indrettet ved eller inden i nævnte hus (102) og konfigureret til at omdanne termisk energi af nævnte fluidiserbare faste partikler til elektrisk energi,

idet den samlede konfiguration er således, at termisk energi overføres fra solindstrålingen til de fluidiserbare faste partikler af nævnte bed (103) og fra nævnte fluidiserbare faste partikler til nævnte termofotovoltaiske celler (104).

2. Indretningen (100; 200) ifølge krav 1, hvor de termofotovoltaiske celler (104) af nævnte flerhed er placeret, mindst delvist, ved et fribordsloft (110) af nævnte hus (102).

3. Indretningen (400) ifølge krav 1 eller 2, hvor de termofotovoltaiske celler (104) af nævnte flerhed er placeret, mindst delvist, inden i en ildfast foring (402) af nævnte hus (102), fortrinsvis ved et lateralt skørt af nævnte hus (102).

4. Indretningen (300) ifølge et hvilket som helst af de foregående krav, hvor de termofotovoltaiske celler (104) af nævnte flerhed er nedsænket, mindst delvist, i nævnte bed (103) af fluidiserbare faste partikler.

5. Indretningen (100; 200; 300; 400) ifølge et hvilket som helst af de foregående krav, hvor de termofotovoltaiske celler (104) af nævnte flerhed er indrettet i grupper, idet hver gruppe deler en fælles støtte (140), og hvor hver støtte strækker sig i overensstemmelse med en hovedudviklingsretning, idet sidstnævnte er en i alt væsentligt vertikal eller 25 i alt væsentligt horisontal retning.

6. Indretningen (100; 200; 300; 400) ifølge et hvilket som helst af de foregående krav, omfattende organ til selektiv variation af hastigheden og/eller flowraten af fluidiseringsgassen.

7. Indretningen (100; 200; 300; 400) ifølge et hvilket som helst af de foregående krav, omfattende yderligere varmeudvekslingsorganer (106), fortrinsvis et eller flere rørbundter, som under brug krydses af et arbejdsfluid, og som indrettet inden i nævnte hus (102) for at blive nedsænket i, eller indesluttet i, nævnte bed (103) af fluidiserbare faste partikler.

8. Indretningen (100; 200; 300; 400) ifølge et hvilket som helst af de foregående krav, hvor nævnte hus (102) har en bestrålingsåbning (250) konfigureret til at tillade indgang af solindstrålingen, hvilken åbning (250) bringer et indvendigt kammer af nævnte hus (102) i direkte forbindelse med de udvendige omgivelser, idet åbningen under brug er uden lukke- eller afskærmningsorganer, idet nævnte åbning (250) fortrinsvis er indrettet ved en øvre væg af nævnte hus (102), således at nævnte bed af fluidiserbare faste partikler (103), eller en del deraf, under brug er direkte eksponeret for solindstrålingen, som kommer ind gennem nævnte åbning (250).

9. Indretningen (100; 200; 300; 400) ifølge det foregående krav, hvor nævnte termofotovoltaiske celler (104), eller en del deraf, er direkte eksponeret for solindstrålingen.

10. Elektrisk energigenereringsanlæg, omfattende en eller flere indretninger (100; 200; 300; 400) ifølge et hvilket som helst af de foregående krav og solindstrålingsindfangningsorgan, som sammen med nævnte indretning(er) definerer en bestrålingskonfiguration, som lader solindstråling konvergere ovenfra.

11. Det elektriske energigenereringsanlæg ifølge det foregående krav, som inkluderer en "beam down-" konfiguration, hvor nævnte ene eller flere indretninger (100; 200; 300; 400) bestråles ovenfra af solindstråling.

12. Det elektriske energigenereringsanlæg ifølge krav 10 eller 11, som er konfigureret til at tilvejebringe elektrisk energi opnået direkte fra de termofotovoltaiske celler (104) af nævnte flerhed og fra yderligere fotovoltaiske celler (114), som er direkte eksponeret for solindstråling.

13. Fremgangsmåde til genereringen af elektrisk energi fra solindstrålingen, hvilken fremgangsmåde tilvejebringer eksponering af et bed (103) af fluidiserbare faste partikler, direkte eller indirekte, for solindstrålingen for at lagre termisk energi og for at tilvejebringe en flerhed af termofotovoltaiske celler (104) indrettet nedsænket i nævnte bed (103) af fluidiserbare faste partikler eller i nærheden deraf, idet den samlede anordning er således, at termisk energi overføres fra solindstrålingen til de fluidiserbare faste partikler af nævnte bed (103) og fra nævnte fluidiserbare faste partikler til nævnte termofotovoltaiske celler (104), idet sidstnævnte omdanner termisk energi af nævnte fluidiserbare faste partikler til elektrisk energi, hvor de faste partikler af nævnte bed (103) fluidiseres ifølge et fluidiseringstrin, som kan aktiveres under udvalgte driftsbetingelser.

14. Fremgangsmåden ifølge det foregående krav, som tilvejebringer et trin til lagring af termisk energi modtaget fra solindstrålingen af nævnte bed (103) af fluidiserbare faste partikler og et trin til overførsel af den termiske energi lagret i nævnte lagringstrin til nævnte termofotovoltaiske celler (104), hvor nævnte lagringstrin og nævnte overførselstrin aktiveres uafhængigt af hinanden, fortrinsvis aktiveres den første om dagen og den anden om dagen og/eller om natten.

15. Fremgangsmåden ifølge krav 13 eller 14, som tilvejebringer en selektiv tilpasning af hastigheden og/eller flowraten af fluidiseringsgassen.

16. Fremgangsmåden ifølge et hvilket som helst af kravene 13 til 15, som anvender en indretning eller et anlæg ifølge et hvilket som helst af kravene 1 til 12.

DRAWINGS

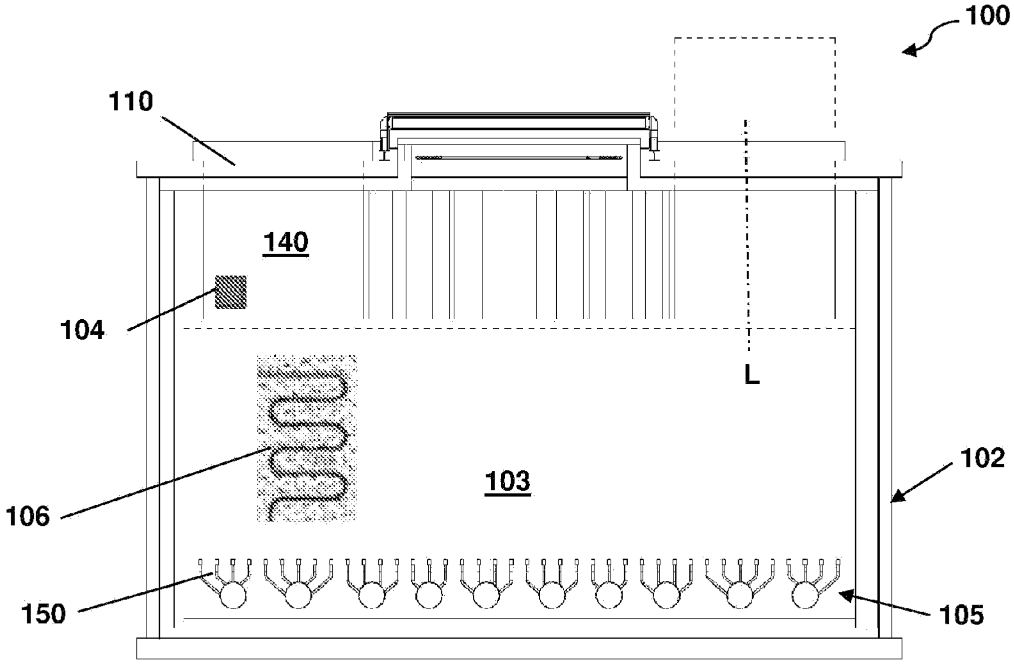

FIG. 1

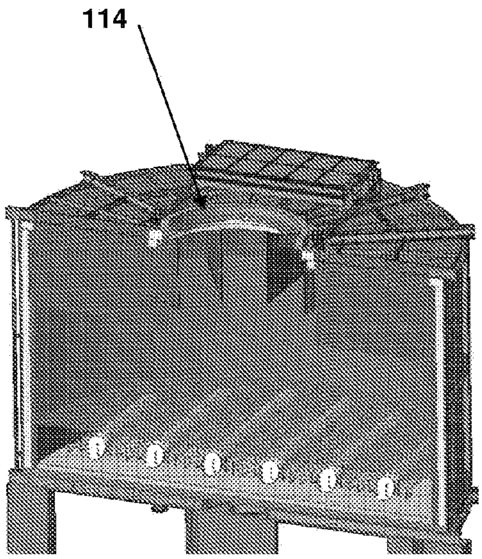

FIG. 2A

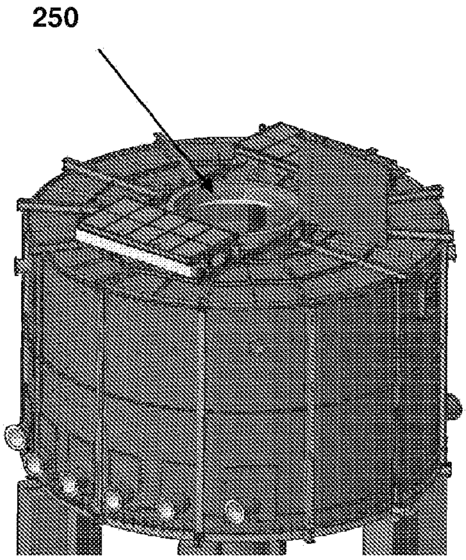

FIG. 2B

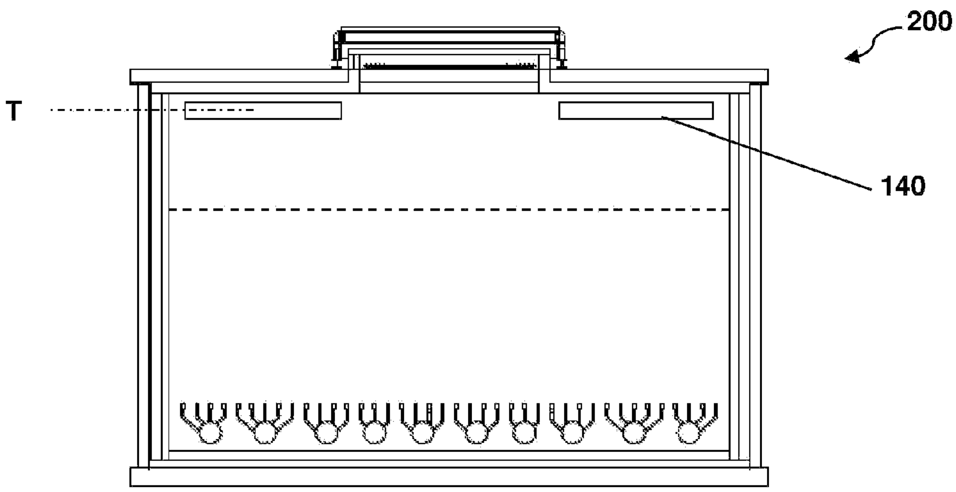

FIG. 3

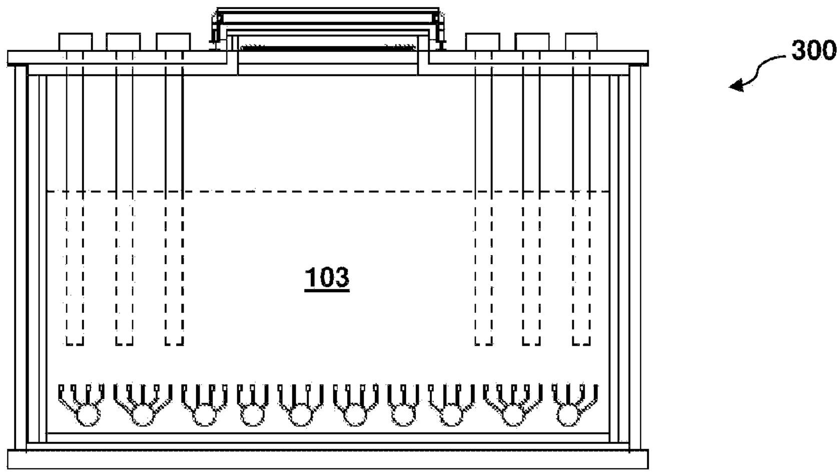

FIG. 4

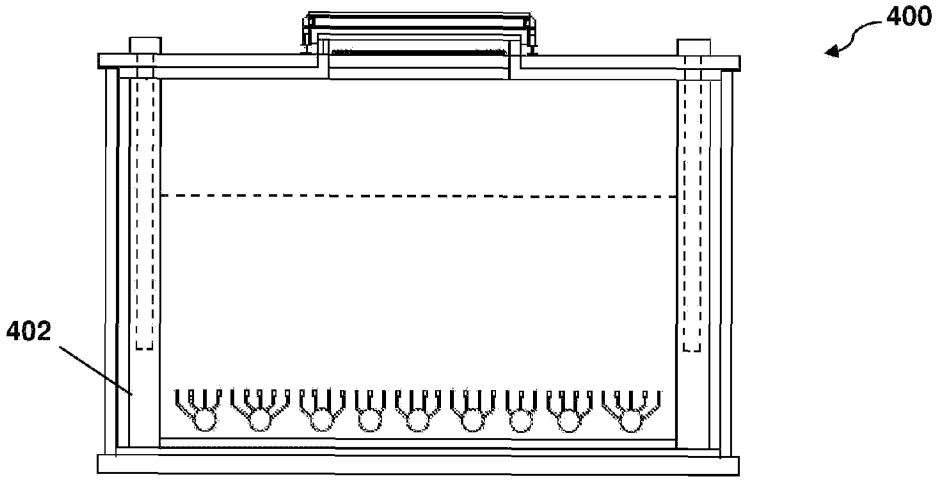

FIG. 5