(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 March 2011 (17.03.2011)

PCT

(10) International Publication Number
WO 2011/032111 A2

(51) International Patent Classification:
F03G 6/00 (2006.01) *F24J 2/24* (2006.01)
F24J 2/04 (2006.01) *F24J 2/34* (2006.01)

(21) International Application Number:
PCT/US2010/048677

(22) International Filing Date:
13 September 2010 (13.09.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/241,909 13 September 2009 (13.09.2009) US

(71) Applicant *(for all designated States except US)*: **US SOLAR HOLDINGS LLC** [US/US]; 1015 W. Hays Street, Boise, ID 83702 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **JETER, Sheldon, M.** [US/US]; 255 Brighton Road, Atlanta, GA 30309 (US). **STEPHENS, Jacob, H.** [US/US]; 1015 W. Hays Street, Boise, ID 83702 (US).

(74) Agent: **LANE, Eric, L.**; Luce, Forward, Hamilton & Scripps LLP, 600 West Broadway, Suite 2600, San Diego, CA 92101 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

WO 2011/032111 A2

(54) **Title**: SYSTEMS AND METHODS OF THERMAL ENERGY STORAGE AND RELEASE

(57) **Abstract**: Systems and methods of energy storage and release comprise at least one storage vessel and a combined conveyor and heat transfer device linked to the at least one storage vessel by at least one discharge device. The combined conveyor and heat transfer device includes a rotatable conveyor drum and at least one heat transfer fluid conduit within the rotatable conveyor drum. A granular material travels from the at least one storage vessel to the combined conveyor and heat transfer device via the at least one discharge device, and the rotatable conveyor drum moves the granular material therethrough in counterflow to a flow of heat transfer fluid traveling through the heat transfer fluid conduit.

SYSTEMS AND METHODS OF THERMAL ENERGY STORAGE AND RELEASE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application Serial No. 61/241,909, filed September 13, 2009, which is incorporated by reference herein in its entirety.

FIELD

[0002] The present disclosure is in the technical field of Thermal Energy Storage (TES).

BACKGROUND

[0003] In concentrated solar power (CSP) or similar energy systems, heat transfer fluid (HTF) is used to convey energy from the heat source to and/or from the energy conversion or use system. In CSP systems, the heat source is an array of concentrating solar collectors, and the energy conversion system is typically a heat engine such as a steam cycle or organic Rankine cycle. In CSP systems in particular, the functionality and, potentially, the economic worth of the system is enhanced by (TES). The benefit of TES comes from extending the operating time of the energy conversion system or shifting the time of energy production to a more favorable time when energy is more valuable.

[0004] Various TES technologies have been developed, particularly for CSP applications, including the two-tank TES system and the single-tank thermocline, both of which have direct and indirect variations (referring to whether the HTF and thermal storage medium are the same or are segregated and interfaced through a heat exchanger). Each of these technologies has pros and cons related to system cost effectiveness, commercial history, and operational attributes. For example, a two-tank system using HTF with high vapor pressure requires plants at high temperature HTFs requires costly pressurized storage tanks. Systems with molten salt varieties as a HTF and/or thermal storage media require specialized tanks and heat exchanger designs. The single-tank thermocline can be a cheaper option due to reduced capital costs, yet must consider the same issues with the type of HTF used. In general, current TES technologies require heat transfer fluids and thermal storage mediums with significant cost and design implications.

[0005] Thus, there is a need for thermal energy storage systems and methods that can effectively use inexpensive materials as a storage medium and are compatible with a variety of heat transfer fluids.

SUMMARY

[0006] Embodiments of the present disclosure provide alternatives to, and alleviate many of the disadvantages of TES systems by providing thermal energy storage devices, systems and methods which utilize granular materials as a thermal energy storage medium that is compatible with a variety of HTFs. Exemplary embodiments include a heat exchanger that is comprised of an Archimedes screw conveyor design to transport sand over an internal HTF tube bundle, which contains heat transfer fluid used to store and remove heat from the sand. Embodiments of the present disclosure effectively use sand, a relatively inexpensive and environmentally benign material, as a thermal storage medium while also providing heat transfer and heat exchange capabilities. Alternative granular materials would include other high temperature tolerant particles.

[0007] Advantages of the disclosed systems and methods include, but are not limited to: (1) use of sand or other inexpensive and inert granular material as the storage medium, which is environmentally benign, inexpensive, non-volatile, acceptable in thermal properties, (2) delivery of a constant temperature heat from the silos since a constant temperature will be maintained in the bins irrespective of current sand volume, (3) compatibility with a variety of HTF fluids, as the design is working-fluid independent, (4) achievement of high "round trip thermal efficiency" since energy loss is minimal, and (5) applicability to other CSP technology and other thermal systems.

[0008] In exemplary embodiments a system of energy storage and release comprises at least one storage vessel and a combined conveyor and heat transfer device linked to the at least one storage vessel by at least one discharge device. The combined conveyor and heat transfer device includes a rotatable conveyor drum and at least one heat transfer fluid conduit within the rotatable conveyor drum. A granular material travels from the at least one storage vessel to the combined conveyor and heat transfer device via the at least one discharge device. The rotatable conveyor drum moves the granular material therethrough in counterflow to a flow of heat transfer fluid traveling through the heat transfer fluid conduit. In exemplary embodiments the granular material is sand.

[0009] In exemplary embodiments, the rotatable conveyor drum may be an Archimedes screw and may comprise one or more vanes fixed to an inner surface of the drum. The one or more vanes may be spiral shaped, longitudinally straight, substantially T-shaped or substantially V-shaped in cross-section to distribute the granular material over the heat transfer fluid conduits. The at least one heat transfer fluid conduit may comprise a plurality of tubes arranged in a bundle. In exemplary embodiments, when the rotatable conveyor drum rotates the granular material pours over the at least one heat transfer fluid conduit such that heat exchange occurs between the granular material and the heat transfer fluid. The one or more vanes may pick up and rain the granular material over the at least one heat transfer fluid conduit.

[0010] In exemplary embodiments, the at least one storage vessel comprises a first and second storage vessel, and the first storage vessel has a higher temperature than the second storage vessel. The at least one storage vessel may be located above or below ground level and may have at least one angled wall. In exemplary embodiments, the stored energy is heat gathered by, or discharged to, a concentrating solar thermal power plant.

[0011] Exemplary embodiments include methods of storing thermal energy. Exemplary methods comprise providing a granular material and a heat transfer fluid. The heat transfer fluid has a temperature relatively higher than a temperature of the granular material. The granular material and the heat transfer fluid are conveyed such that the granular material continually pours over a tube carrying the heat transfer fluid such that heat exchange occurs between the granular material and the heat transfer fluid. A set of vanes may direct the pouring of the conveyed granular material, and the granular material may be sand. The granular material may travel in overall counterflow to a flow of heat transfer fluid or in overall cocurrent flow to the flow of heat transfer fluid.

[0012] Exemplary methods may further include methods of releasing stored thermal energy comprising providing a granular material and a heat transfer fluid. The granular material has a temperature relatively higher than a temperature of the heat transfer fluid. The granular material and the heat transfer fluid are conveyed such that the granular material pours over a tube carrying the heat transfer fluid such that heat exchange occurs between the granular material and the heat transfer fluid.

[0013] In exemplary embodiments, a combined conveyor and heat transfer device comprises a rotatable conveyor drum and at least one heat transfer fluid conduit within the rotatable conveyor drum. The rotatable conveyor drum moves a granular material therethrough in counterflow to a flow of heat transfer fluid traveling through the heat transfer fluid conduit. The rotatable conveyor drum may be an Archimedes screw. When the rotatable conveyor drum rotates, the granular material pours over the at least one heat transfer fluid conduit such that heat exchange occurs between the granular material and the heat transfer fluid. The rotatable conveyor drum may be capable of rotating at one or more speeds.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. 1 is a perspective view of an embodiment of the present disclosure, showing a thermal energy storage and release system with above ground storage vessels containing sand thermal storage medium;

[0015] FIG. 2 is a front view of an embodiment of a rotatable conveyor drum containing the heat transfer tube bundle in accordance with the present disclosure;

[0016] FIG. 3A is a side view of an embodiment of a rotatable conveyor drum containing an embodiment of a heat transfer tube bundle in accordance with the present disclosure;

[0017] FIG. 3B is a side view of an embodiment of a rotatable conveyor drum containing an embodiment of a heat transfer tube bundle in accordance with the present disclosure;

[0018] FIG. 4 is a top view of an embodiment of a supply and return piping arrangement for a heat transfer tube bundle in accordance with the present disclosure;

[0019] FIG. 5 is a perspective view of an embodiment of a thermal energy storage and release system with in-ground storage vessels containing sand thermal storage medium in accordance with the present disclosure;

[0020] FIG. 6 is a side view of an embodiment of a thermal energy storage and releasesystem with in-ground storage vessels during the thermal energy storage charging process in accordance with the present disclosure;

[0021] FIG. 7 is a side view of an embodiment of a thermal energy storage and release system with in-ground storage vessels during the thermal energy discharge process in accordance with the present disclosure; and

[0022] FIG. 8 is a side view of an embodiment of a storage vessel of a thermal energy storage and release system in accordance with the present disclosure.

DETAILED DESCRIPTION OF THE INVENTION

[0023] Referring now to the invention in more detail, FIG. 1 depicts an exemplary embodiment of a thermal energy storage system (sometimes referred to herein as “sand-shifter”) that uses a very inexpensive and benign storage medium: sand or similar granular material. Exemplary embodiments of a sand-shifter thermal energy storage system consist of a higher temperature above ground vessel 2 as well as a lower temperature above-ground storage vessel 3, each filled with sand to function as the thermal energy storage medium. The lower temperature above ground storage vessel 3 contains only moderately warm sand that is available to be heated and store energy, and the higher temperature above ground storage vessel 2 contains hot sand after it has been heated to store energy.

[0024] As shown in FIGS. 1-3B, a system of energy storage and release 30 includes a combined conveyor and heat transfer device 40 comprising a conveyor 1, which may be an Archimedes screw conveyor and heat transfer fluid inner heat transfer tube bundle 8. In exemplary embodiments, the sand or similar granular material is moved by the conveyor in a direction 35 roughly in counterflow to the flow 38 of the heat transfer fluid 28, but cocurrent flow may also be employed. The HTF 28 will be circulated through a heat transfer tube bundle to contact the sand within the conveyor 1. The heat transfer tube bundle 8 may be one of various designs including a tube bundle of pipes, bare tubes, finned tubes, and/or plate heat exchangers; where the design consists of the basic concept of effectively transporting heat transfer fluid through the conveyor 1 to come into contact with the sand thermal energy storage medium. FIG. 1 provides an illustration of how the HTF heat transfer tube bundle 8 may be configured within the conveyor 1, which will pour sand or similar granular material 15 over the HTF 28 to adsorb or give up heat depending on whether the sand is being heated or cooled. Sand or other granular material enters the conveyor 1 via the horizontal discharge augers (or other suitable conveyor) 9, 10, and sand is recovered to the top of the storage vessels via vertical conveyors 6, 7.

[0025] It is understood that alternatively the granular material might be moved between the top and the bottom of a single vessel. It is also understood that the heat transfer tube bundle may employ finned tubes to promote heat transfer and distribution of the sand.

[0026] As shown in FIG. 1, when energy is being stored the lower temperature sand is removed from the lower temperature above ground storage vessel 3, heated by the heat transfer tube bundle 8 containing higher temperature HTF 28 from the solar collector field 4, 5 and transferred to the higher temperature above ground storage vessel 2. When energy storage is complete, the higher temperature above ground storage vessel 2 will be largely full of hot sand. When stored energy is needed, hot sand will be returned to the lower temperature above ground storage vessel 3 while stored heat in the sand is recovered by warm outlet HTF. The practical design shown allows free expansion and contraction of the metal parts to account for thermal expansion.

[0027] An exemplary conveyor used to move the sand is a variation of an Archimedes screw. The Archimedes screw is normally used as a type of lift pump. In this case, it is used as a sand conveyor and heat exchanger. As more specifically shown in FIGS. 2 and 3A-3B, the Archimedes screw conveyor 1 is a rotating sand conveyor drum 11 with one or more spiral vanes 12 fixed to the inner surface of the drum. As the drum turns, the spiral vane 12 pushes the sand 15 along the bottom of the rotating drum 11. The Archimedes screw has no close sliding fits to achieve this pushing motion; indeed, there is no sliding metal-to-metal contact at all. As the sand 15 is conveyed by the spiral vane 12, a set of longitudinal straight vanes 13 acts to simultaneously lift and convey the sand 15 over the heat transfer tube bundle 8 containing the heat transfer fluid (HTF) 28. By this action the HTF 28 flowing in the tubes 8 is made to either adsorb or give up heat. As shown in FIG. 1, vertical conveyors 6, 7 will top-load each storage vessel, and horizontal discharge augers or other conveyors 9, 10 will unload them from below.

[0028] The Archimedes screw sand conveyor 1 has the great advantage that switching the direction of rotation changes the direction of the motion of the sand. This feature makes it is easy to change the direction of the motion of the sand as the system is switched between the heat storage function and the heat recovery function.

[0029] Details of the Archimedes screw conveyor 1 are shown in FIGS. 2 and 3. The spiral vane 12 (the "screw" of the Archimedes screw) is shown attached to the interior of a drum 11. Inside the drum 11, is shown a heat transfer tube bundle 8 containing the HTF 28. As the drum 11 rotates, sand or other granular material 15 is pushed along laterally by the screw spiral vane 12. An advantageous feature is that the drum also carries a series of longitudinal vanes 13 that pick up and rain the sand 15 over the tube bundle, thus providing heat exchange as the sand 15 is conveyed (FIG. 3). Note again that the Archimedes screw has no close sliding fits and no sliding metal to metal contact at all, which is in contrast to an auger or screw conveyor. As the HTF 28 passes through the heat transfer tube bundle 8, the sand 15 pours over the pipes, either charging the HTF 28 with heat from hot sand or, conversely, charging the sand 15 with heat from the hot HTF 28. The tubes may be equipped with longitudinal or transverse fins to increase the outside heat-transfer area and to retard and redirect the fall of the conveyed sand 15 providing adequate time for heat transfer to or from the sand. In this application, the function of the tubes and fins is analogous to the action of the so-called "fill" in a cooling tower or packed column. The rotating drum 11 will be insulated 14 to avoid heat losses.

[0030] Various types of extended surfaces such as longitudinal, latitudinal, and/or corrugated fins may be used to increase the heat transfer surface on the sand side. Furthermore, the fins may have additional features to improve the contact between the flowing sand and the base tubes. In addition the tubes may have elongated or elliptical shapes to improve the contact and heat transfer with the sand. Indeed, the preferred "tube" cross section may be more plate like or similar to an elongated rectangular passage than a generally circular "tube". These additional features enhance the contact between tube and fins with the sand and heat transfer to or from the sand may be included

[0031] Various additional features to enhance heat transfer to or from the sand or from the tube to the internal heat transfer fluid may be included. In some situations, for example, it may be advantageous for the granular material to travel in overall cocurrent flow to the flow of internal heat transfer fluid. FIG 3B illustrates an exemplary embodiment in which the sand or similar granular material 15 is moved by the conveyor in a direction 35 roughly in cocurrent flow to the flow 38 of the heat transfer fluid 28.

[0032] An overhead view of the supply and return piping, including the heat transfer tube bundle 8 is shown in FIG. 4. The heat transfer tube bundle 8 is integrated into the plant via inlet and outlet large central large diameter pipes 16, 17. These pipes are connected to the heat transfer tube bundle 8 through left and right hand large diameter pipes 18, 19, which are in turn connected to left and right hand plenums 20, 21. The plenums 20, 21 handle the transfer of HTF 28 between the large diameter pipes and the heat transfer tube bundle 8. It should be noted that the structural outriggers support the heat transfer tube bundle and both plenums at each end. This allows free expansion from the central support to account for thermal expansion.

[0033] It may be further understood that the option exists for the sand-shifter system to employ in ground storage vessels or pits as the storage volume as opposed to above ground storage vessels. FIG. 5 shows a perspective view of the sand-shifter thermal energy storage system with an in ground storage vessel setup. The main difference in this system is the need for vertical conveyors 24, 25 to transport sand out of the higher temperature in ground storage vessel 22 and lower temperature in ground storage vessel 23.

[0034] Embodiments of charging processes to store thermal energy in the sand are shown by a side view in FIG. 6. This process will be largely similar regardless if practiced with in ground or above ground storage vessels. Higher temperature heat transfer fluid inlet from the solar collector field 5 flows into the sand-shifter system by way of an inlet large diameter supply pipe 16. Next the hot HTF 28 flows through the left hand large diameter pipe (LHLDP) 18 into the left hand plenum (LHP) 20. In the LHP 20, hot HTF is distributed to the heat transfer inner flow core 8, and flows to the right in counterflow to the conveyed sand 15. The lower temperature sand is lifted out of the lower temperature in ground storage vessel 23 via a vertical conveyor 24 and enters the Archimedes screw sand conveyor 1 from a horizontal discharge auger 27 or other suitable conveyor. Heat transfer fluid 28 exchanges heat with conveyed sand 15 roughly in counterflow until it reaches right hand plenum (RHP) 21. HTF flows are combined in the RHP 21 and directed into the right hand large diameter pipe (RHLDP) 19, which is now used as the return pipeline. The conveyed sand 15 exits the Archimedes screw and enters storage vessel 22 view auger 26. Warm HTF in the RHLDP 19 returns to the outlet central large diameter pipe 17 and exits the Thermal Energy Storage system.

[0035] Embodiments of Discharging Processes to release stored thermal energy and heat the HTF are shown by a side view in FIG. 7. Again, this process will be largely similar regardless if practiced with in ground or above ground storage vessels. The operation of heating the HTF 28 is accomplished by using hot sand stored in the higher temperature in ground storage vessel 22.

Warm HTF 28 flows in by way of an inlet large diameter supply pipe 16 and then flows in the right hand large diameter pipe (RHLDP) 19 into the right hand plenum (RHP) 21. In the RHP 21, warm HTF 28 is distributed to multiple pipes in the heat transfer tube bundle 8 and flows to the left in counterflow to the conveyed sand 15. The hot sand is conveyed 15 from the higher temperature in ground storage vessel 22 into the Archimedes screw conveyor 1 via vertical conveyor 24 and horizontal discharge auger 26 or other suitable conveyor and exchanges heat with the warm HTF roughly in counterflow. When the warm sand reaches the end of the Archimedes screw conveyor 1, it is returned to the lower temperature in ground storage vessel 23 where it awaits the Charging Process. The now hot HTF reaches the left hand plenum (LHP) 20 and is directed into the left hand large diameter pipe 18, now used as the return pipeline. Hot HTF then returns to the outlet large diameter supply pipe 17 and exits the Thermal Energy Storage system to produce usable energy.

[0036] Turning to FIG. 8, exemplary embodiments of storage vessels 102, 103 are illustrated in greater detail. The storage vessels 102, 103 may have angled walls 132 to facilitate flow of granular materials 15 into and out of the storage vessels during operation. In exemplary embodiments, the wall angle may be about 30° or greater. This advantageous configuration can be employed in either above ground or in-ground storage vessels.

[0037] In concentrator solar thermal power, embodiments of the disclosed systems and methods are used to store heat gathered during the day that is not needed for power generation or that is in excess of the heat needed for power generation at some time. This heat will be stored and used to generate power when needed, such as during afternoon peaking periods, or during the evening and nighttime. The basic concept of the sand shifter may be applicable in other applications in power generation cycles, in materials processing, or in other heat and mass transfer applications.

[0038] It should be understood that good heat transfer performance is obtained by raining the sand 15 over a heat transfer tube bundle 8 carrying the HTF used to convey heat alternatively from the collector field or to a power conversion plant. Ideally, heat transfer coefficients moderately approximating the performance seen in similarly-agitated fluidized beds will be achieved. Good heat exchange effectiveness means close approach of the thermal storage medium to the inlet temperature of the HTF during charging of the storage and close approach of the HTF temperature to the maximum temperature of the storage medium during discharge. This good effectiveness will be obtained by heating sand or alternatively removing heat from the sand while moving the sand to or from a higher temperature above ground storage vessel 2 in a novel conveyor that doubles as a counter flow heat exchanger. The counter flow arrangement promotes high effectiveness. The sand storage containers will be simple and inexpensive insulated silos or bins above ground or buried pits.

[0039] Thus, it is seen that systems and methods of storing and releasing thermal energy are provided. It should be understood that any of the foregoing configurations and specialized components or chemical compounds may be interchangeably used with any of the systems of the preceding embodiments. Although illustrative embodiments of the present invention are described hereinabove, it will be evident to one skilled in the art that various changes and modifications may be made therein without departing from the invention. It is intended in the appended claims to cover all such changes and modifications that fall within the true spirit and scope of the invention.

CLAIMS

What is Claimed is:

1. A system of energy storage and release, comprising:

at least one storage vessel;

a combined conveyor and heat transfer device linked to the at least one storage vessel by at least one discharge device, the combined conveyor and heat transfer device including:

a rotatable conveyor drum; and

at least one heat transfer fluid conduit within the rotatable conveyor drum;

wherein a granular material travels from the at least one storage vessel to the combined conveyor and heat transfer device via the at least one discharge device, and the rotatable conveyor drum moves the granular material therethrough in counterflow to a flow of heat transfer fluid traveling through the heat transfer fluid conduit.

2. The system of claim 1 wherein the granular material is sand.

3. The system of claim 1 wherein the rotatable conveyor drum is an Archimedes screw.

4. The system of claim 1 wherein the rotatable conveyor drum comprises one or more vanes fixed to an inner surface thereof.

5. The system of claim 1 wherein the at least one storage vessel has at least one angled wall.

6. The system of claim 1 wherein the at least one heat transfer fluid conduit comprises a plurality of fluid conduits arranged in a bundle.

7. The system of claim 1 wherein when the rotatable conveyor drum rotates the granular material pours over the at least one heat transfer fluid conduit such that heat exchange occurs between the granular material and the heat transfer fluid.

8. The system of claim 4 wherein the rotatable conveyor drum rotates such that the one or more vanes pick up and rain the granular material over the at least one heat transfer fluid conduit.

9. The system of claim 1 wherein the at least one storage vessel comprises a first and second storage vessel, the first storage vessel having a higher temperature than the second storage vessel.

10. The system of claim 1 wherein the stored energy is heat gathered by, or discharged to, a concentrating solar thermal power plant.

11. The system of claim 4 wherein the one or more vanes are one of: spiral shaped, longitudinally straight, substantially T-shaped and substantially V-shaped.

12. A method of storing thermal energy, comprising:

providing a granular material and a heat transfer fluid, the heat transfer fluid having a temperature relatively higher than a temperature of the granular material;

conveying the granular material and the heat transfer fluid such that the granular material pours over a tube carrying the heat transfer fluid such that heat exchange occurs between the granular material and the heat transfer fluid.

13. The method of claim 12 wherein the granular material travels in overall counterflow to a flow of heat transfer fluid.

14. The method of claim 12 wherein the granular material travels in overall cocurrent flow to a flow of heat transfer fluid.

15. The method of claim 12 wherein the granular material is sand.

16. The method of claim 12 further including releasing stored thermal energy, comprising:

providing a granular material and a heat transfer fluid, the granular material having a temperature relatively higher than a temperature of the heat transfer fluid;

conveying the granular material and the heat transfer fluid such that the granular material pours over a tube carrying the heat transfer fluid such that heat exchange occurs between the granular material and the heat transfer fluid.

17. A combined conveyor and heat transfer device, comprising:

a rotatable conveyor drum; and

at least one heat transfer fluid conduit within the rotatable conveyor drum;

wherein the rotatable conveyor drum moves a granular material therethrough in counterflow to a flow of heat transfer fluid traveling through the heat transfer fluid conduit.

18. The device of claim 17 wherein the rotatable conveyor drum is an Archimedes screw.

19. The device of claim 17 wherein when the rotatable conveyor drum rotates the granular material pours over the at least one heat transfer fluid conduit such that heat exchange occurs between the granular material and the heat transfer fluid.

20. The device of claim 17 wherein the rotatable conveyor drum is capable of rotating at one or more speeds.

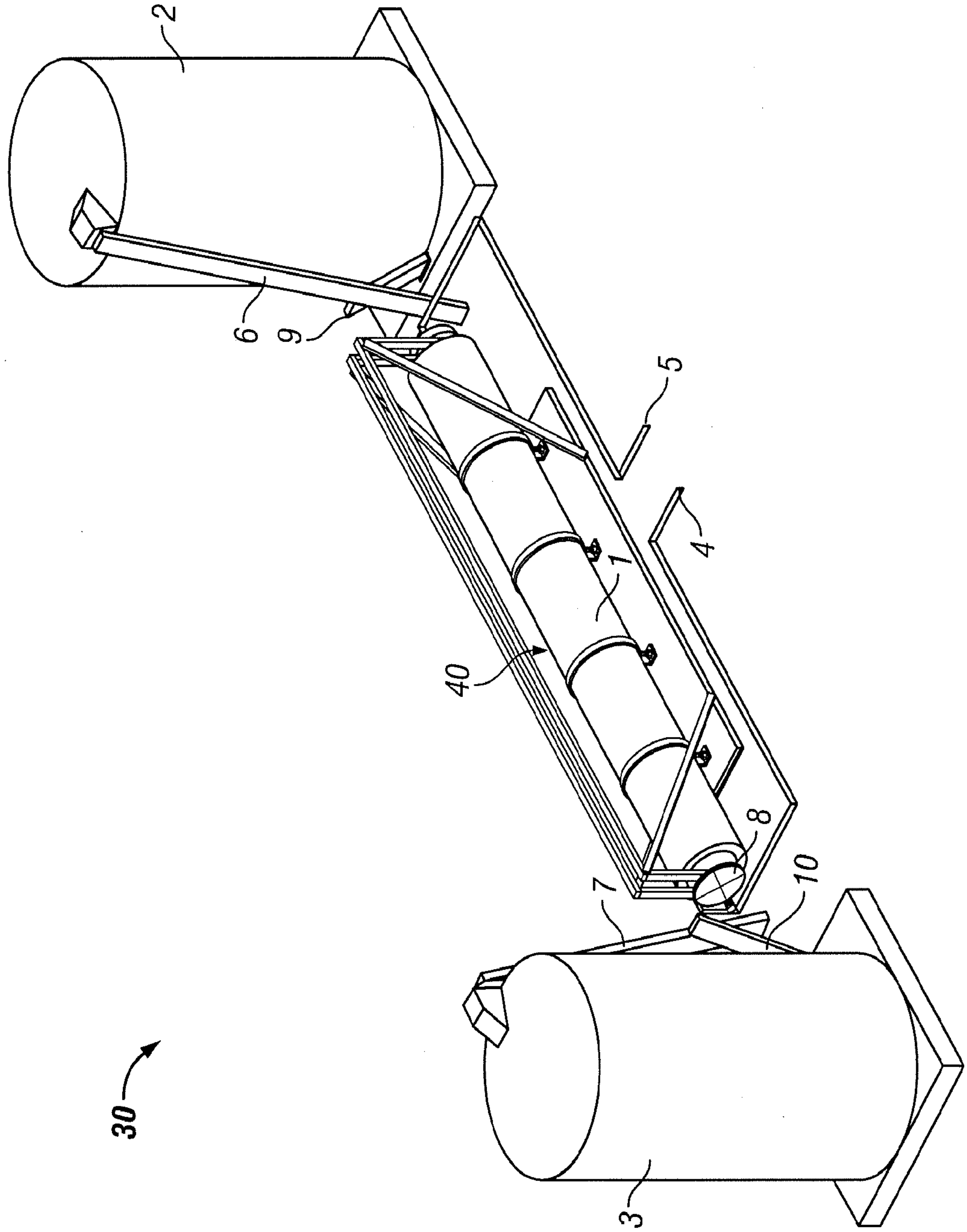

FIG. 1

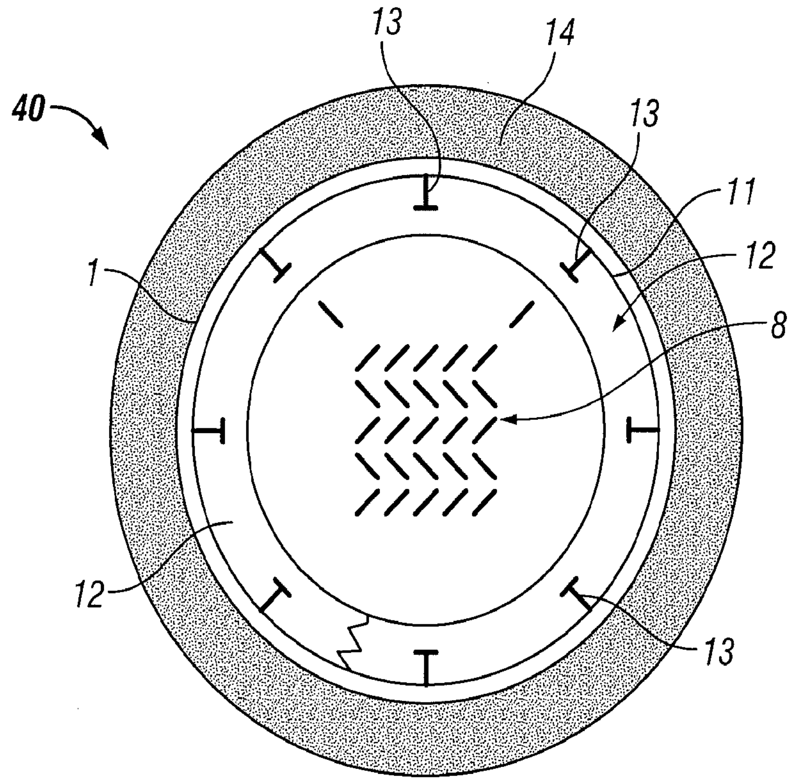
40
13
14
13
11
1
12
8
12
13

FIG. 2

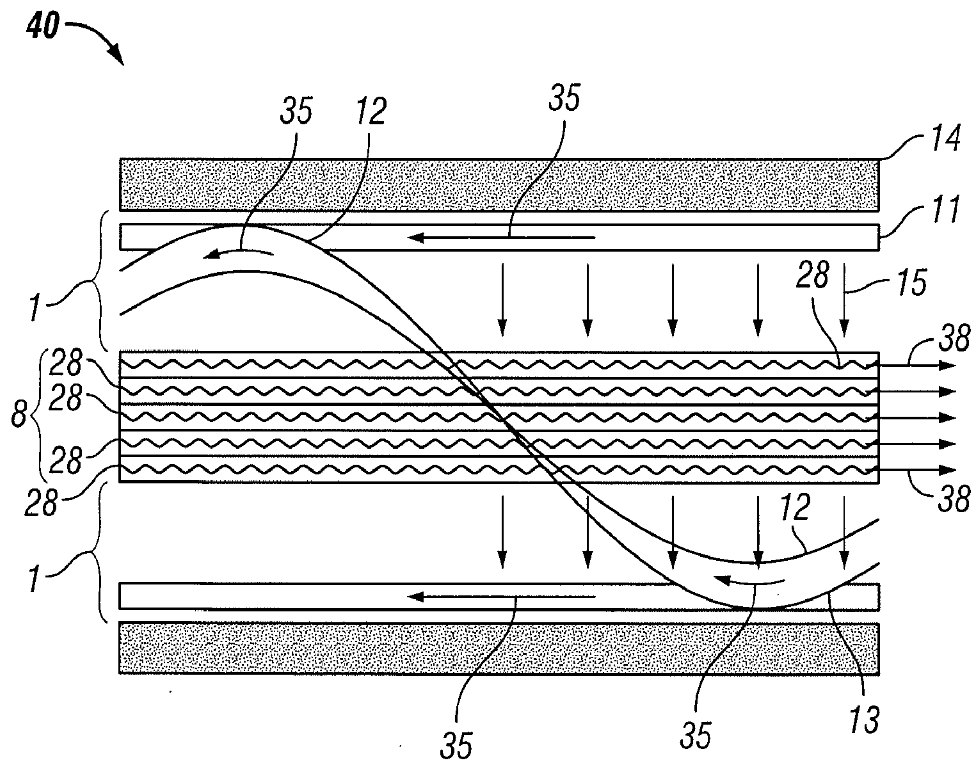
40
35
12
35
14
11
1
28
15
28
28
38
8
28
28
28
38
12
1
35
35
13

FIG. 3A

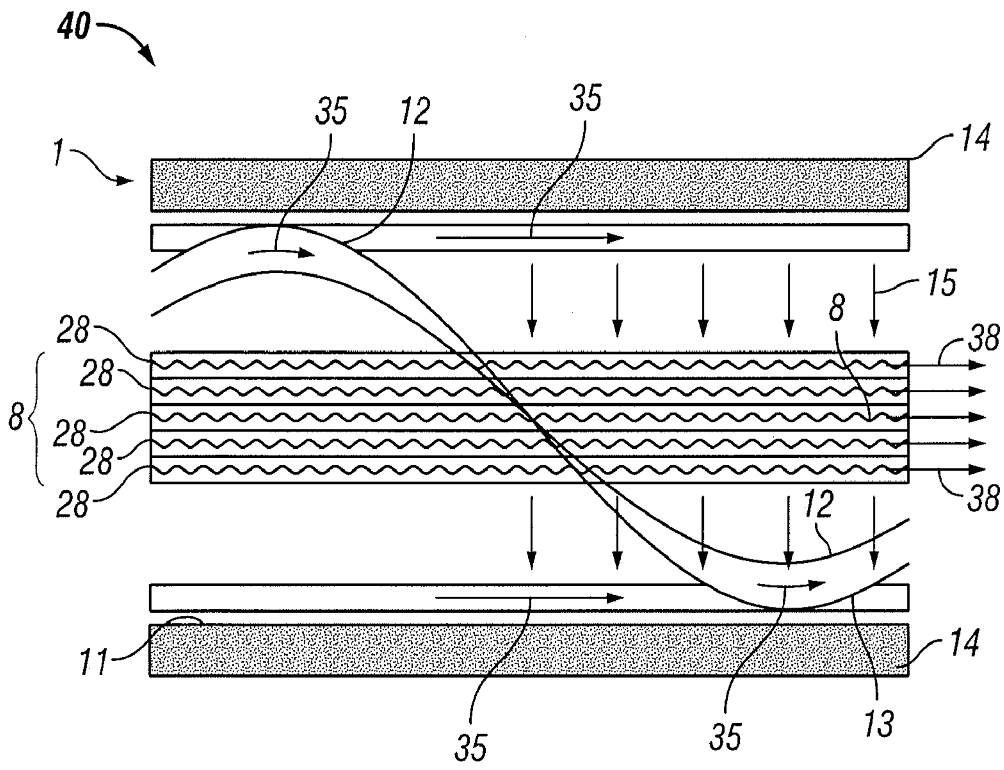

FIG. 3B

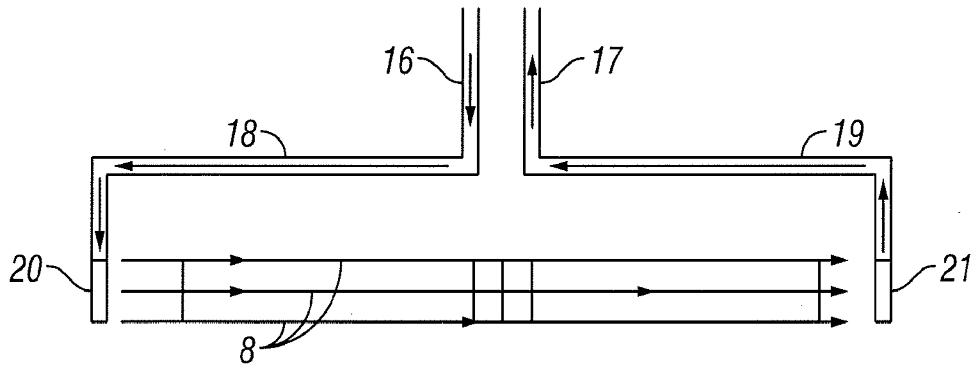

FIG. 4

5/8

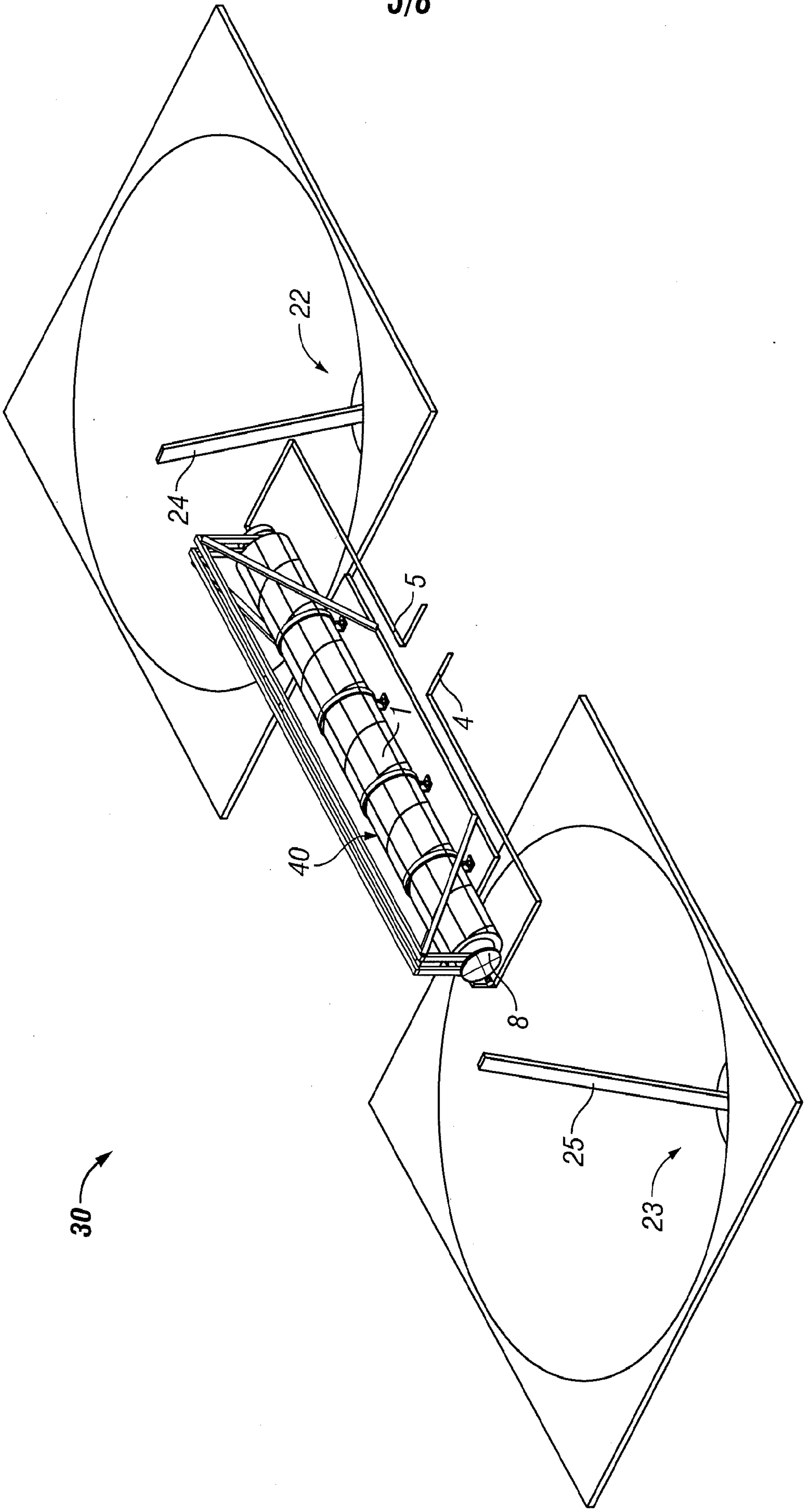

FIG. 5

6/8

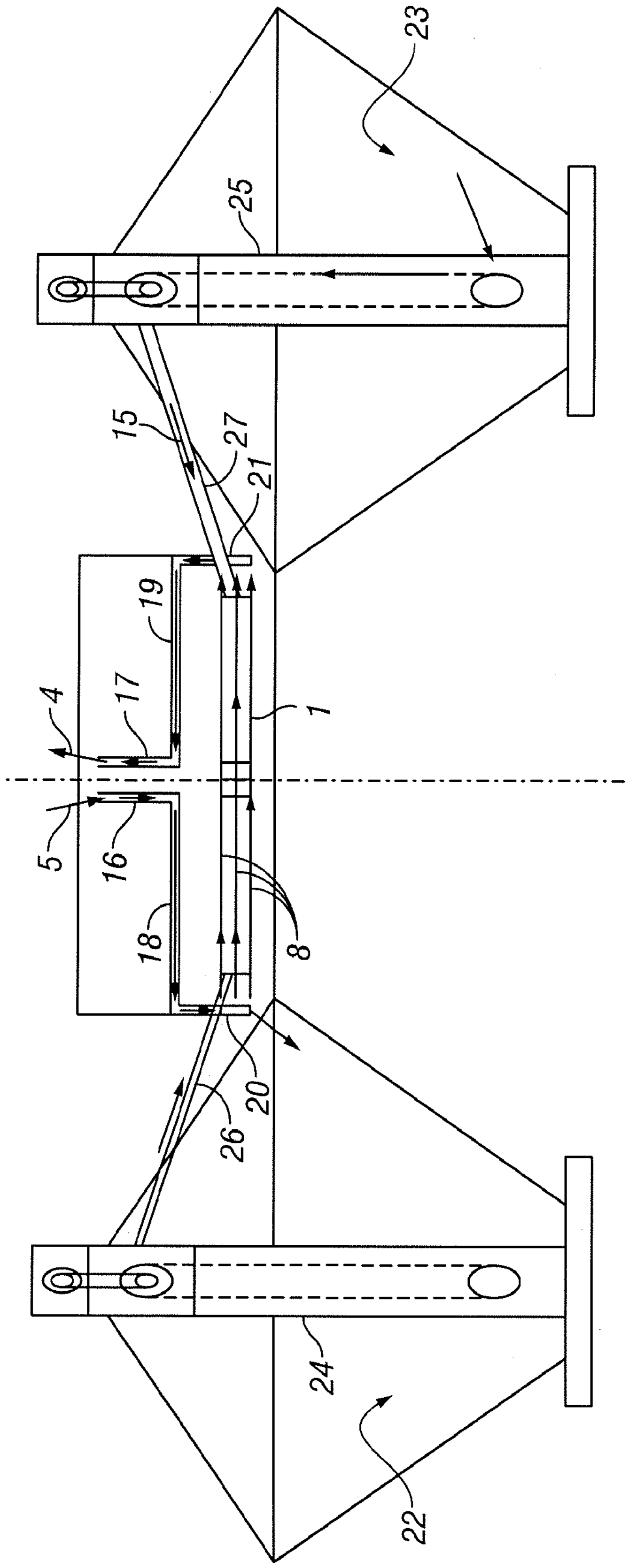

FIG. 6

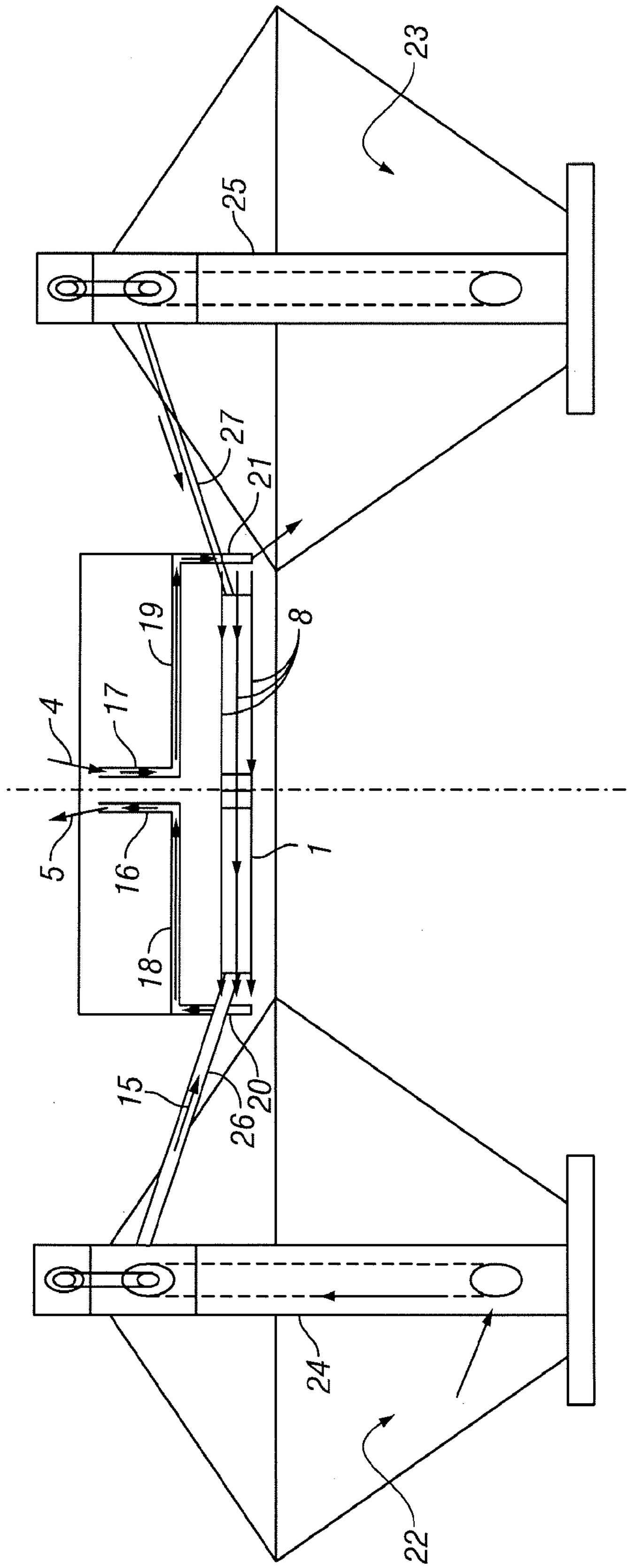

FIG. 7

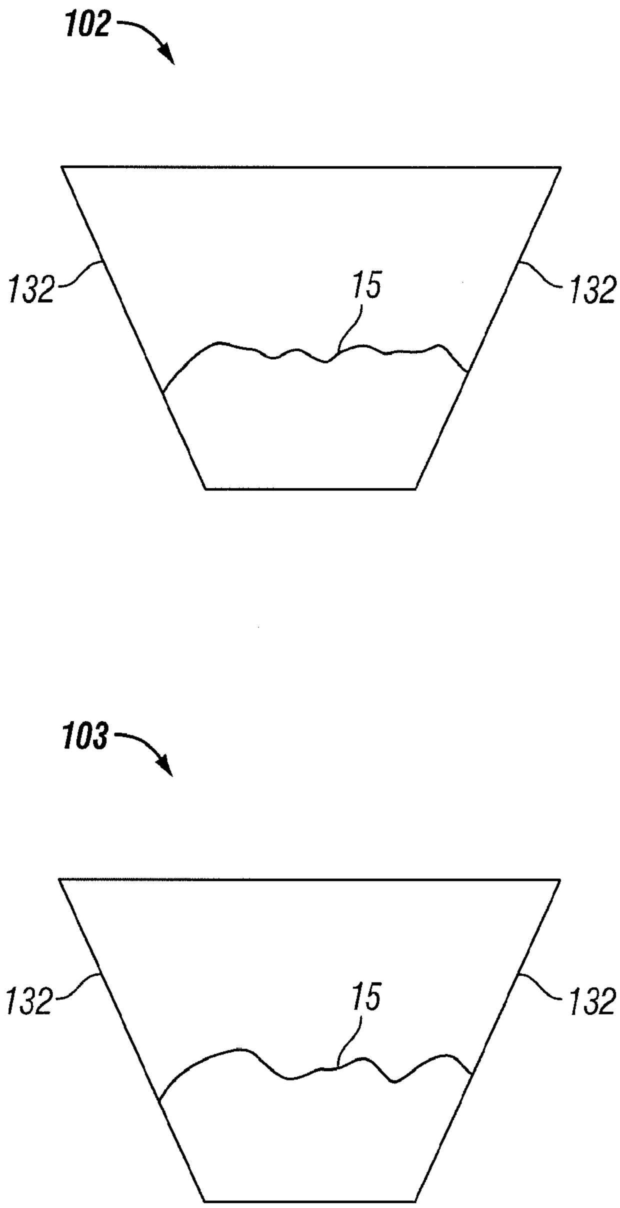

FIG. 8