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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 May 2013 (23.05.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/074818 A1

(51) International Patent Classification: *F24J 2/24* (2006.01)

(21) International Application Number: PCT/US2012/065324

(22) International Filing Date: 15 November 2012 (15.11.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/560,527 16 November 2011 (16.11.2011) US
13/677,519 15 November 2012 (15.11.2012) US

(71) Applicant: **BABCOCK & WILCOX POWER GENERATION GROUP INC.** [US/US]; 20 S. Van Buren Avenue, Barberton, OH 44203 (US).

(72) Inventors: **KRAFT, David, L.**; 5882 Great Court Circle NW, Massillon, OH 44646 (US). **WASYLUK, David, T.**; 2350 Sesame Street NW, Mogadore, OH 44260 (US). **PERSINGER, Justin, A.**; 3340 Columbia Woods, Apt. F, Norton, OH 44203 (US). **MARSHALL, Jason, M.**; 861 Longbrook Drive, Wadsworth, OH 44281 (US).

(74) Agent: **MARICH, Eric**; Babock & Wilcox Power Generation Group, Inc., Law Dept-I.P. (BVCB2K), 20 S. Van Buren Avenue, Barberton, OH 44203 (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, BN, 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, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, 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.

[Continued on next page]

(54) Title: SOLAR TUBE PANEL WITH DUAL-EXPOSURE HEAT ABSORPTION

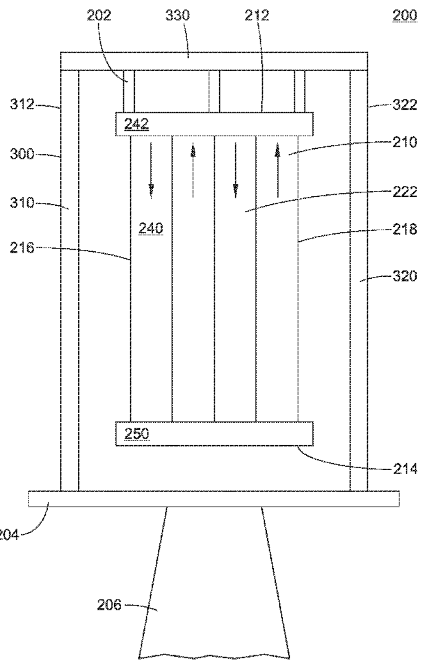

FIG. 2

(57) Abstract: A dual-exposure heat absorption panel is disclosed, which can be used in a solar receiver design. Generally, the heat absorption panel includes a tube panel through which a heat transfer fluid is flowed to absorb solar energy from heliostats that are focused on the tube panel. A structural support frame surrounds the tube panel. A stiffener structure runs across the exposed faces of the tube panel. The headers and other support structures on the periphery are protected by use of a heat shield. Different tube couplings are possible with this structure, as well as different stiffening structures at the headers. The heat shield can be shaped to create an open space, permitting focusing of sunlight on the edge tubes as well. A curtain can be used as an additional heat shield in certain scenarios.

WO 2013/074818 A1

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, 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, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

SOLAR TUBE PANEL WITH DUAL-EXPOSURE HEAT ABSORPTION

BACKGROUND

[0001] This application claims priority to U.S. Provisional Patent Application Serial No. 61/560,527, filed on November 16, 2011. The disclosure of this application is hereby fully incorporated herein by reference in its entirety.

[0002] The present disclosure relates broadly to the field of solar power generation used to produce electricity. More particularly, this disclosure relates to a dual-exposure or two-sided heat absorption panel, and a solar receiver including one or more of such panels. These solar receiver designs can be used with Concentrated Solar Tower technology, also known as Concentrating Solar Power (CSP) technology to harness the sun's energy to produce "green" electricity.

[0003] A solar receiver is a primary component of a solar energy generation system whereby sunlight is used as a heat source for the eventual production of superheated high quality steam that is used to turn a turbine generator, and ultimately produce electricity using the Rankine cycle or provide steam for other thermal processes.

[0004] Generally, the solar receiver is positioned on top of an elevated support tower which rises above a ground level or grade. The solar receiver is strategically positioned within an array of reflective surfaces, namely a field of heliostats (or mirrors), that collect rays of sunlight and then reflect and concentrate those rays back to the heat absorbing surfaces of the solar receiver. This solar energy is then absorbed by the working heat transfer fluid (HTF) flowing through the solar receiver. The reflective surfaces may be oriented in different positions throughout the day to track the sun and maximize reflected sunlight to the heat absorbing surfaces of the receiver.

[0005] The solar receiver is an assembly of tubes with water, steam, molten salts, or other heat transfer fluid (HTF) flowing inside the tubes. The HTF inside the tubes of the receiver absorbs the concentrated solar energy, causing the HTF to increase in temperature and/or change phases, so that the HTF captures the solar energy. The heated HTF is then either directly routed to a turbine generator to generate electrical power or is indirectly routed to a storage tank for later use.

[0006] Solar receiver designs typically include an arrangement of panels with vertically oriented tubes, i.e. tube panels, along with a support structure for maintaining the tube panels in place and other associated equipment (pumps, pipes, storage vessels, heat shields, etc.). In conventional designs, the solar receiver has a square, rectangular, or circular cross-section (in a plan view from above). The tube panels are arranged on the exterior of the cross-section, so that the solar energy from the heliostats is directed at (and absorbed by) only one face of a tube panel. This is illustrated in, for example, U.S. Patent Application Serial No. 12/605,241, which is entitled "Shop-Assembled Solar Receiver Heat Exchanger" and is assigned to Babcock & Wilcox Power Generation Group, Inc., and which is hereby fully incorporated by reference herein.

[0007] In this regard, **FIG. 1** is a plan view (i.e. viewed from above) of one solar receiver design **100** discussed above, which has four tube panels **110**, **120**, **130**, **140**, arranged as a square. Each tube panel has one exterior face **112**, **122**, **132**, **142** which is exposed to solar energy from heliostats, and one interior face **114**, **124**, **134**, **144** which is not exposed to such solar energy.

[0008] The interior non-absorbing face of a tube panel usually has a buckstay system that supports the tube panels against high wind, seismic forces, and thermally induced forces. The buckstay system typically includes "I" beams or other structural steel shapes that are clipped onto the tube panel in such a way that the tube panel can expand independent of the support structure itself and independent of the other tubes and panels. Clips are usually welded to the tubes so that the tube panel can move relative to the stationary support structure when heat is applied to the tubes, yet the support structure can still provide rigidity to the tube panel. On a solar receiver, the tubes in the tube panel are not welded together along their axes (i.e. membrane construction) as in a fossil fuel fired boiler, but are of loose construction. This allows the tubes to expand independently of each other when heat is applied. As a result, each tube must have a clip to attach to the buckstay at a support elevation.

[0009] One problem that results due to only one face of a tube being exposed to solar energy is that a temperature differential arises between the exposed hot face and the non-exposed cold face. This results in differential expansion between the hot and cold faces of the tube, which causes the tube to bow. The severity of bowing depends on the magnitude of the temperature differential and the rigidity of the tube panel. Because the clip connecting the tube to the buckstay keeps the tube in place at the support elevation, bowing occurs between support elevations. This creates high compressive stress on the heated side of the tube at each support elevation.

[0010] Due to daily heating and cooling of the tubes during startup, shutdown, and cloud passages, such stresses are cyclic, which can eventually lead to fatigue failure. For receivers that use molten salt as the HTF, impurities in the molten salt can also cause corrosion, which can be exacerbated where stress is located.

BRIEF DESCRIPTION

[0011] The present disclosure relates, in various embodiments, to heat absorbing tube panels and solar receivers incorporating such panels that are exposed to solar energy on two opposite faces. Compared to panels that absorb energy on a single face, heat absorption on two faces can reduce the temperature differential between the hot face and the cold face and therefore provide more uniform tube temperature around the circumference of the tube. This results in significantly reduced thermal stresses in the tube and lower potential for tube failures. With lower tube stresses, the risk of failure due to stress corrosion is also reduced. Also, for a given panel size the available heat absorbing area is doubled compared to a single side heated panel. The combination of reduced stresses and doubled absorbing area results in a panel that can accept more than twice as much solar energy, significantly increasing the efficiency of the panel. The solar receivers comprise an arrangement of heat transfer surfaces, a heat transfer fluid system structurally and functionally interconnected thereto, a vertical support structure, and a stiffener structure. Various structural features and other additions are also described herein.

[0012] Disclosed in embodiments herein is a dual-exposure heat absorption panel, comprising a tube panel and a structural support frame. The tube panel comprises a plurality of vertical tubes for conveying a heat transfer fluid. The tubes are interconnected by at least one upper header and at least one lower header. The tube panel has a first exposed face, an opposite second exposed face, an upper edge, a lower edge, a first side edge, and a second side edge. The structural support frame runs along the upper edge, the first side edge, and the second side edge of the tube panel. At least one tube in the tube panel is connected to the at least one upper header or the at least one lower header by a repair coupling surrounding the at least one tube and a prior header tube stub.

[0013] The repair coupling may be located behind heat shields mounted to the structural support frame so that the repair coupling is not exposed to direct sunlight.

[0014] The dual-exposure panel may further comprise a first stiffener structure running from the first side edge to the second side edge across the first exposed face and the second exposed face of the tube panel at a first support elevation.

[0015] In some embodiments, the stiffener structure is formed from a first support assembly and a second support assembly, each support assembly including: a support tube; a horizontal flange extending from the support tube and having a slot therein; and a scallop bar engaging one or more vertical tubes of the tube panel and having at least one lug, the scallop bar engaging the horizontal flange by a pin passing through the at least one lug and the slot of the horizontal flange. The support tube of each support assembly may have a different diameter from any tube in the tube panel, and in some embodiments is larger.

[0016] The dual-exposure panel may further comprise a second stiffener structure running from the first side edge to the second side edge across the first exposed face and the second exposed face of the tube panel at a second support elevation. In specific embodiments, the first support elevation and the second support elevation are not located at a middle section of the tube panel.

[0017] Also disclosed herein in different embodiments is a dual-exposure heat absorption panel, comprising a tube panel and a structural support frame. The tube panel comprises a plurality of vertical tubes for conveying a heat transfer fluid. The tubes are interconnected by at least one upper header and at least one lower header. The tube panel has a first exposed face, an opposite second exposed face, an upper edge, a lower edge, a first side edge, and a second side edge. The structural support frame runs along the upper edge, the first side edge, and the second side edge of the tube panel. The tube panel includes at least one tube joined to a header tube stub on either the at least one upper header or the at least one lower header, an exterior diameter of the header tube stub being greater than a central exterior diameter of the at least one tube. In more specific embodiments, an interior diameter of the at least one tube is the same as an interior diameter of the header tube stub.

[0018] Also disclosed herein in different embodiments is a dual-exposure heat absorption panel, comprising a tube panel and a structural support frame. The tube panel comprises a plurality of vertical tubes for conveying a heat transfer fluid. The tubes are interconnected by at least one upper header and at least one lower header. The tube panel has a first exposed face, an opposite second exposed face, an upper edge, a lower edge, a first side edge, and a second side edge. The structural support frame runs along the upper edge, the first side edge, and the second side edge of the tube panel. The structural support frame includes a first heat shield framing the first exposed face of the tube panel, an open space being present between the first heat shield and the tube panel.

[0019] Also disclosed herein in different embodiments is a dual-exposure heat absorption panel, comprising a tube panel, a structural support frame, a curtain, and means for guiding the curtain. The tube panel comprises a plurality of vertical tubes for conveying a heat transfer fluid. The tubes are interconnected by at least one upper header and at least one lower header. The tube panel has a first exposed face, an opposite second exposed face, an upper edge, a lower edge, a first side edge, and a second side edge. The structural support frame runs along the upper edge, the first side edge, and the second side edge of the tube panel. The structural support frame includes a first heat shield framing the first exposed face of the tube panel, the first heat shield including an upper face, a first side face, and a second side face. The curtain is located on the upper face of the first heat shield above the tube panel. The means for guiding the curtain is located on the first side face and the second side face of the heat shield.

[0020] The curtain may have a length sufficient to cover the entirety of the tube panel. The means for guiding can include rails or cables. Sometimes, a bottom edge of the curtain includes weights.

[0021] These and other non-limiting aspects and/or objects of the disclosure are more particularly described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The following is a brief description of the drawings, which are presented for the purposes of illustrating the exemplary embodiments disclosed herein and not for the purposes of limiting the same.

[0023] **FIG. 1** is a plan (i.e. top) view of a conventional solar receiver design having a square orientation, with each tube panel having one exterior exposed face and one interior non-exposed face.

[0024] **FIG. 1A** is a side cross-sectional view of a conventional tube panel with a light barrier and insulation.

[0025] **FIG. 1B** is a perspective view of the panel of **FIG. 1A**.

[0026] **FIG. 2** is a first front view of a solar receiver of the present disclosure using a dual-exposure heat absorption panel having a limited number of tube passes. In this figure, heat shields and panel stiffener support structures are removed to provide an interior view.

[0027] **FIG. 3** is a second front view of a solar receiver of the present disclosure using a dual-exposure heat absorption panel. In this figure, panel stiffener support structures are visible, and heat shields are removed to provide another interior view.

[0028] **FIG. 4** is an exterior front view of a solar receiver of the present disclosure using a dual-exposure heat absorption panel. Here, the heat shields are in place.

[0029] **FIG. 5** is an exterior side view of a solar receiver of the present disclosure.

[0030] **FIG. 6** is a plan view showing a tube panel and a stiffener structure for the tube panel of the present disclosure.

[0031] **FIG. 7** is a side cross-sectional view of a tube panel and a stiffener structure for the tube panel as depicted in **FIG. 6**.

[0032] **FIG. 8** is a front view of the tube panel and stiffener structure as depicted in **FIG. 6**.

[0033] **FIG. 8A** is a perspective view of the tube panel and stiffener structure as depicted in **FIG. 6**.

[0034] **FIG. 9** is an enlarged front view of a tube panel without stiffener structure showing the tube panel having multiple tube passes, upper headers, and lower headers.

[0035] **FIG. 10** is a schematic showing fluid flow through the dual-exposure heat absorption panel.

[0036] **FIG. 11** is a side cross-sectional view of the upper header and the tube panel, showing a possible repair coupling arrangement between an original tube and a replacement tube.

[0037] **FIG. 12** is a side cross-sectional view of the lower header and the tube panel, showing a tube stiffening arrangement.

[0038] **FIG. 13** is a front view of an alternative arrangement of the heat absorption panel, wherein an open space is located between the heat shield and the tube panel.

[0039] **FIG. 14** is a front view of the heat absorption panel showing a curtain arrangement by which the tube panel can be quickly covered.

[0040] **FIG. 15** is a side view of the heat absorption panel of **FIG. 14**.

[0041] **FIG. 16** is a front view depicting the lowering of a curtain to cover the tube panel of **FIG. 14**.

DETAILED DESCRIPTION

[0042] A more complete understanding of the processes and apparatuses disclosed herein can be obtained by reference to the accompanying drawings. These figures are merely schematic representations based on convenience and the ease of demonstrating the existing art and/or the present development, and are, therefore, not intended to indicate relative size and dimensions of the assemblies or components thereof.

[0043] Although specific terms are used in the following description for the sake of clarity, these terms are intended to refer only to the particular structure of the embodiments selected for illustration in the drawings, and are not intended to define or limit the scope of the disclosure. In the drawings and the following description below, it is to be understood that like numeric designations refer to components of like function.

[0044] The modifier "about" used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (for example, it includes at least the degree of error associated with the measurement of the particular quantity). When used with a specific value, it should also be considered as disclosing that value. For example, the term “about 2” also discloses the value “2” and the range “from about 2 to about 4” also discloses the range “from 2 to 4.”

[0045] It should be noted that many of the terms used herein are relative terms. For example, the terms “interior”, “exterior”, “inward”, and “outward” are relative to a center, and should not be construed as requiring a particular orientation or location of the structure. Similarly, the terms “upper” and “lower” are relative to each other in location, i.e. an upper component is located at a higher elevation than a lower component.

[0046] The terms "horizontal" and "vertical" are used to indicate direction relative to an absolute reference, i.e. ground level. However, these terms should not be construed to require structures to be absolutely parallel or absolutely perpendicular to each other. For example, a first vertical structure and a second vertical structure are not necessarily parallel to each other.

[0047] To the extent that explanations of certain terminology or principles of the solar receiver, boiler and/or steam generator arts may be necessary to understand the present disclosure, the reader is referred to *Steam/its generation and use*, 40th Edition, Stultz and Kitto, Eds., Copyright 1992, The Babcock & Wilcox Company, and to *Steam/its generation and use*, 41st Edition, Kitto and Stultz, Eds., Copyright 2005, The Babcock & Wilcox Company, the texts of which are hereby incorporated by reference as though fully set forth herein.

[0048] The present disclosure relates to a dual-exposure or two-sided heat absorption panel and to solar receivers incorporating one or more two-sided heat absorption panels. The panels are designed to accept heat on two opposite sides or faces, rather than on only one side or face. This can reduce tube failures due to fatigue or stress corrosion, and for a given panel size the available heat absorbing area is doubled compared to a single side heated panel. The panels may include one or more stiffener structures or heat shields. Generally, the solar receiver is located at the top of a vertical support structure which rises above a ground level or grade. The vertical support structure may be supported from a base. The heat transfer surfaces advantageously comprise loose tangent tube panels, which allows for unrestrained thermal expansion of the tubes / tube panels in both the horizontal and vertical directions, thereby eliminating additional tube stresses. As is known to those skilled in the art, the sizes of tubes, their material, diameter, wall thickness, number and arrangement for the heat transfer surfaces are based upon temperature and pressure for service, according to applicable design codes. Required heat transfer characteristics, circulation ratios, spot absorption rates, mass flow rates of the working fluid within the tubes, etc. are also important parameters which must be considered. Depending upon the geographic location where the solar receiver is to be installed, applicable seismic loads and design codes are also considered.

[0049] It should be noted that in some embodiments, molten salt is used as the heat transfer fluid (HTF) that is run through the absorption panel. In this regard, molten salt solidifies at approximately 430°F (221°C, 494°K). When the tube panel(s) of the solar receiver is not exposed to light/heat, either intentionally at shutdown or unexpectedly due to a heliostat field malfunction, the molten salt can quickly cool and form plugs. Plugged tubes can cause delays at start up and could lead to tube failures. Thus, the ability to drain molten salt quickly is typically part of the solar receiver design. The valves and additional piping for such draining may not be depicted herein, but should be considered as being present. The present disclosure also contemplates the use of water, steam, or any other heat transfer fluid, with appropriate modifications made to other components of the solar receiver.

[0050] **FIG. 1A** is a side view of a conventional tube panel **12** which utilizes one sided heat absorption, and **FIG. 1B** is an enlarged perspective exploded view of the tube panel. This one-sided heat absorbing tube panel is used in the conventional solar receiver of **FIG. 1**. A reflective modular panel light barrier **36** is located behind the tubes **13** (i.e. the non-exposed face of the tube panel) opposite the heat absorbing (i.e. exterior) side of the tube panel. The light barrier **36** is composed of an array of metal sheets and may be coated with white paint or other reflective material on the tube side to maximize reflectance of light energy back to the tubes and reduce operating temperatures of the barrier plate. The light barrier is supported by a tube attachment structure, such as a buckstay support system **20**. Behind the light barrier (i.e. further interior of the solar receiver) is the insulation **38**, which is covered by lagging. The light barrier is designed to protect the insulation **38**, support structure **20**, and the interior parts of the solar receiver from rain and heat exposure that may travel through the gaps between the loose tangent tubes of the tube panels.

[0051] **FIGS. 2-4** are various front views of a solar receiver design with a dual-exposure or two-sided heat absorption panel, differing in the presence or absence of certain structures and allowing for a better comprehension of the present disclosure.

[0052] In **FIG. 2**, a two-sided heat absorption panel **200** is visible. The absorption panel **200** includes a tube panel **210**. The tube panel **210** has a first exposed face **222** and a second exposed face **224** (not visible; see **FIG. 5**) opposite the first exposed face. The term “exposed” refers to the fact that concentrated sunlight from heliostats can be directed against the face of the tube panel. The first face **222** and second face **224** may also be referred to as exterior faces, which also refers to their being able to receive concentrated sunlight from heliostats. The first face and the second face are generally planar surfaces. The tube panel **210** extends between an upper header **242** and a lower header **250**. Put another way, the tubes in the tube panel are interconnected by at least one upper header and at least one lower header. It should be noted that in practice, the tube panel may include multiple upper headers and lower headers. The tube panel **210** also has an upper edge **212**, a lower edge **214**, a first side edge **216**, and a second side edge **218**. It should be noted that in this view, one can see through the structure between the tube panel **210** and the structural support frame **300**.

[0053] A structural support frame **300** runs along the upper edge **212**, the first side edge **216**, and the second side edge **218** of the tube panel. The structural support frame **300** includes a first vertical column **310**, a second vertical column **320**, and an upper horizontal beam **330** extending from an upper end **312** of the first vertical column to an upper end **322** of the second vertical column. As seen here, the first vertical column **310** is adjacent the first side edge **216**, the second vertical column **320** is adjacent the second side edge **218**, and the upper horizontal beam **330** is adjacent the upper edge **212** of the absorption panel. The tube panel **210** is connected to the structural support frame **300** through the upper header **242**. Here, the tube panel is top supported. At least one panel support rod **202** extends between the structural support frame **300** and the upper header **242**; three such panel support rods are shown here.

[0054] The structural support frame **300** rests upon a base platform **204**, which may be considered as providing a platform for the absorption panel. The base platform **204** is attached to or located upon a tower **206**.

[0055] Generally, a tube panel **210** requires at least one tube pass **240**, an upper header **242**, and a lower header **250**. HTF flows from the inlet header to the outlet header (e.g. here the upper header can be the inlet header) and is heated in the tube pass by solar energy from heliostats. Each tube pass **240** includes at least one tube, and generally includes a plurality of such tubes. In **FIG. 2**, the tube panel is shown with a plurality of tube passes (here four). The tube panels and tube passes contemplated herein are of loose tube construction to allow independent differential expansion between tubes, reducing tube stresses. The exposed faces of the tubes may be coated or painted to increase/maximize heat absorption, for example with a special high temperature black paint. Adjacent tube passes are arranged so that heat transfer fluid flows upward through one tube pass and down through another tube pass in a serpentine manner. Various fluid flow arrangements may be used to facilitate draining of the HTF and minimize the number of vent and drain valves. Arrows here illustrate one such fluid flow arrangement.

[0056] In **FIG. 3**, two stiffener structures are shown. Each stiffener structure preferably runs from the first side edge **216** to the second side edge **218** across the first face **222** and the second face **224** of the tube panel. Here, a first stiffener structure **401** is located at a first support elevation **225** and a second stiffener structure **402** is located at a second support elevation **226**. The two stiffener structures are arranged in parallel. As explained further below, each stiffener structure is formed from two support assemblies, one support assembly on each face of the tube panel. Each support assembly includes a support tube. Here, support tube **400** is visible on this first face. The support tube **406** provides stiffener structures on the second face.

[0057] Generally, the number of stiffener structures can depend on the maximum unsupported length of the tube panel that will resist wind and seismic loads. In this regard, the tube panel **210** can be considered as being divided into an upper section **230**, a middle section **232**, and a lower section **234**, which generally (but not necessarily) divide the exposed portion of the tube panel into equal sections along its height. The first stiffener structure **401** is shown in the upper section **230**, and the second stiffener structure **402** is shown in the lower section **234**. Put another way, the stiffener structures are typically not located in the middle section. This keeps the stiffener structures out of the peak heat flux zone and reduces their operating temperatures. It is contemplated that the stiffener structures will include support tubes that will be cooled by some heat transfer fluid, which could be the same as or different from the HTF that is passed through the tube panel. For example, the use of oil or water can eliminate the potential for molten salt freezing in the stiffener structure during startup and shutdown. Here, the stiffener structures are illustrated as being formed in part by a support tube **400** which is connected to the upper header **242** and lower header **250**, which uses the same HTF as that passing through the tube panel **210**. The stiffener structures **401**, **402** are the portions of the support tube **400** that run across the face **222** of the tube panel **210**. The circuitry is ultimately designed to minimize temperatures and stresses, allow independent thermal expansion of the stiffener structure, and minimize the potential for freezing of fluid during startup. The outer face of the stiffener structure can be painted or coated to reduce/minimize heat absorption.

[0058] In **FIG. 4**, the structural support frame (not visible; see **FIG. 2**) is shown with heat shields mounted to protect certain parts of the design from exposure to the concentrated sunlight coming from the heliostats. The structural support frame **300** is not visible in **FIG. 4**, but is visible in **FIG. 2**. Here, a first heat shield **340** frames the first face **222** of the tube panel **210**. A second heat shield **360** (not visible; see **FIG. 5**) also frames the second face **224** of the tube panel. In this regard, the heat shield **340** includes an interior edge **342** that forms a window in the heat shield through which the tube panel **210** is visible. Dotted lines show the outline of the tube panel **210**, the upper header **242**, and the lower header **250**. As seen here, the interior edge **342** of the heat shield abuts the side edges **216**, **218** of the tube panel, but could also be arranged with a gap between the heat shield and side edges of the tube panel to reduce spillage onto the heat shields. Each heat shield **340, 360** could also be considered as having an upper face, a first side face, a second side face, and a lower face. The first heat shield and the second heat shield are generally made from a heat-resistant material. The heat shield(s) can also be coated or painted with a reflective high temperature white paint to decrease/minimize heat absorption and/or operating temperature.

[0059] **FIG. 5** is an exterior side view of the solar receiver design. The first heat shield **340** and the second heat shield **360** are visible here. The exposed first face **222** and second face **224** are also indicated. The base **302** of the structural support frame is shown here as being wider than the apex **304** of the structural support frame; this provides additional stability. It should be noted that a heat shield **370** is also present on the sides of the structural support frame **300**.

[0060] As noted in **FIG. 3**, stiffener structures are used to support and strengthen the tube panel. **FIGS. 6-8A** are different views of one exemplary embodiment of a stiffener structure. **FIG. 6** is a plan (i.e. top) view of the exemplary embodiment. **FIG. 7** is a side cross-sectional view of the exemplary embodiment. **FIG. 8** is a front view of the exemplary embodiment. **FIG. 8A** is a perspective view.

[0061] Referring to **FIG. 6**, the stiffener structure **401** is formed from a first support assembly **410** and a second support assembly **470**, which are located on the opposite exposed faces of the tube panel. (Referring back to **FIG. 3**, the first support assembly **410** is part of the support tube **400**, and the second support assembly **470** is part of the support tube **406**.) Each support assembly **410** includes a support tube **420**, horizontal flange **430**, and scallop bar **440**. The support tube **420** is contemplated to be hollow and allow a cooling fluid to pass through. A horizontal flange **430** extends from the support tube inwards towards the tube panel **210**. The horizontal flange **430** has a slot **432** therein. As seen here, the horizontal flanges **430**, **472** on the two support assemblies are opposed to each other. The scallop bar **440** has a contoured face that engages the tube panel **210**, and lugs **448** on an opposite face. The scallop bar is connected to the support tube by a pin **450** which passes through the lugs **448** and the slot **432**. The scallop bar is held snug (but not fixed) against the panel tubes **460** with pins **452** that pass through lugs **454** that are welded to some of the panel tubes, and the scallop bar engages one or more of the tubes. The lugs **454** holding the scallop bar **440** between the tubes **460** and pins **452** are offset from the lug **448** connecting the scallop bar **440** to the support tube **420**. This allows the panel tubes and scallop bars to thermally expand in unison in the vertical direction, independent of the relatively stationary (in the vertical direction) support assembly. A protective sleeve **446** can be placed between the panel tube and the scallop bar as shown to protect the tubes from wear and/or gouging if any relative motion (sliding contact) occurs between the scallop bar and panel tubes. It is noted that only one pair of flanges and lugs **430, 478** is depicted here, but additional flanges and lugs may be present on each support assembly to resist panel twisting and maintain panel-to-panel alignment. Similarly, only one scallop bar **440** is shown attached to support tube **420**, but multiple scallop bars could be used along the support tube to stiffen a single wide panel or multiple panels, for example, if there is a significant difference in vertical thermal expansion between tubes within a panel or between panels, as desired. Also, each scallop bar **440** could have multiple lugs **448**.The stiffener structure can be supported by the structural support frame (see **FIG. 3**). The support tubes can be attached or connected to the vertical columns of the support frame, though they are not shown here as such.

[0062] The stiffener structure allows for independent thermal expansion of the individual tubes in the tube panel, as well as for independent thermal expansion of the stiffener structure and the support tubes. The pin/slot arrangement between the scallop bar and the support tube permits the support tubes to thermally expand axially independently of the radial expansion of the tubes in the tube panel. (Note the axis of the support tube is perpendicular to the axis of the tubes in the tube panel.)

[0063] The support system described above allows the individual tubes **460** to be arranged in a tangent tube fashion with minimal gap between the tubes. This reduces energy loss from light passing through the gaps and therefore increases receiver heat absorption and efficiency. The individual tubes **460** are seen here with their centers **462** along the midline **405** of the tube panel. Other variations on the tube layout are also contemplated.

[0064] Referring now to **FIG. 7**, in some embodiments, the support tube **420** of the support assembly could have a different diameter **425** from the diameter **465** of any tube **460** in the tube panel to provide the support tubes with additional stiffness and in order to stiffen the panel and shade the parts associated with the support assembly, thus reducing part operating temperatures. In some embodiments, the support tube diameter **425** is larger than the diameter **465** of any tube **460** in the tube panel. The support tube **420** can also be considered as having an inner face **422** and an outer face **424**, the outer face being exposed to reflected sunlight from the heliostats. The outer face **424** of the support tube can be coated or painted to decrease/minimize heat absorption and/or operating temperature.

[0065] Referring to **FIG. 3**, at least three variations on the stiffener structures are specifically contemplated. First, the support tubes **400**, **406** that make up the stiffener structures **401**, **402** are illustrated as being connected to the upper header **242** and the lower header **250**, so that they use the same HTF as flows through the tube panel **210**. However, other embodiments are contemplated in which the support tubes use a different cooling fluid. This could be accomplished, for example, by connecting the support tubes to separate headers. Second, support tube **400** is illustrated here as contributing the support assembly to both stiffener structures **401**, **402**. In other embodiments, the stiffener structures could be made using separate support tubes. For example, a support tube could run across the first support elevation **225**, but would not run back across the second support elevation **226**; a different support tube could be used for the stiffener structure at the second support elevation if necessary. Third, as illustrated here a stiffener structure **401** uses two separate support tubes **400**, **406**. Other embodiments are contemplated where only one support tube is used for the stiffener structure. This could be done, for example, by forming the support tube as a rectangular torus that surrounds the tube panel. This single support tube would provide the stiffener structure **401** adjacent to the first face of the panel and then wrap around the panel at the same elevation and provide the stiffener structure adjacent to the opposite face of the tube panel. This could be done at the second stiffener structure elevation **402** also by the same support tube or a different support tube.

[0066] It is also noted that in **FIG. 3**, each support tube connects to the upper header and the lower header on the same side of the tube panel. For example, support tube **400** connects to both the upper header **242** and the lower header **250** along first side edge **216**. It should be understood that this may differ. For example, if only one stiffener structure is present, support tube **400** could connect to the upper header **242** along first side edge **216**, then cross the first face and connect to the lower header along second side edge **218**.

[0067] **FIG. 9** is an enlarged front view of the tube panel, with the stiffener structure removed. Generally speaking, the tube panel **500** includes a plurality of tube passes **510**, depicted here with four tube passes. Each tube pass comprises one or more tubes **512** which are parallel to each other. The tubes **512** pass between an inlet header **514** and an outlet header **516** to form a body or wall **537** upon which the focused solar energy from the heliostats can be directed. The tube passes **510** are interconnected using jumper pipes **502**. The tube passes **510** are organized in a vertical or axial direction, such that the heat transfer fluid flows in an alternating up-down direction through the tube passes, which is indicated with arrows **505**. This change in flow direction is referred to herein as a serpentine flow path.

[0068] The flow path begins at inlet **504** and ends at outlet **506**. It should be noted that if there is an even number of tube passes **510**, the inlet **504** and the outlet **506** may be located along a common edge **508** or **544** of the tube panel **500**. Alternatively, the inlet **504** and outlet **506** can be located on opposite edges **508** and **544** of the tube panel **500** when an odd number of tube passes is used. In other words, the inlet and the outlet can be independently located at the top edge **544** or the bottom edge **508**, as required by the design of the receiver. As depicted here, the inlet **504** and the outlet **506** are both located along the top edge **544**.

[0069] An inlet header is defined as such relative to the direction of flow. Thus, for tube pass **530**, header **531** is considered the inlet header and header **532** is considered the outlet header. However, for adjacent tube pass **540**, header **542** is considered the inlet header and header **541** is considered the outlet header. The headers of the tube passes can also be designated as upper headers **531**, **541**, **551**, **561** and lower headers **532**, **542**, **552**, **562** wherein the upper headers are located above the lower headers. Put another way, one set of headers **532**, **542**, **552**, **562** is located in lower plane **508**, and the other set of headers **531**, **541**, **551**, **561** is located in an upper plane **544**.

[0070] Referring again to tube pass **530**, the tubes **536** form a body **537**. The tubes are closely spaced and parallel to each other. The upper header **531** has a width **533**, and the lower header **532** has a width **534**. In some contemplated embodiments, and as illustrated here, the body **537** can have a width **538** that is greater than the header widths **533**, **534**. In other words, the body **537** may be wider than the lower header **532** and the upper header **531**. The width is measured in the horizontal direction. The lower header and the upper header of each tube panel are the same width. The ratio of the body width **537** to the width of the lower header or upper header **532**, **531** can at least 1.01:1, and may range from 1.01 to 1.5. This permits the spacing between edge tubes in adjacent panels to be the same as the close spacing between tubes within a panel. In such embodiments, the upper headers of adjacent tube panels would be laterally separated from each other. The lower headers of adjacent tube panels would also be laterally separated from each other. This may allow the tube panels to expand differentially with respect to each other because they are operating at different temperatures.

[0071] **FIG. 10** is a schematic diagram illustrating fluid flow through the dual-exposure heat absorption panel **600**. Initially, a riser **670** provides cold fluid to an inlet vessel **660** from cold storage tank **652**. For example, "cold" molten salt may be pumped from the cold storage tank having a temperature of about 550°F. An inlet pipe **672** fluidly connects the inlet vessel **660** to the tube panel inlet **674**. The jumper pipes **696** between tube passes is also illustrated. An outlet pipe **678** fluidly connects the tube panel outlet **676** to an outlet vessel **662**. The heat transfer fluid (HTF) can flow from the inlet vessel **660** through the tube panel **684** to the outlet vessel **662**. A downcomer pipe **688** leads from the outlet vessel **662** back down to grade, where the "hot" fluid can flow into hot storage tank **650**.

[0072] The inlet vessel **660** is optional and not required, which is indicated by the use of dotted lines, for example if the heat transfer fluid is steam/water. The outlet pipe **678** and outlet vessel **662** are also optional and not required, which is indicated by dotted line. Without an outlet vessel, the HTF flows from the tube panel outlet **676** directly to the downcomer pipe **688** via outlet pipe **691**. A bypass line **690** also connects the riser **670** to the downcomer pipe **688**. If desired, this bypass flow path can prevent the HTF from flowing through the tube panel **684**.

[0073] This completes the energy collection process. The stored thermal energy in the heat transfer fluid can be used to generate steam and electricity. This is done by, for example, pumping the hot HTF from the hot storage tank **650** through the shell side of a heat exchanger **654**. Water enters the tube side of heat exchanger **654** and is converted to steam. The steam can be sent to turbine **656**, which drives an electrical generator **658**. The cooler HTF leaving the heat exchanger then returns to the cold storage tank **652**, where it is pumped to the receivers to repeat the energy collection process described above.

[0074] For a molten salt receiver, the tube panels must be fully drainable and ventable. The receiver is usually drained when not in use, at sunset, or when available solar energy is too low. Molten salt solidifies at approximately 430°F (221°C, 494°K). If not drained, the salt can freeze inside the tubes, plug the receiver, and could rupture the tubes. As seen here, the solar receiver can include a vent valve **692** for each independent flow path which are both vented through the top of the downcomer pipe **688**. The vent valve is typically located near the top of the downcomer pipe **688**, and the vent piping **694** is also illustrated connecting the flow path to the downcomer pipe. One drain valve **697** is typically provided for each pair of tube passes, and is located beneath the tube passes. The drain piping **698** is also illustrated, and connects to the downcomer **688** so that fluid present in the tube panel drains and flows into the downcomer pipe **688**. The vent valves and drain valves are automated.

[0075] It should be noted that in **FIG. 10**, the various pipes are illustrated as being relatively straight fluid paths. However, it will be appreciated by those skilled in the art that their actual design in terms of arrangement and length will be determined by the degree of flexibility required to accommodate expected motions caused by thermal expansion and contraction during operation of the solar receiver. It is thus likely that additional bends or length may be necessary to provide such flexibility.

[0076] One problem with traditional solar receiver arrangements that have only one exposed face is that there is only limited access to the tubes in the tube panels if a tube should fail. Referring back to **FIG. 1**, such solar receivers typically have panels around 360° of a supporting structure, which leaves only one side for access to the tube panel (i.e. the interior side). In addition, referring to **FIG. 1A** and **FIG. 1B**, the presence of the insulation and the light barrier increases the maintenance time needed to complete any repairs to the tube panels. The two-sided heat absorption panel of the present disclosure allows maintenance access along the upper edge, lower edge, and two side edges, providing access around 360° of the tubes for removing a failed tube and inserting a new replacement. In addition, the tube-to-tube weld between the headers and the tube panel is located within the heat-shielded area (see **FIG. 5**). This is desirable to reduce tube temperature due to filler material in the new weld being thicker than the tube wall.

[0077] Traditional solar receivers typically use a tube-to-tube butt weld of very thin tubes. Because the new / repair weld is out of the concentrated sunlight, different tube couplings can be used. One such repair tube coupling is seen in **FIG. 11**. This repair coupling is significantly easier to weld when replacing a failed tube. The header **750** is shown here, with a header tube stub **760** from the prior (failed) tube extending from the header. The prior header tube stub ends at a line **762**, which can be cut in the field depending on the failure location of the original tube. The prior tube stub is a portion of the former existing tube that did not fail. The new replacement tube **780** is abutted to the field-cut line **762**. A repair coupling **770** is used to surround the ends of the tube stub and the replacement tube, similar to inserting the two tubes into a cylindrical sleeve. Field welds can then be used to join the repair coupling **770** to the tube stub **760** and the replacement tube **780** respectively (e.g. using a fillet weld). This repair coupling **770** is located behind a heat shield, and is not exposed to the sunlight from the heliostats.

[0078] The tube panel can be stiffened using different means, such as the stiffener structure seen in **FIGS. 6-8**. Another stiffening structure can be located in the heat-shield protected sections of the absorption panel. This is shown in **FIG. 12**. The lower header **250** is depicted here as having a header tube stub **720**. The header tube stub has an exterior diameter **722** and an interior diameter **724**. Also illustrated is a wall tube **700** in the tube panel. The tube has an exterior diameter **712** and an interior diameter **714**. The interior diameter **724** of the tube stub **720** is the same as the interior diameter **714** of the tube **710**. However, the exterior diameter **722** of the tube stub is larger than the exterior diameter **712** of the tube. In other words, the wall of the tube stub **720** has a thickness **707** that is greater than the thickness **705** of the wall of the tube **710**. The tube stub **720** and the tube **710** are welded together using a fillet weld. Put another way, there is a discontinuous change in thickness. The heavier and thicker wall tube would increase the rigidity of the tube panel between the upper header and the lower header, permitting longer light exposed sections for the tube panel. Additionally, any support clips or welds could be larger and stronger due to the thicker tubes.

[0079] **FIG. 13** presents an alternative heat shield design. In **FIG. 4**, the interior edge **342** of the heat shield **340** abuts the side edges **216**, **218** of the tube panel. Here, a gap or an open space **201** is present between the side edges **216**, **218** of the tube panel and the interior edge **342** of the heat shield. Such an open space creates a free-standing tube panel. This arrangement allows the heliostats to be focused more uniformly across the width of the tube panel, which generally requires some heliostats to be focused towards the edges of the tube panel. The open space provides a buffer that reduces spillage of concentrated sunlight upon the heat shields. Instead, the concentrated sunlight can pass through the open space, though it would be considered an energy loss. In more detail, the interior edge **342** of the heat shield includes an upper edge **344**, a lower edge **346**, a first side edge **348**, and a second side edge **350**. An open space **201** is present between the interior side edges **216**, **218** of the heat shield and the side edges **348**, **350** of the tube panel. In particular embodiments, the open space has a width of at least 1% of the width of the tube panel. Support tubes **400** and **406** are also visible here.

[0080] Another consideration in designing a solar receiver is a scenario in which heat transfer fluid (HTF) ceases to flow through the tube panel, for example by loss of plant power or loss of the pumps used to move the HTF through the solar receiver. In this scenario, the heliostats are all still focused on the tube panel(s) of the solar receiver. The heliostats cannot be instantaneously defocused, and without HTF flow the high heat flux can quickly overheat the tube panel.

[0081] In a prior solar receiver known as Solar Two, which was operated from January 1998 to April 1999, inlet and outlet HTF vessels were used as buffers. The inlet vessel was pressurized with compressed air at a pressure high enough to continue flowing HTF contained within the inlet vessel through the tube panels long enough to allow the heliostats to be defocused off of the receiver.

[0082] **FIG. 14** and **FIG. 15** depict another arrangement which is permitted with the solar receiver designs of the present disclosure. Here, the heat shield **340** includes an upper face **352**, a first side face **354**, and a second side face **356**. Again, a window or aperture **355** is present within the heat shield through which the tube panel **210** is visible. A curtain **750** is located on the exterior of the upper face **352** of the first heat shield above the tube panel **210**. Here, the curtain is rolled up in a stowed position. The curtain can be made from a high temperature resistant material, such as a ceramic blanket. Means **752** for guiding the curtain are located on the first side face **354** and the second side face **356** of the heat shield. As seen in **FIG. 15**, a curtain can also be located on the second side on the second heat shield **360**. Support tubes **400** and **406** are also visible in **FIG. 14**.

[0083] When a trip condition exists, the curtain would be released and fall in front of the tube panel to block the concentrated sunlight coming from the heliostats. This would protect the tube panel from overheating until the heliostats could be defocused off of the receiver, eliminating the need for an inlet vessel. One benefit of this solar receiver design is that the edges of the curtain can be positively guided to pull the curtain down and keep the curtain from blowing in the wind, which could uncover portions of the tube panel. Here, the curtain can extend beyond the width of the tube panel. Thus, the edges of the curtain can be guided, for example via rails (like a garage door) or using guide cables. Here, the guidance means is shown as a path **758** through the heat shield, with cables attached to the curtain. This also protects the mechanism for driving the curtain down over the tube panel. For example, the bottom edge of the curtain may be weighted. Alternatively, cables could be used to pull the curtain down from the sides.

[0084] **FIG. 16** is a front view illustrating the lowering of the curtain. The curtain **750** is illustrated as being lowered about halfway down. The bottom edge of the curtain is weighted (reference numeral **754**). Guide cables **756** are running down the cable paths **758**, and are attached to the bottom corners of the curtain.

[0085] The present disclosure has been described with reference to exemplary embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the present disclosure be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

1. A dual-exposure heat absorption panel, comprising:

a tube panel comprising a plurality of vertical tubes for conveying a heat transfer fluid, wherein the tubes are interconnected by at least one upper header and at least one lower header, and wherein the tube panel has a first exposed face, an opposite second exposed face, an upper edge, a lower edge, a first side edge, and a second side edge; and

a structural support frame that runs along the upper edge, the first side edge, and the second side edge of the tube panel;

wherein at least one tube in the tube panel is connected to the at least one upper header or the at least one lower header by a repair coupling surrounding the at least one tube and a prior header tube stub.

2. The dual-exposure panel of claim 1, wherein the repair coupling is behind heat shields mounted to the structural support frame and is not exposed to direct sunlight.

3. The dual-exposure panel of claim 1, further comprising a first stiffener structure running from the first side edge to the second side edge across the first exposed face and the second exposed face of the tube panel at a first support elevation.

4. The dual-exposure panel of claim 3, wherein the stiffener structure is formed from a first support assembly and a second support assembly, each support assembly including:

a support tube;

a horizontal flange extending from the support tube and having a slot therein; and

a scallop bar engaging one or more vertical tubes of the tube panel and having at least one lug, the scallop bar engaging the horizontal flange by a pin passing through the at least one lug and the slot of the horizontal flange.

5. The dual-exposure panel of claim 4, wherein the support tube of each support assembly has a different diameter from any tube in the tube panel.

6. The dual-exposure panel of claim 3, further comprising a second stiffener structure running from the first side edge to the second side edge across the first exposed face and the second exposed face of the tube panel at a second support elevation.

7. The dual-exposure panel of claim 6, wherein the first support elevation and the second support elevation are not located at a middle section of the tube panel.

8. A dual-exposure heat absorption panel, comprising:

a tube panel comprising a plurality of vertical tubes for conveying a heat transfer fluid, wherein the tubes are interconnected by at least one upper header and at least one lower header, and wherein the tube panel has a first exposed face, an opposite second exposed face, an upper edge, a lower edge, a first side edge, and a second side edge; and

a structural support frame that runs along the upper edge, the first side edge, and the second side edge of the tube panel;

wherein the tube panel includes at least one tube joined to a header tube stub on either the at least one upper header or the at least one lower header, an exterior diameter of the header tube stub being greater than a central exterior diameter of the at least one tube.

9. The dual-exposure panel of claim 8, wherein an interior diameter of the at least one tube is the same as an interior diameter of the header tube stub.

10. A dual-exposure heat absorption panel, comprising:

a tube panel comprising a plurality of vertical tubes for conveying a heat transfer fluid, wherein the tubes are interconnected by at least one upper header and at least one lower header, and wherein the tube panel has a first exposed face, an opposite second exposed face, an upper edge, a lower edge, a first side edge, and a second side edge; and

a structural support frame that runs along the upper edge, the first side edge, and the second side edge of the tube panel;

the structural support frame including a first heat shield framing the first exposed face of the tube panel, an open space being present between the first heat shield and the tube panel.

11. A dual-exposure heat absorption panel, comprising:

a tube panel comprising a plurality of vertical tubes for conveying a heat transfer fluid, wherein the tubes are interconnected by at least one upper header and at least one lower header, and wherein the tube panel has a first exposed face, an opposite second exposed face, an upper edge, a lower edge, a first side edge, and a second side edge; and

a structural support frame that runs along the upper edge, the first side edge, and the second side edge of the tube panel;

wherein the structural support frame includes a first heat shield framing the first exposed face of the tube panel, the first heat shield including an upper face, a first side face, and a second side face;

a curtain on the upper face of the first heat shield above the tube panel; and

means for guiding the curtain located on the first side face and the second side face of the heat shield.

12. The dual-exposure panel of claim 11, wherein the curtain has a length sufficient to cover the entirety of the tube panel.

13. The dual-exposure panel of claim 11, wherein the means for guiding includes rails or cables.

14. The dual-exposure panel of claim 11, wherein a bottom edge of the curtain includes weights.

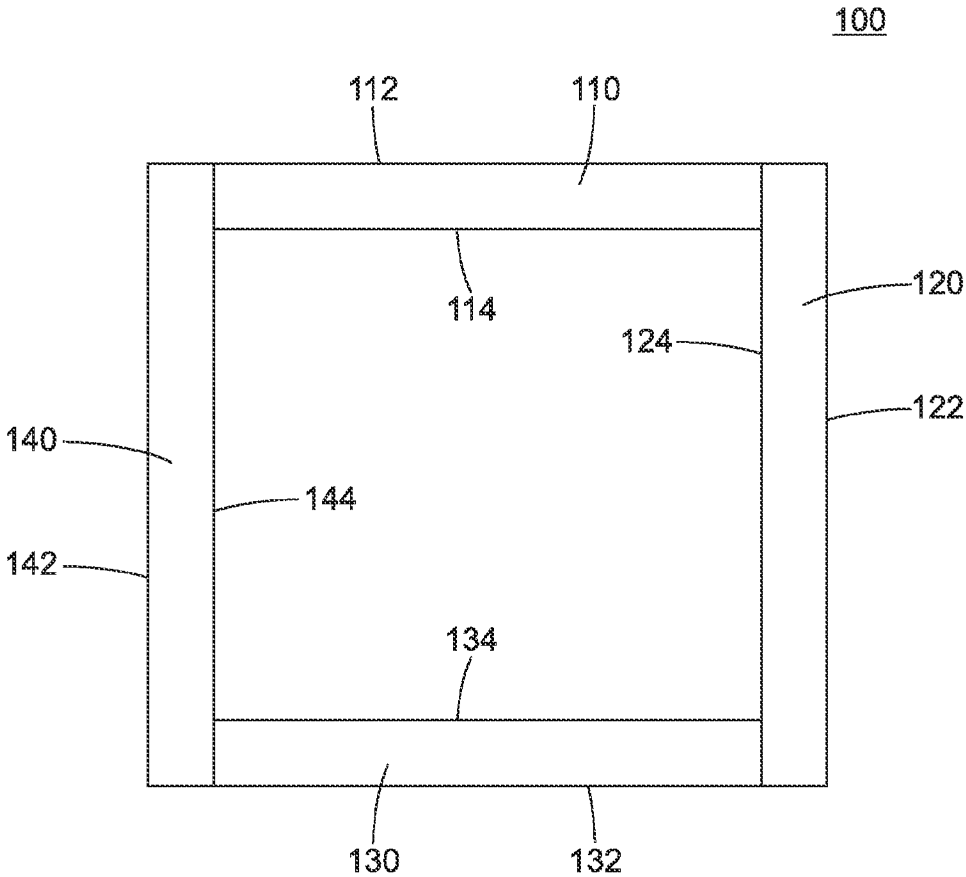

FIG. 1

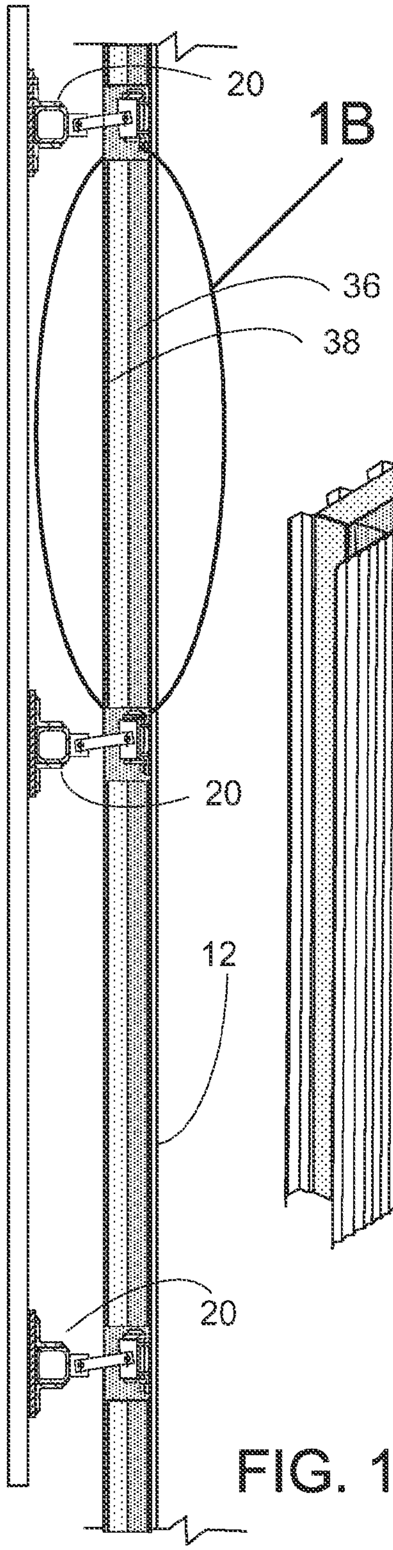

FIG. 1A

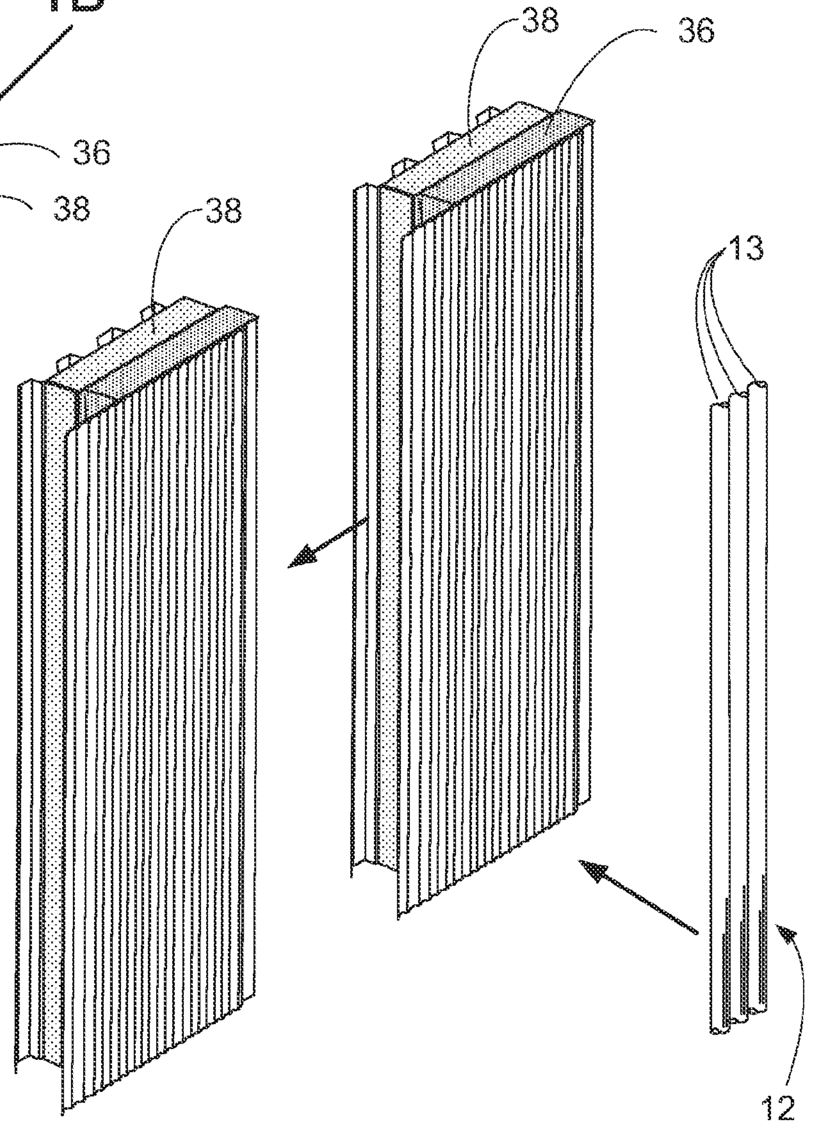

FIG. 1B

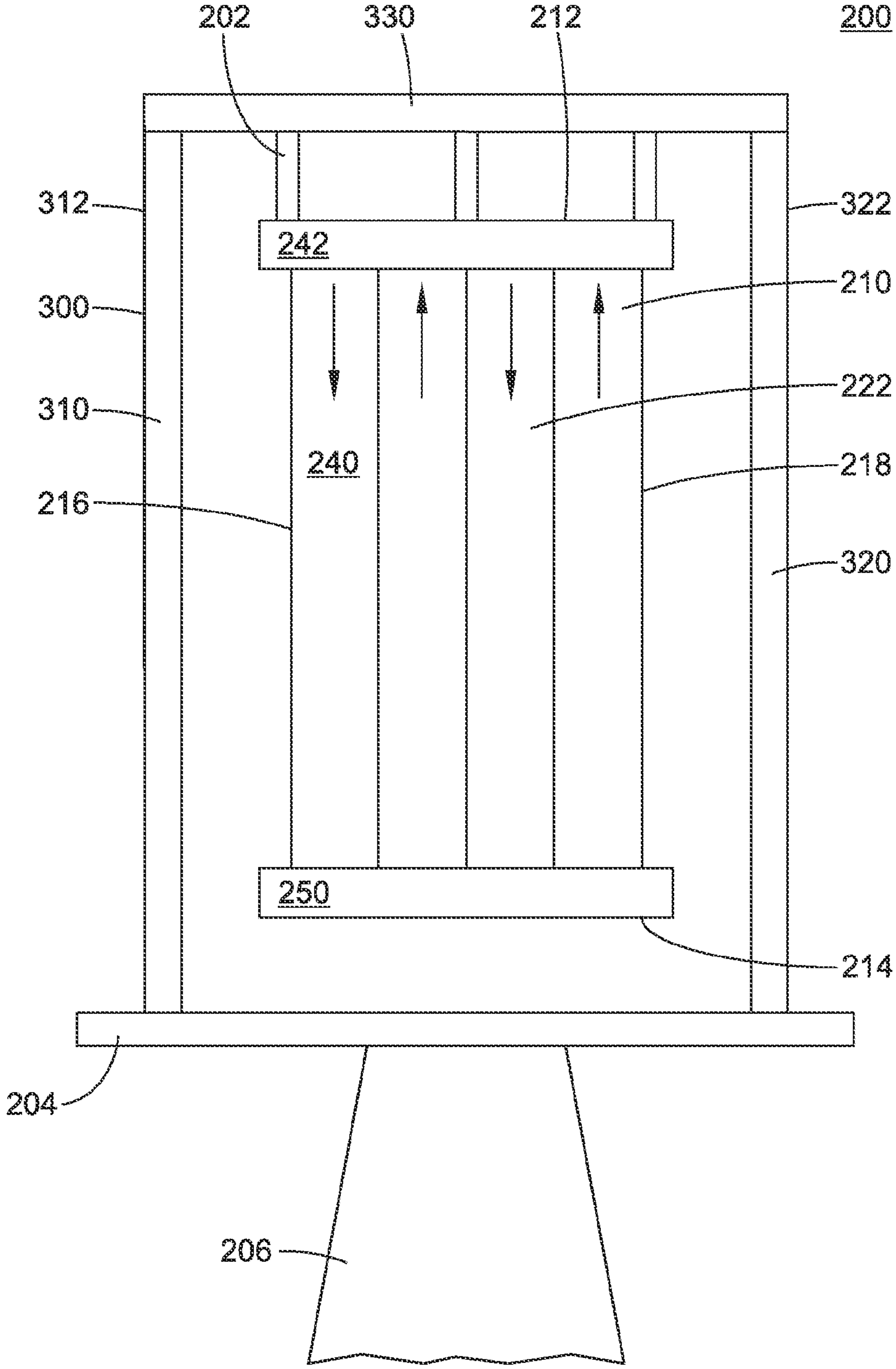
202
330
212
200
312
322
242
300
210
310
222
240
218
216
320
250
214
204
206

FIG. 2

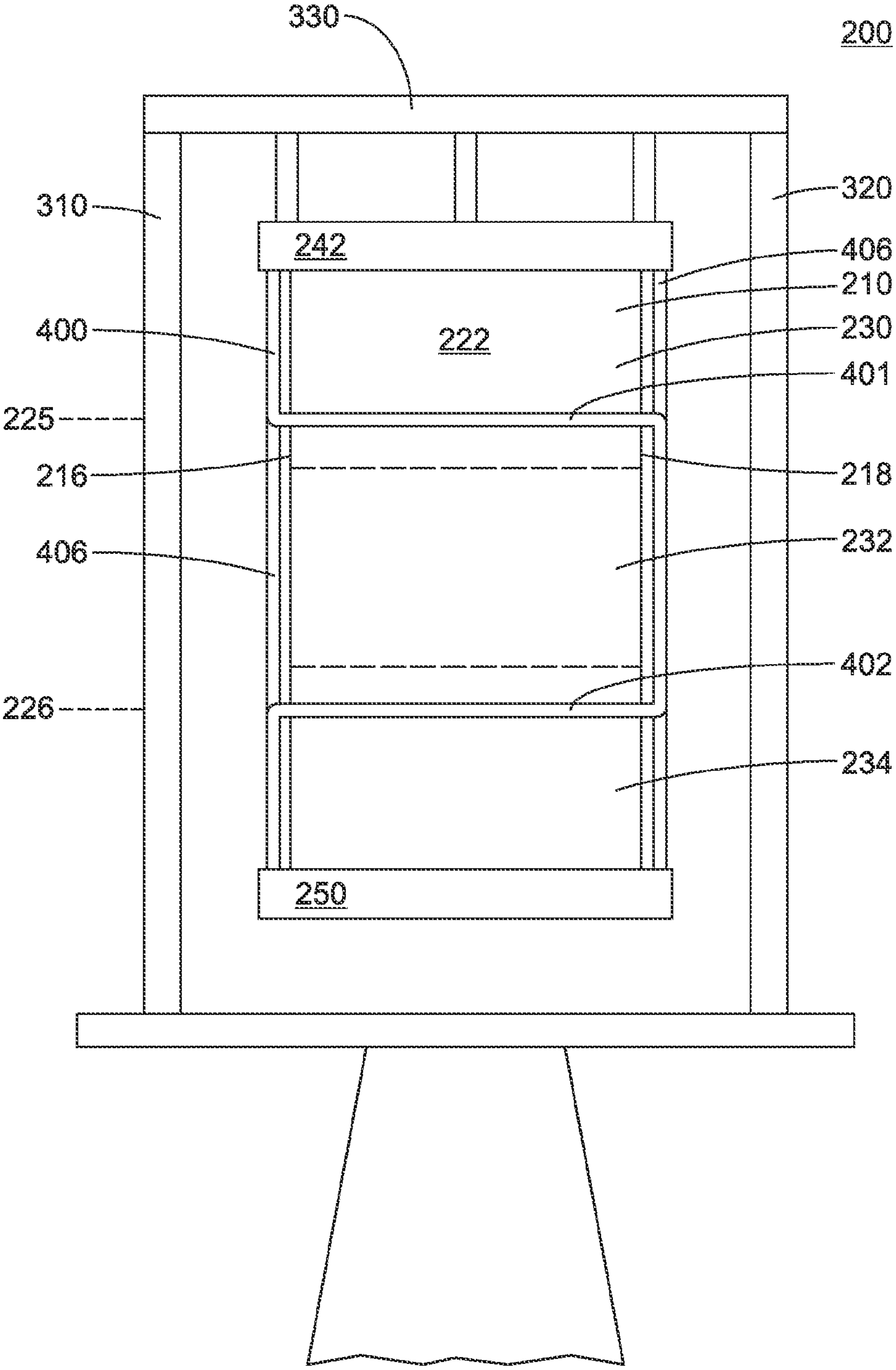
330
200
310
320
242
406
210
400
222
230
401
225
216
218
406
232
402
226
234
250

FIG. 3

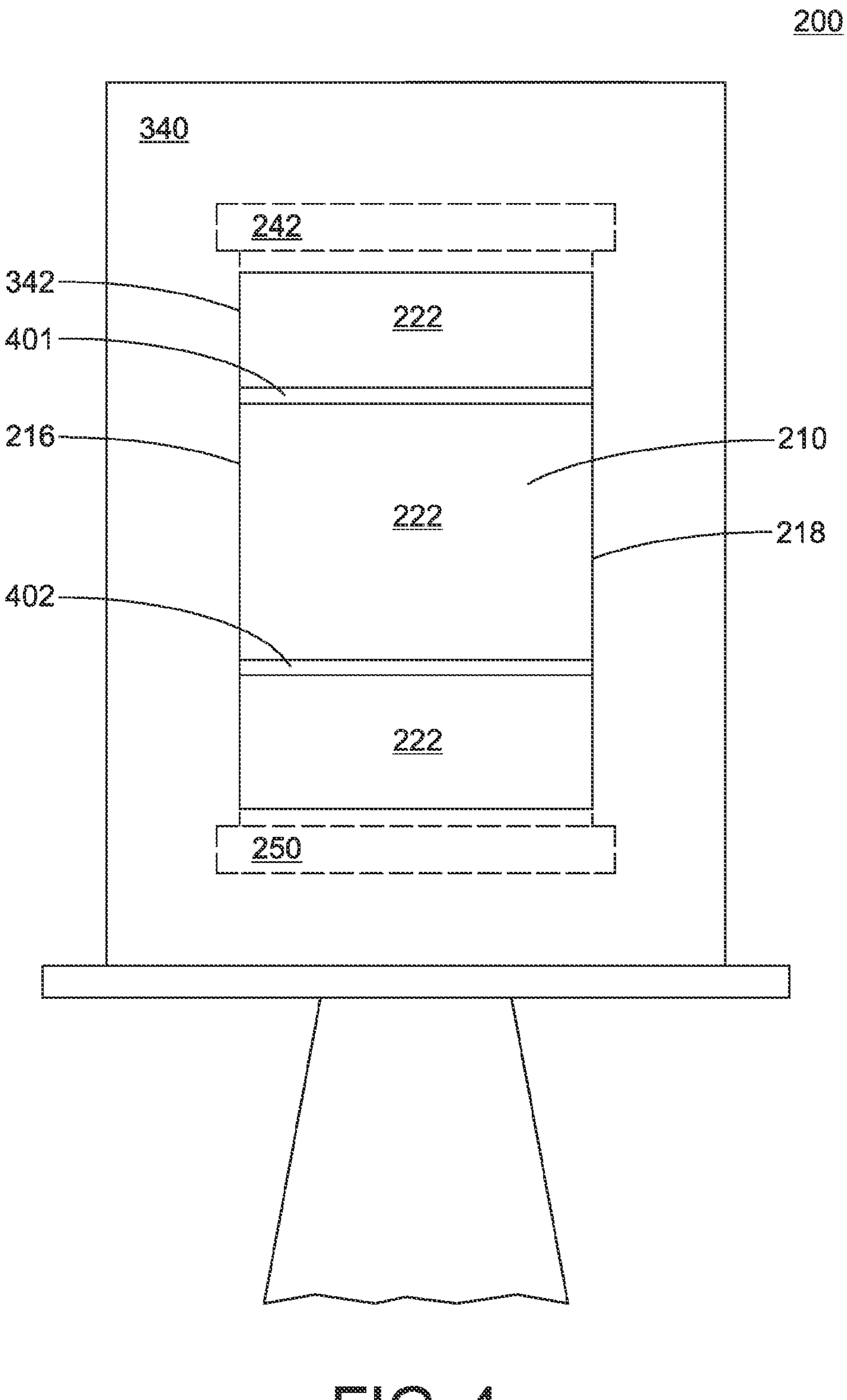

FIG. 4

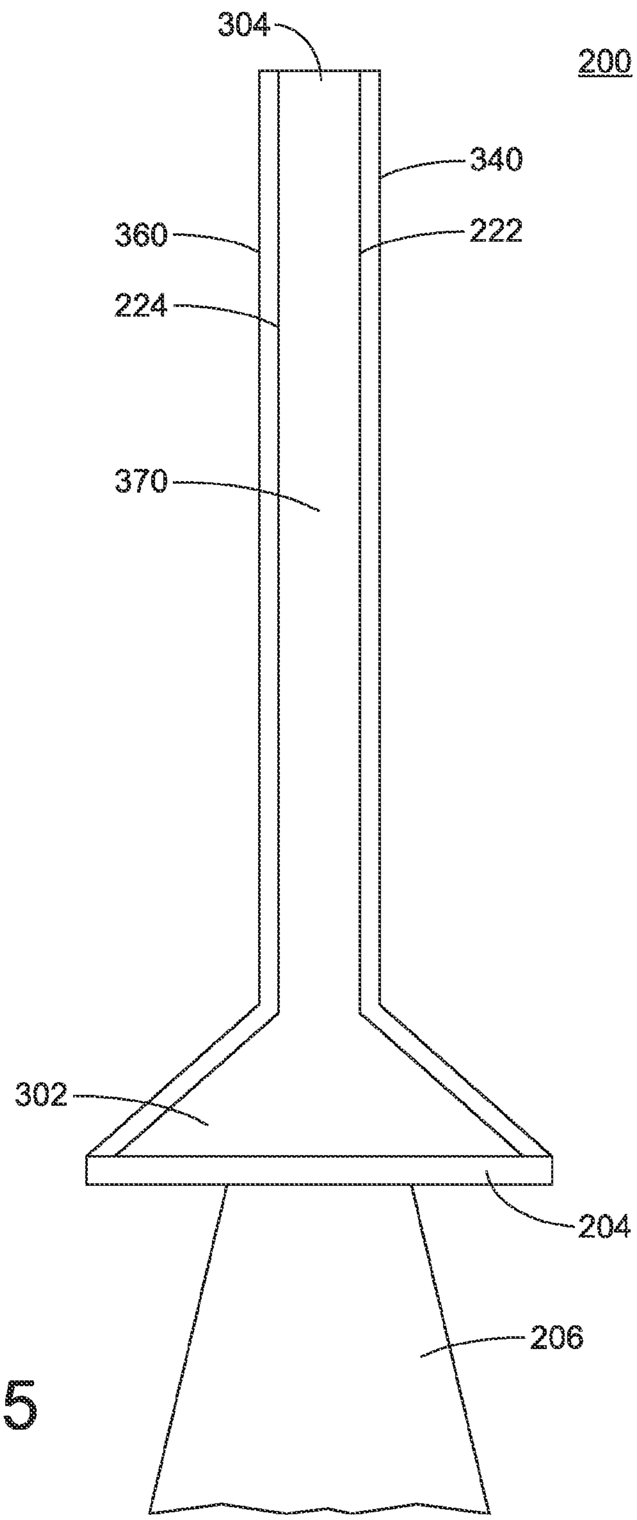

FIG. 5

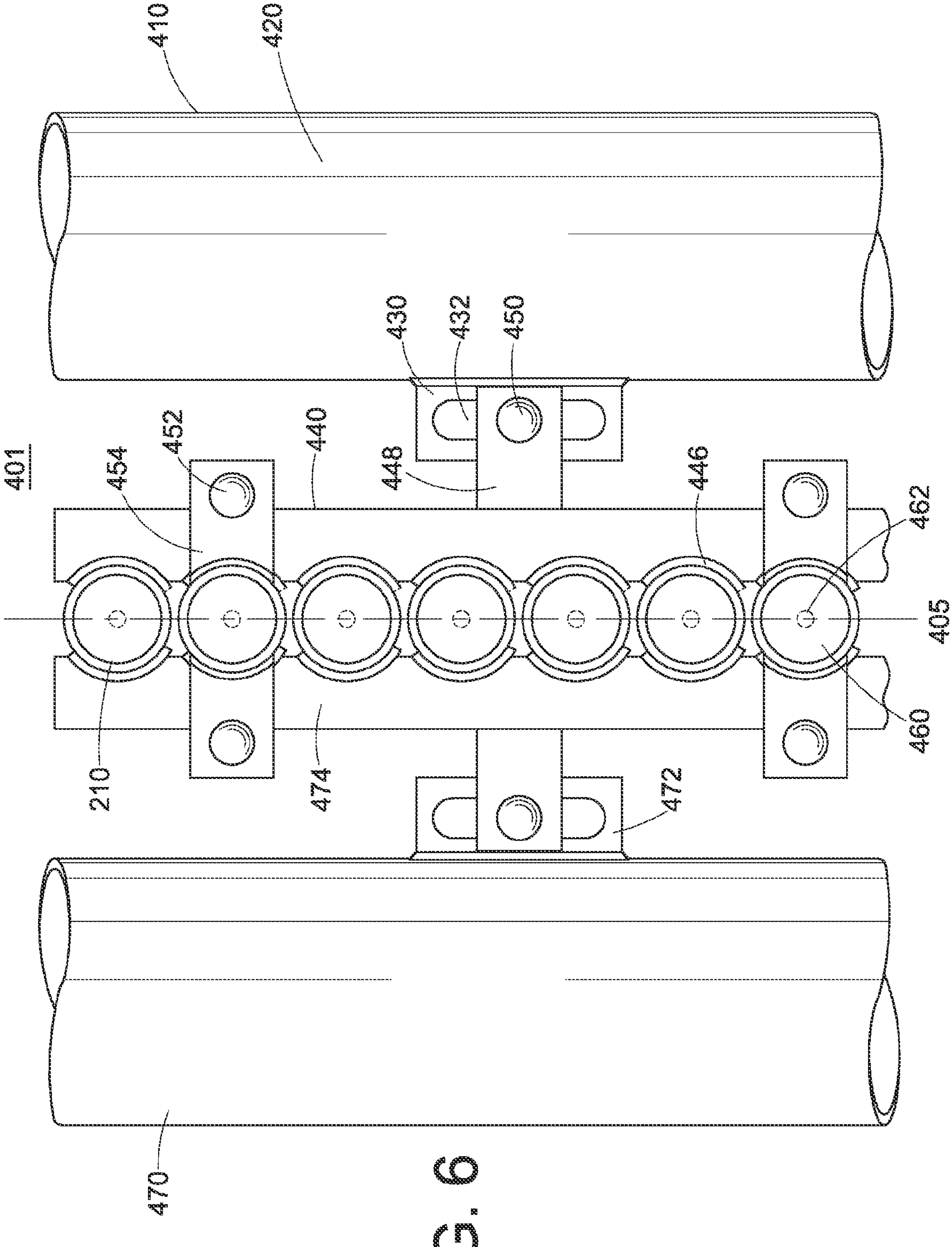
410
420
430
432
450
401
452
454
440
448
446
462
405
460
210
474
472
470

FIG. 6

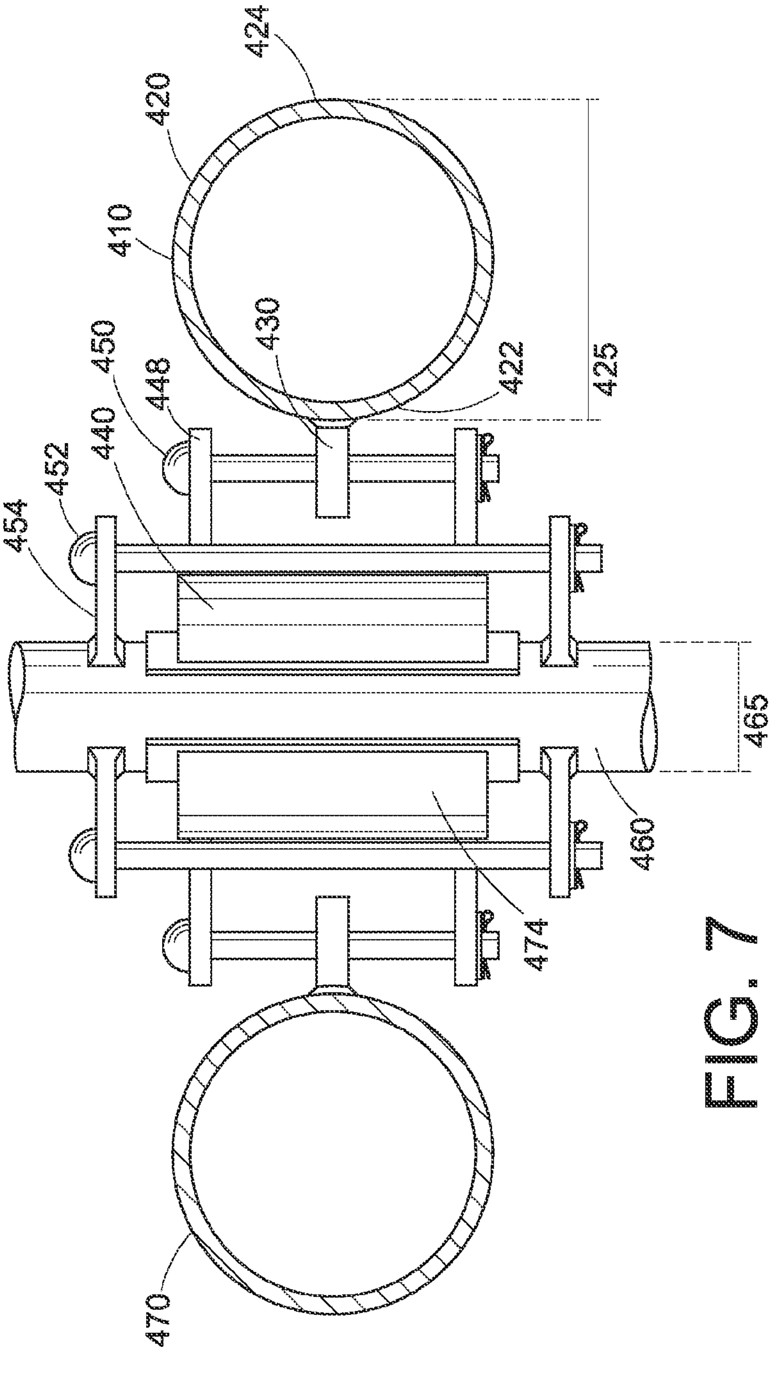

FIG. 7

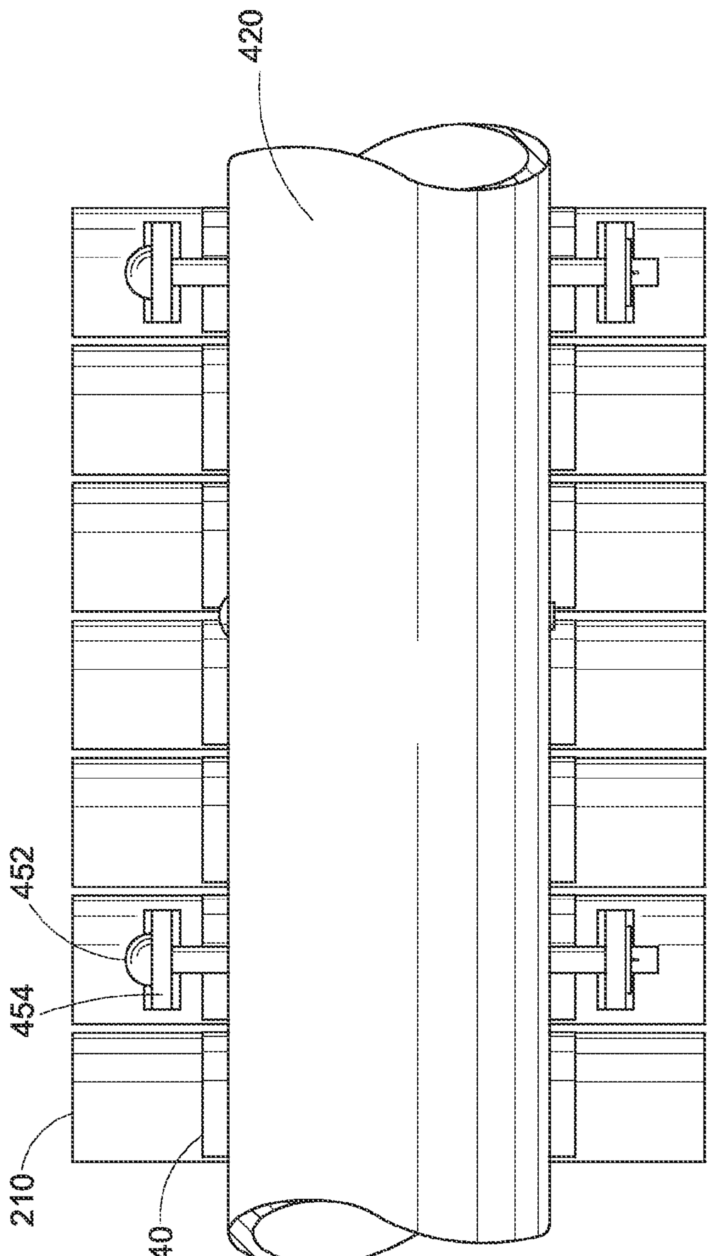

FIG. 8

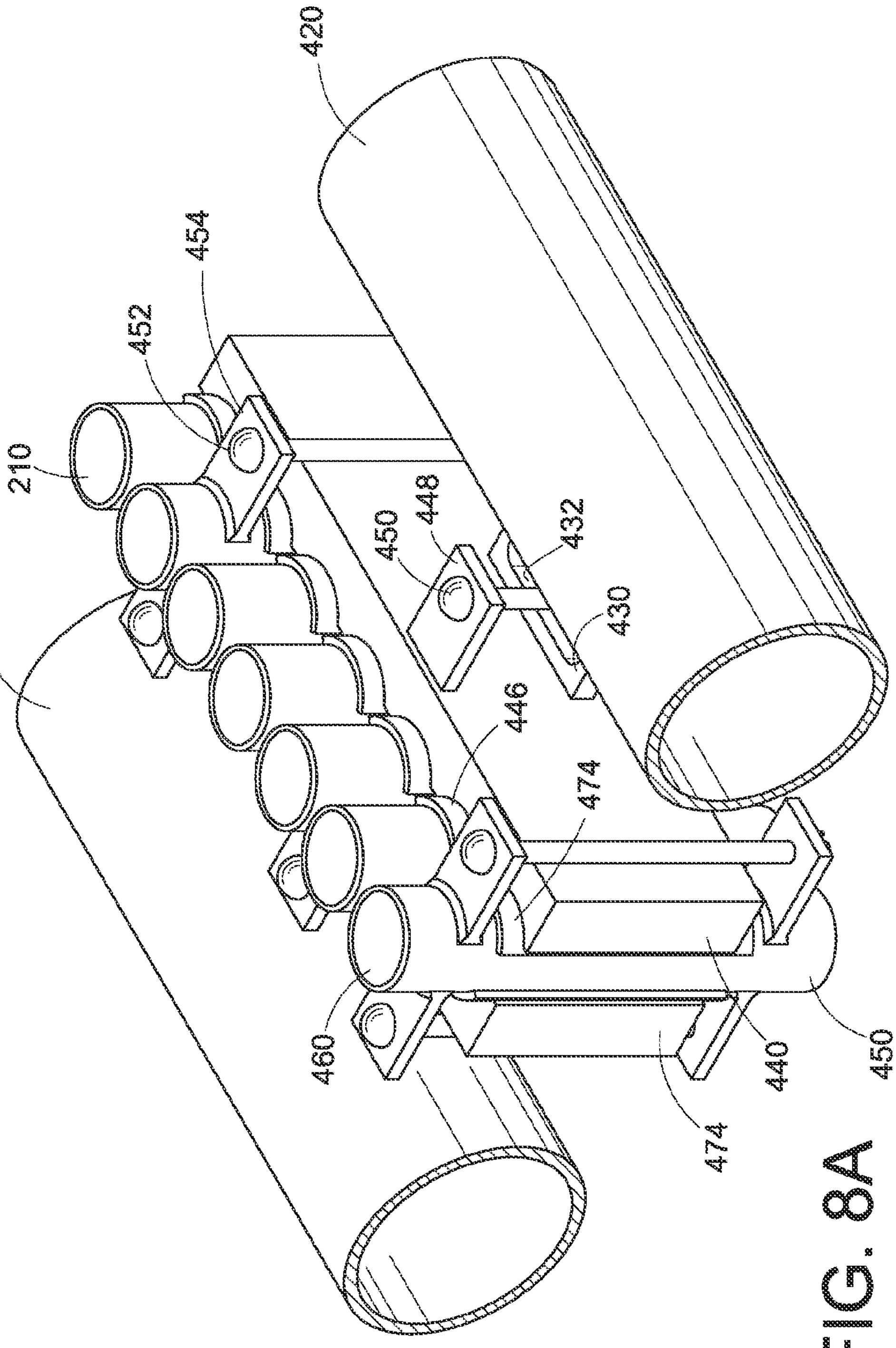

FIG. 8A

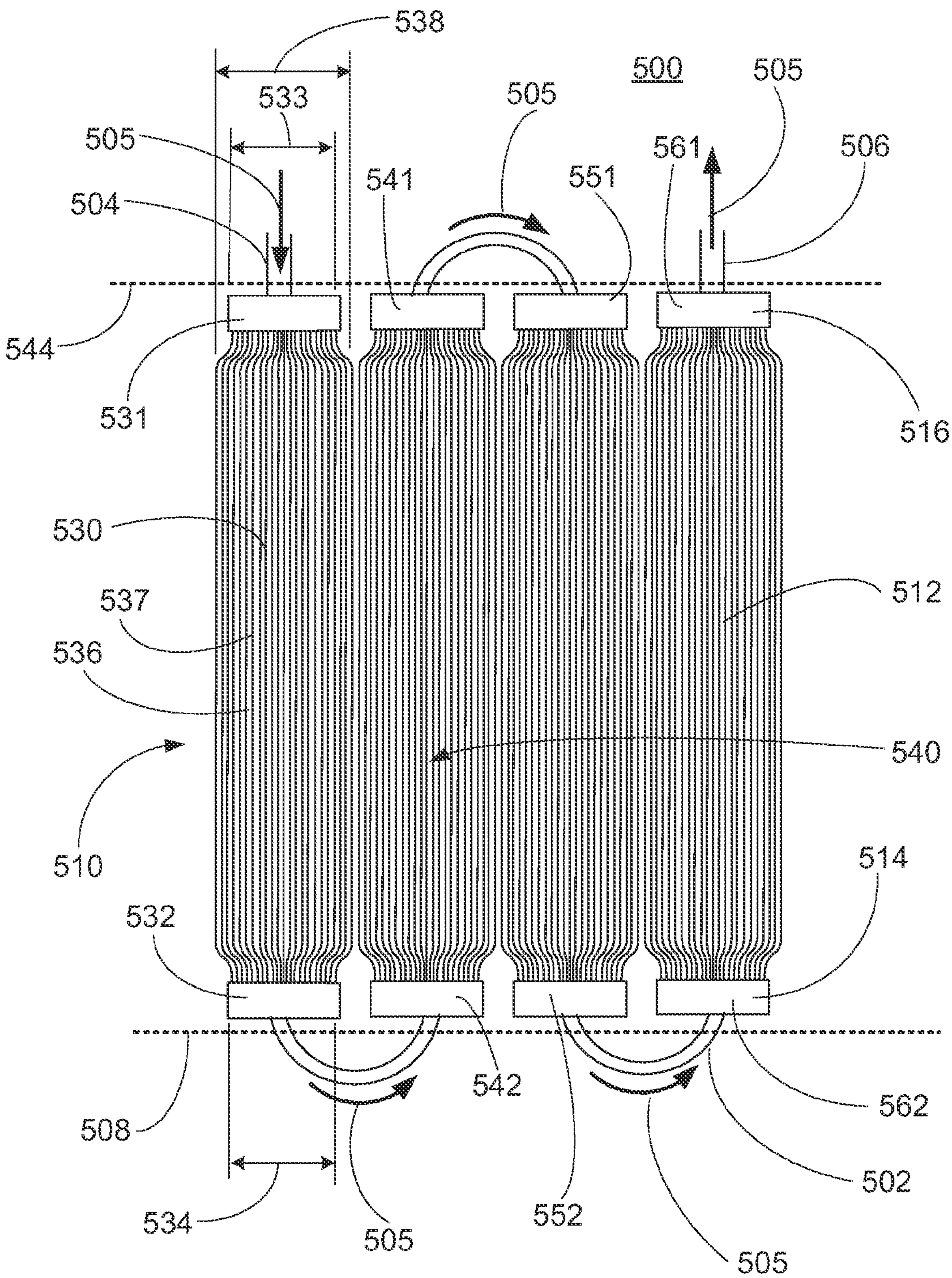
538
533
500
505
505
505
561
506
541
551
504
544
531
516
530
512
537
536
540
510
514
532
542
508
562
502
534
505
552
505

FIG. 9

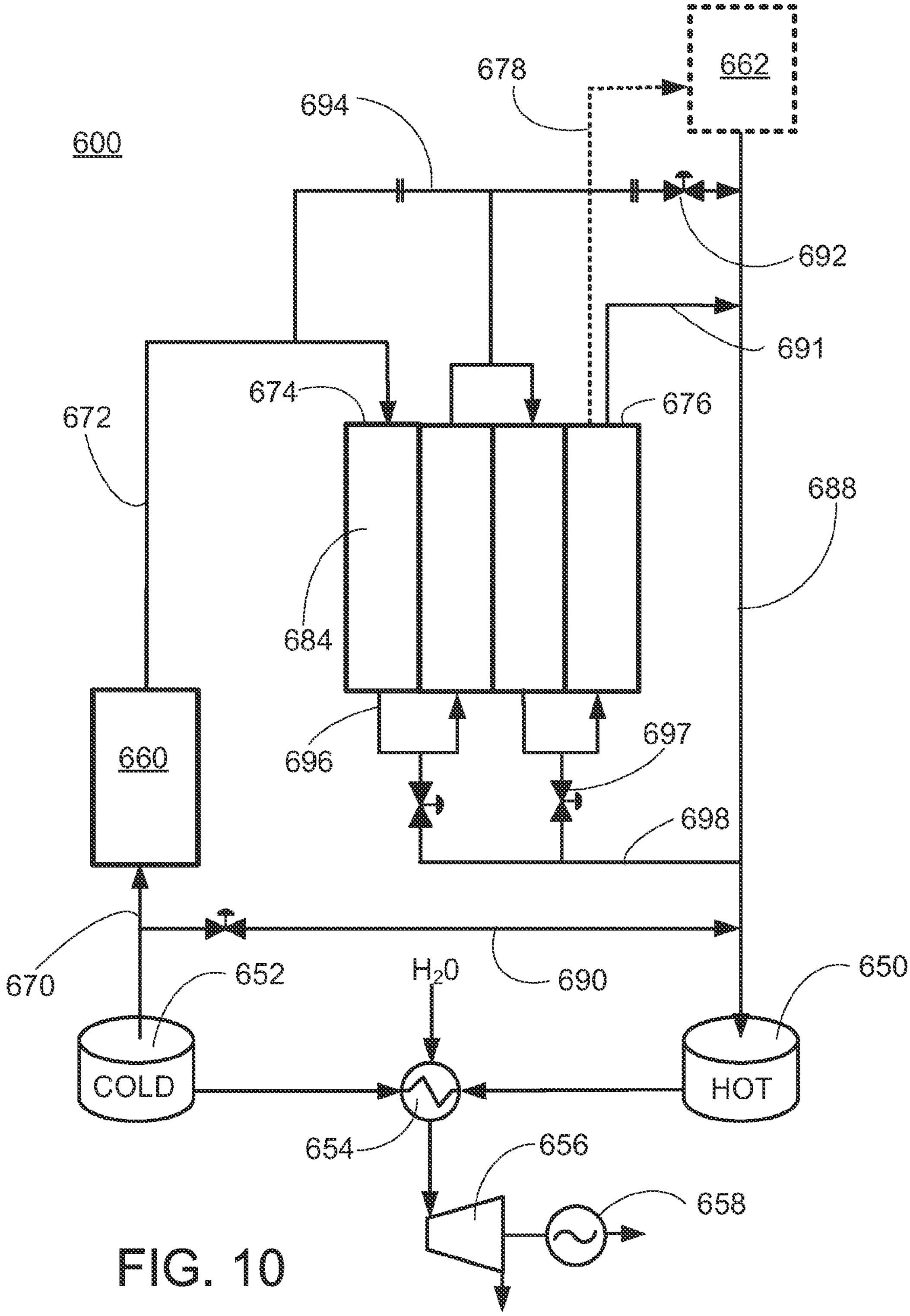
600
662
678
694
692
691
674
676
672
688
684
660
696
697
698
670
690
652
650
H_20
COLD
HOT
654
656
658

FIG. 10

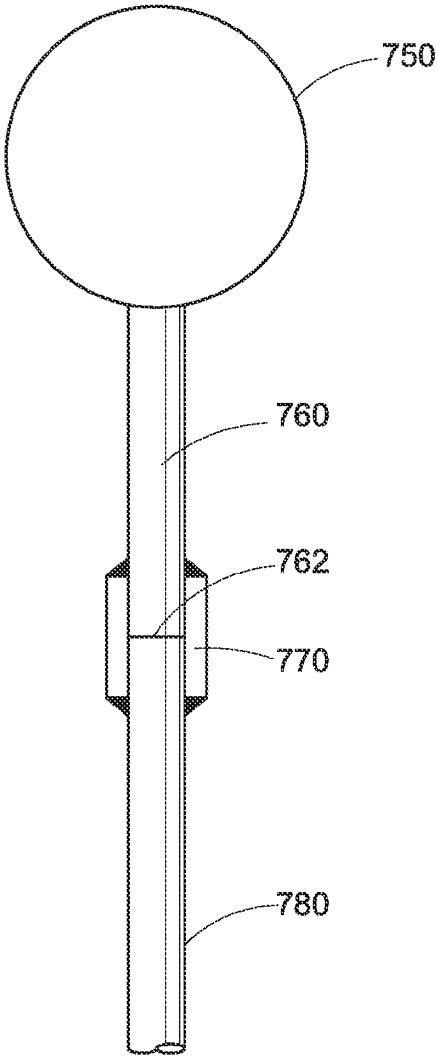

FIG. 11

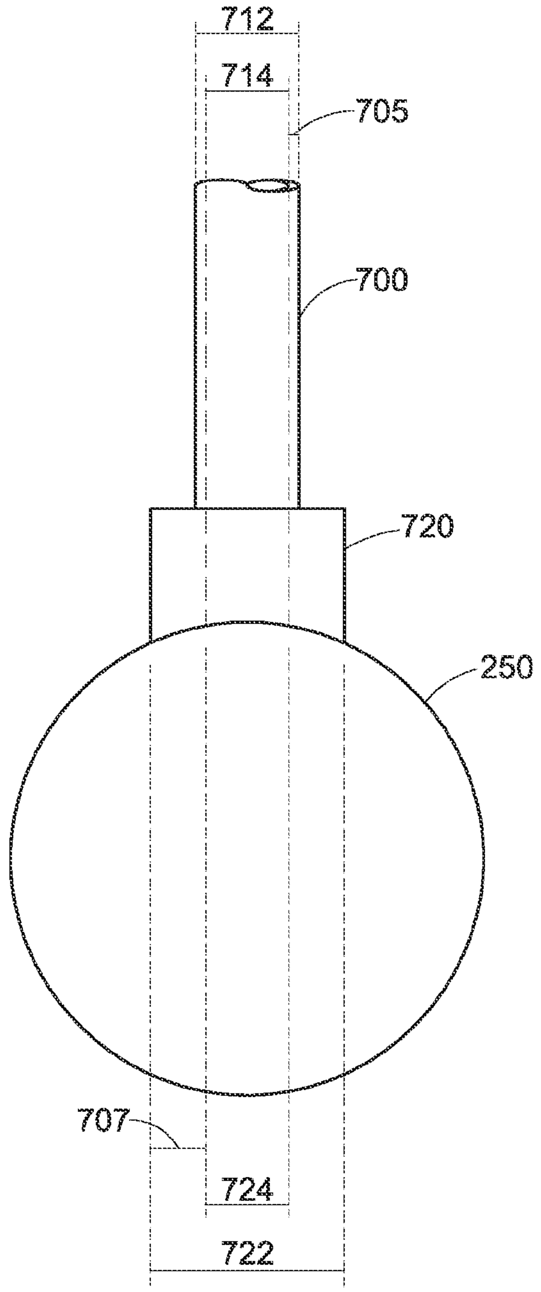

FIG. 12

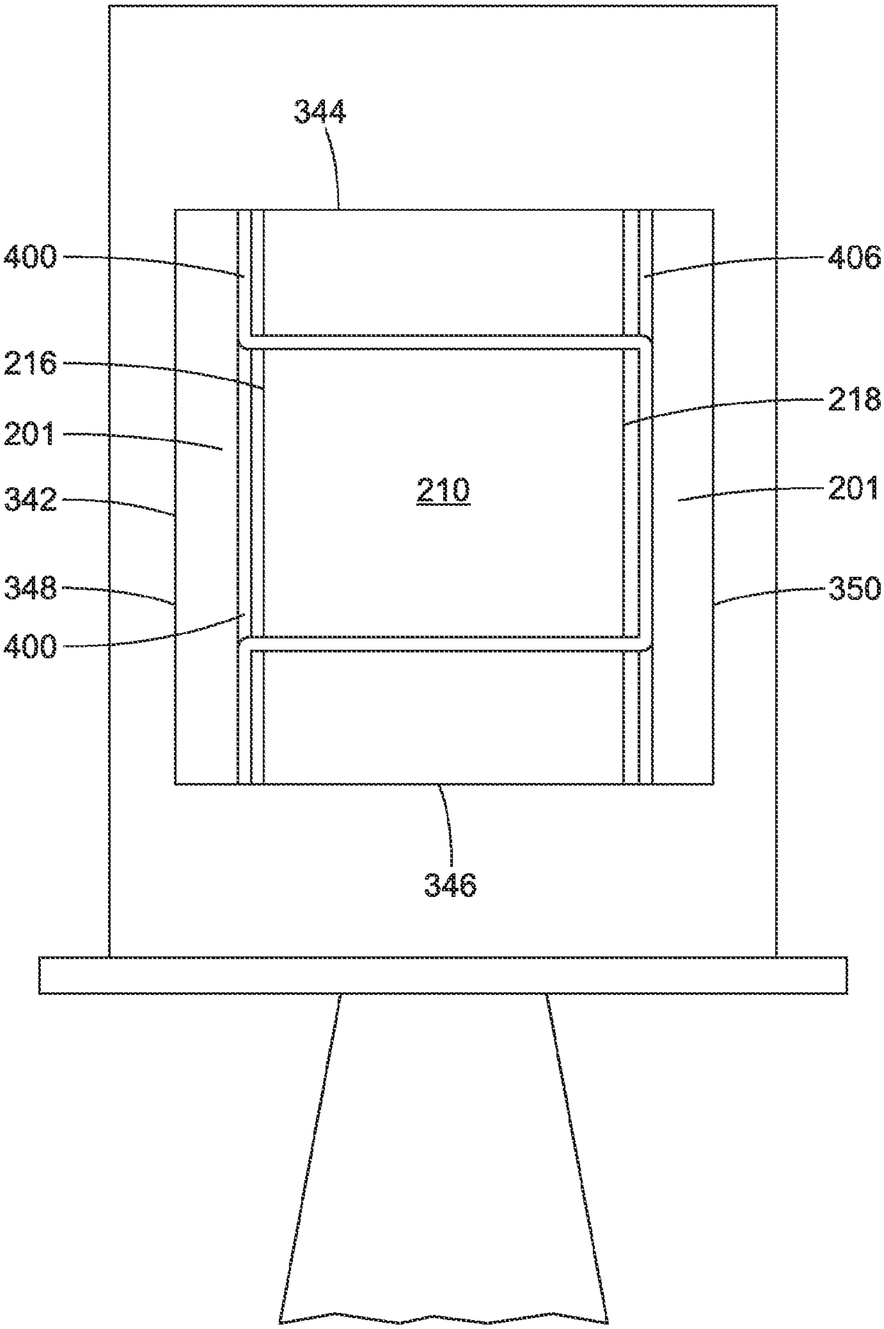

FIG. 13

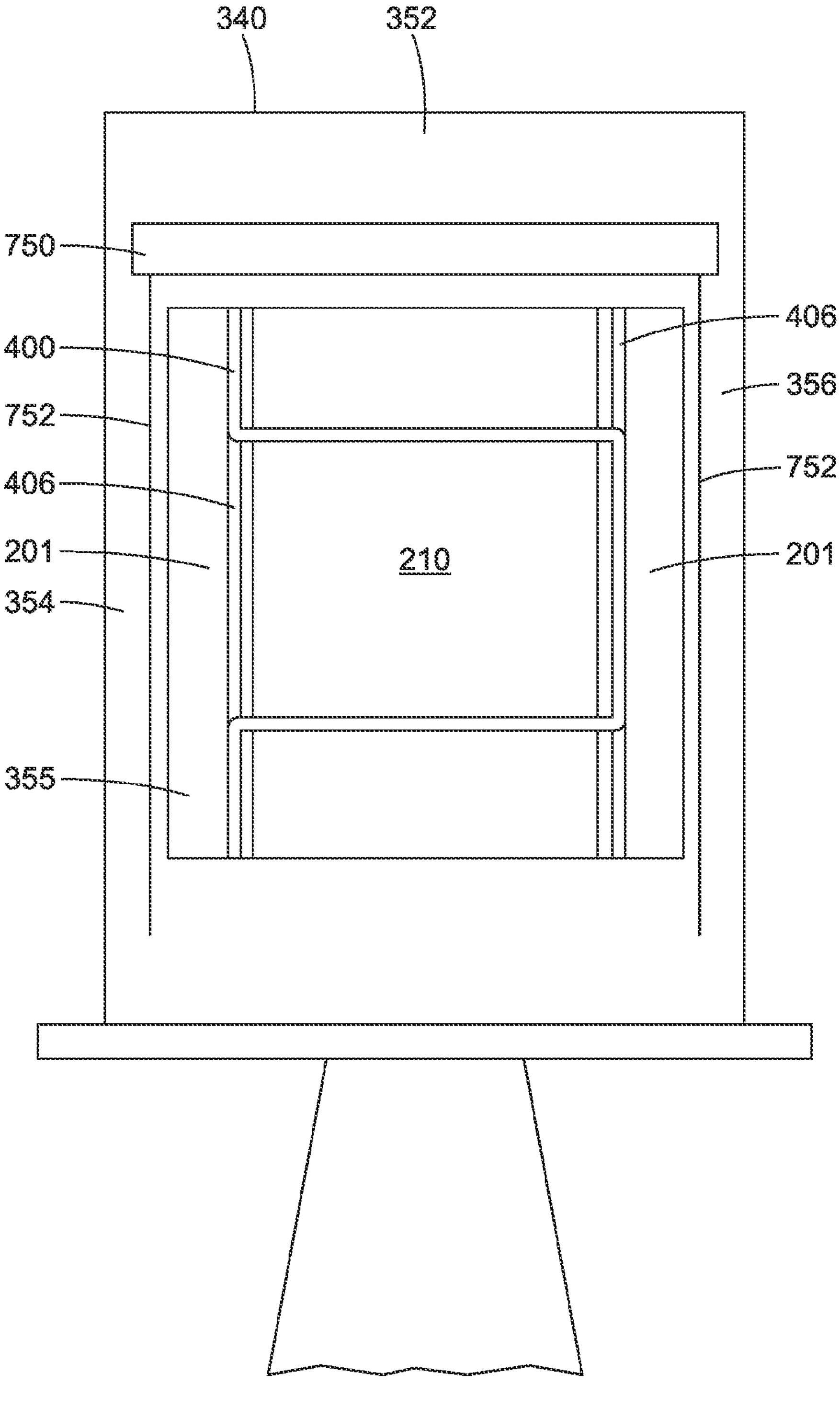

FIG. 14

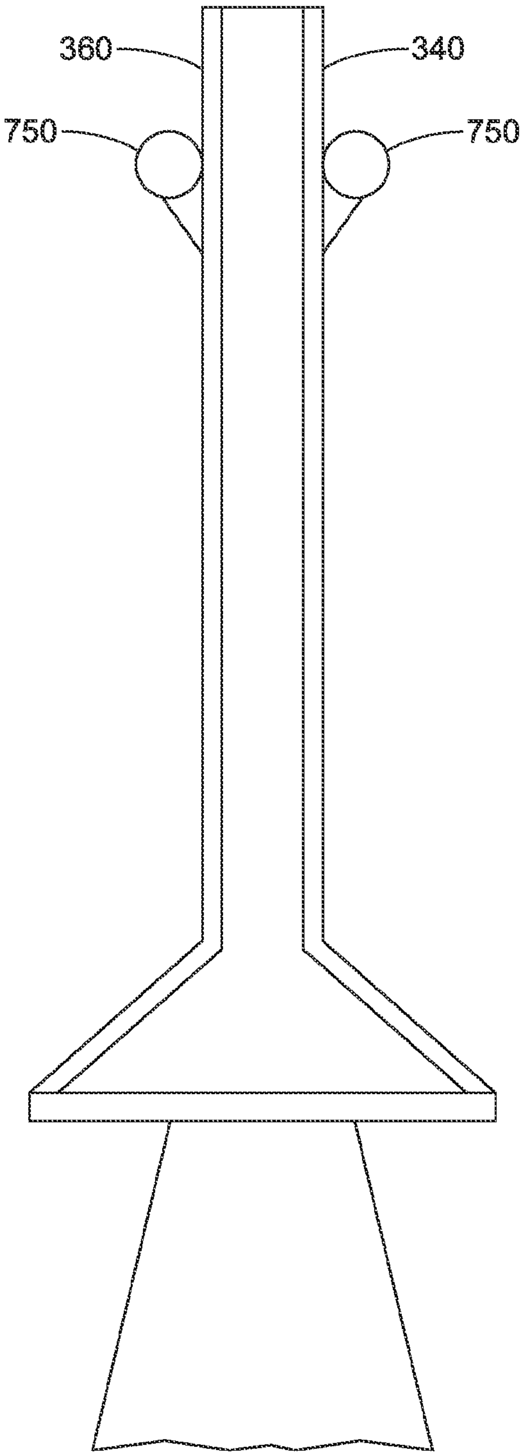

FIG. 15

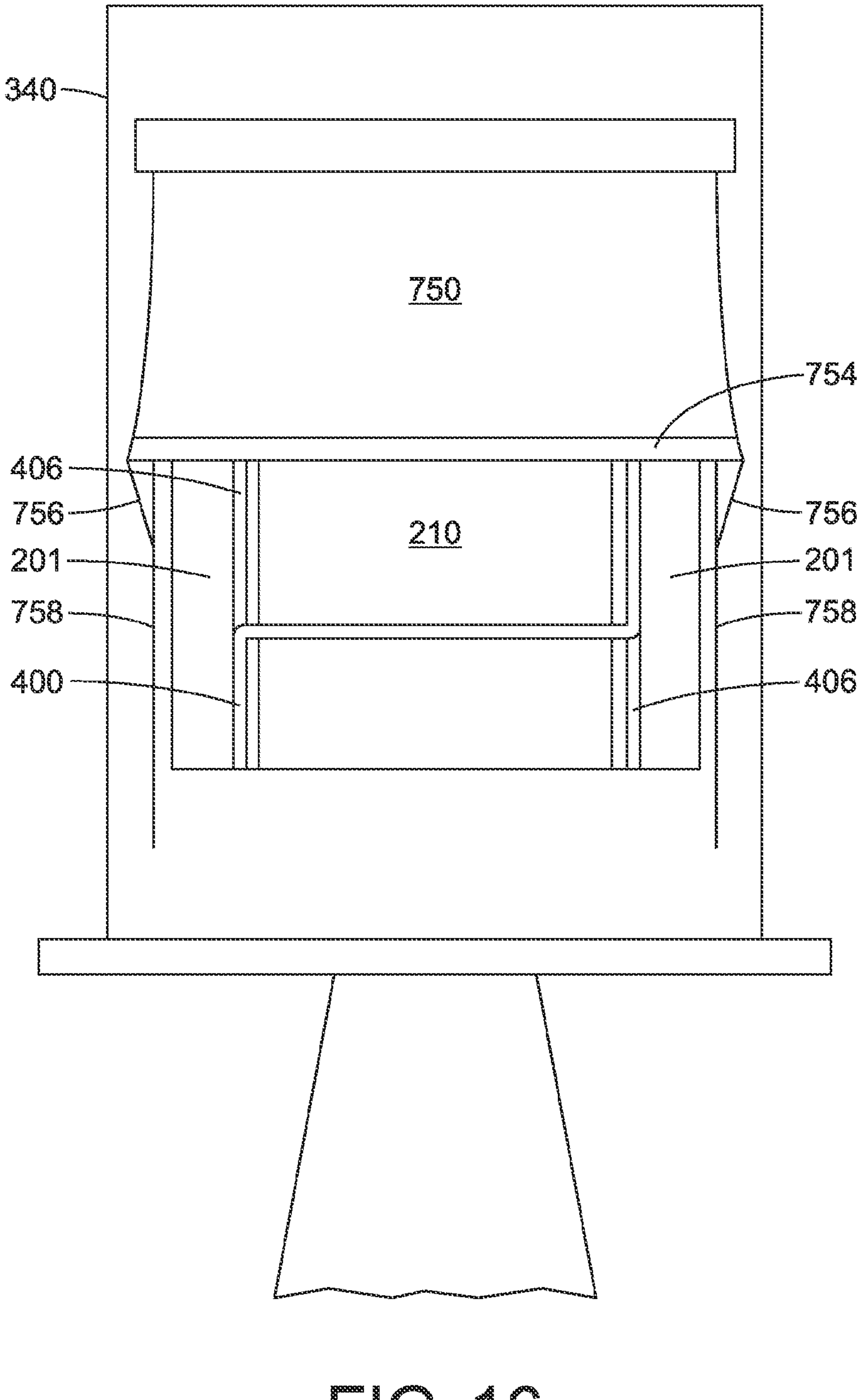

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/065324

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F24J 2/24 (2013.01)
USPC - 126/663
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - F03G 6/00, 6/02, 6/06; F24J 2/00, 2/04, 2/24 (2013.01)
USPC - 60/641.1, 641.8, 641.15; 126/569, 634, 651, 655, 661, 663, 664, 666, 668, 670, 672, 704, 714; 165/76, 177, 178, 181, 183, 186

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - F03G 6/00, 6/02, 6/06; F24J 2/00, 2/04, 2/24, 2/242, 2/245, 2/4647; Y02B 10/20; Y02E 10/40, 10/44, 10/46, 10/47 (2013.01)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
MicroPatent, Orbit.com, Google Patents, Google Scholar, ProQuest

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,125,108 A (PORTER et al) 14 November 1978 (14.11.1978) entire document	1-14
A	US 2010/0252025 A1 (KROIZER et al) 07 October 2010 (07.10.2010) entire document	1-14
A	US 2010/0101564 A1 (IANNACCHIONE et al) 29 April 2010 (29.04.2010) entire document	1-14
A	WO 2010/093235 A2 (DE BRUIJN et al) 19 August 2010 (19.08.2010) entire document	1-14
A	JP 2011-43128 A (TAMAURA et al) 03 March 2011 (03.03.2011) entire document	1-14

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 January 2013	07 FEB 2013

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774