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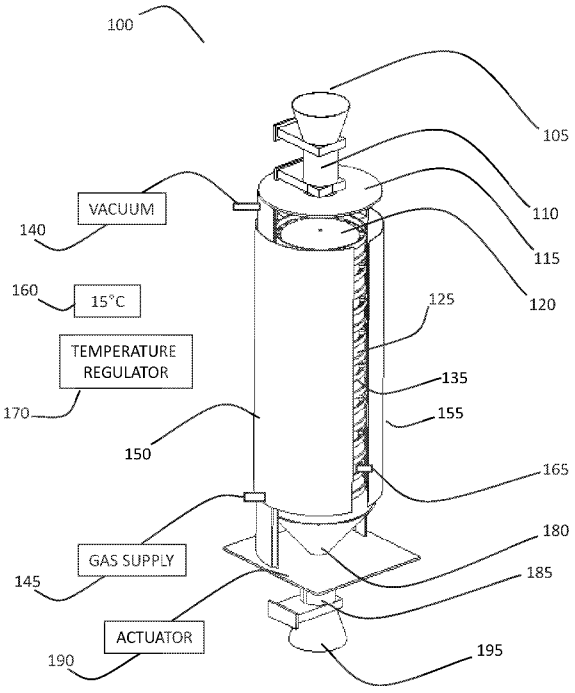


FIG. 1a

(57) Abstract: Methods and apparatuses to activate, modify, and sanitize the surfaces of granular, powdered, or seed material placed in a continuous flow of a low- temperature, reduced-pressure gas plasma. Said plasma may be created with radio- frequency power, using capacitive-inductive, or a combination of both types of discharge. The plasma is generated at pressures in the 0.01 to 10 Torr range. RF frequency ranges from 0.2 to 220 MHz, and correspond to a plasma density between about $n_e \times 10^8$ - $n_e \times 10^{12}$ or 0.001 to 0.4 W/cm^3. Inserts and electrodes may be temperature controlled to control process conditions. RF discharge may be pulsed or modulated by different frequency in order to stimulate energy exchange between gas plasma and process material. The apparatuses may be grounded, biased and mechanically activated (e.g., vibration, rotation, etc.).

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METHODS AND APPARATUSES FOR TREATING AGRICULTURAL MATTER

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/240,317, filed on October 12, 2015, the disclosure of which is incorporated by reference herein in its entirety.

FIELD OF INVENTION

[0002] The present disclosure is directed to methods and apparatuses used in the treatment of matter. More particularly, the present disclosure is directed to methods for treating agricultural matter, such as seeds, with plasma. Further, the present disclosure is directed to apparatuses for treating agricultural matter with plasma.

BACKGROUND

[0003] Treating agricultural matter for sanitation and germination purposes is known. Known treatments include washing, scrubbing, and applying substances (e.g., powder) to agricultural matter. The treatments may be modified to produce various activation, modification, and sanitization results.

SUMMARY OF THE INVENTION

[0004] In one embodiment, a treatment module comprises an airtight cylindrical housing comprising an external wall and an internal chamber, the housing having a structural integrity to withstand a low-pressure environment, at least one inlet for loading plant seeds into the chamber, wherein the inlet is sealable and distal to the

chamber, and at least one port for creating a low-pressure environment substantially free of gas and introducing gas into the chamber. The treatment module further comprises at least one plasma generator, selected from the group consisting of an electrode pair, a coil, and electrode pair and coil, for creating a plasma from gas introduced into the chamber, a plurality of discs, disposed substantially linearly within the chamber, and at least one egress for unloading plant seeds from the chamber, wherein the egress is sealable and distal to the chamber.

[0005] In another embodiment, an apparatus comprises a hopper having an upper opening, a lower opening, and at least one side wall that connects the upper and lower openings, an elongated, airtight seed-processing chamber that receives seeds fed through the hopper, a load lock seal, disposed between the hopper and the airtight chamber, a vacuum, operably connected to the chamber, for removing gas from the chamber, and a gas supply, operably connected to the chamber, for delivering gas to the chamber. The apparatus further comprises at least one pair of electrodes, disposed about the chamber, capable of generating a plasma environment, a temperature regulator comprising a temperature sensor, a temperature control unit, a temperature control element, a plurality of first inserts, disposed in the chamber, each first insert having an annular passage and a cross sectional area that substantially coincides with the cross sectional area of the chamber, a plurality of second inserts, disposed in the chamber, each second insert having apertures and a cross sectional area that substantially coincides with the cross sectional area of the chamber, and an

outlet, through which seeds processed in the chamber pass, and a load lock seal, disposed between the chamber and the outlet.

[0006] In a different embodiment, a method for treating agricultural matter comprises providing seeds to a cascading treatment apparatus, introducing seeds into a chamber in the cascading treatment apparatus, hindering the vertical flow of seeds within the chamber with encumbrance structures, evacuating gas from the chamber, introducing gas to the chamber, ionizing gas introduced into the chamber, monitoring and regulating ionizing energy within the chamber, and monitoring and regulating temperature within the chamber. The method may further comprise the steps of introducing seeds into a second chamber in the cascading treatment apparatus, hindering the vertical flow of seeds within the second chamber with encumbrance structures, evacuating gas from the second chamber, introducing gas to the second chamber, ionizing gas introduced into the second chamber, and monitoring and regulating temperature within the second chamber.

[0007] In one embodiment, an apparatus for processing agricultural matter comprises a first compartment, for receiving agricultural matter from an external source, a second compartment, for processing agricultural matter, and a third compartment, for receiving processed agricultural matter. The apparatus also comprises a first re-sealable airtight seal, disposed between the first compartment and the second compartment, and a second re-sealable airtight seal, disposed between the second compartment and third compartment, through which agricultural matter

passes, a vacuum, operably connected to the second compartment, that evacuates air from at least the second compartment; a gas supply, operably connected to at least the second compartment, that provides gas to the second compartment. The apparatus further comprises a plasma ionizer, operably associated with the second compartment, that ionizes gas in the second compartment into a plasma, an RF generator configured to provide a plasma striking voltage, an RF matching network, configured to match the impedance of the RF generator, a plasma controller, operably associated with the second compartment, that controls plasma flow within the second compartment, and a first ridged sheet, operably connected to an actuator, that moves agricultural matter within the second chamber, and a second ridged sheet, operably connected to an actuator, that moves agricultural matter within the second chamber.

[0008] In a different embodiment, a plasma treatment module comprises a hopper, for holding seeds for treatment, a first load lock seal, partitioning the exterior of the apparatus from an interior vacuum chamber, the chamber being plasma-tolerant, a feeder, for dispensing seeds from the hopper at a predetermined rate, a first tray, disposed within the vacuum chamber, that receives seeds from the feeder, a second tray, disposed within the vacuum chamber, that receives seeds from the first tray, at least one linear actuator that moves at least one of the trays, at least one pair of electrodes, disposed about the chamber, capable of generating a plasma environment, a temperature regulator comprising a temperature sensor, a temperature

control unit, a temperature control element, a second load lock seal, partitioning the interior of the apparatus from an exterior vacuum chamber.

[0009] In a different embodiment, a method for treating agricultural matter comprises providing seeds to a linear processing apparatus; introducing seeds into a chamber in the linear processing apparatus; moving seeds linearly within the chamber with actuators; evacuating gas from the chamber; introducing gas to the chamber; ionizing gas introduced into the chamber; monitoring and regulating ionizing energy within the chamber; monitoring and regulating temperature within the chamber; and removing seeds from the linear processing apparatus.

[0010] For apparatuses and methods used for treating seeds, a wide variety of seeds may be used. In one embodiment, the seeds are broadcasting- or row-crop seeds. In another embodiment, the seeds are selected from the group consisting of sorghum, tomato, corn, and alfalfa.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] In the accompanying drawings, structures are illustrated that, together with the detailed description provided below, describe exemplary embodiments of the claimed invention. Like elements are identified with the same reference numerals. It should be understood that elements shown as a single component may be replaced with multiple components, and elements shown as multiple components may be replaced with a single component. The drawings are not to scale and the proportion of certain elements may be exaggerated for the purpose of illustration. For the

methods disclosed, the steps described need not be performed in the same sequence discussed or with the same degree of separation. Likewise, various steps may be omitted, repeated, or combined, as necessary, to achieve the same or similar objectives.

[0012] **Figure 1a** is a perspective view of one embodiment of a treatment apparatus;

[0013] **Figure 1b** is a perspective view of one embodiment of an insert with an aperture;

[0014] **Figure 1c** is a perspective view of one embodiment of an insert;

[0015] **Figure 1d** is a perspective view of one embodiment of an apparatus utilizing a coil;

[0016] **Figure 2a** is a perspective view of an embodiment of the temperature control element shown in **Figure 1a**;

[0017] **Figure 2b** is a front elevational view of an alternative embodiment of the temperature control element shown in **Figure 2a**;

[0018] **Figure 2c** is a isometric view of an alternative embodiment of the temperature control element shown in **Figure 2a**;

[0019] **Figure 2d** is a perspective view of select components of an alternative embodiment of a treatment apparatus;

[0020] **Figure 2e** is an alternative embodiment of the components shown in **Figure 2d**;

[0021] **Figure 2f** is an alternative embodiment of the components shown in **Figure 2d** and **Figure 2e**;

[0022] **Figure 3** is a perspective view of one embodiment of a modular treatment apparatus;

[0023] **Figures 4a–h** are top views of discs and inserts used in the apparatuses of **Figures 1–3**;

[0024] **Figures 5a–5d** are block diagrams depicting RF power source systems used to create and maintain plasma environments;

[0025] **Figures 6a–6b** are flowcharts depicting generalized processes for treating matter; and

[0026] **Figures 7a** and **7b** are flowcharts depicting processes for treating matter using a cascade treatment apparatus.

[0027] **Figure 8a** is a simplified side view of an one embodiment of a modular treatment apparatus;

[0028] **Figure 8b** is a perspective view of one embodiment of an apparatus as depicted in **Figure 8a**;

[0029] **Figure 8c** is a side view of one embodiment of an apparatus as depicted in **Figure 8a**;

[0030] **Figure 8d** is an end view of one embodiment of an apparatus as depicted in **Figure 8a**;

[0031] **Figure 8e** is a perspective view of one embodiment of a ridged sheet as depicted in **Figure 8a**;

[0032] **Figure 8f** is a close-up perspective view of one embodiment of a ridged sheet as depicted in **Figure 8a**;

[0033] **Figure 9** is a side view of one embodiment of a modular treatment apparatus;

[0034] **Figure 10** is a flowchart depicting processes for treating matter using the apparatuses described in **Figures 8–9**.

DETAILED DESCRIPTION

[0035] The following includes definitions of selected terms employed herein. The definitions include various examples and/or forms of components that fall within the scope of a term and that may be used for implementation. The examples are not intended to be limiting. Both singular and plural forms of terms may be within the definitions.

[0036] "Etching" refers to a process for removing a layer of material from the surface of an object.

[0037] "Surface activation," when used in conjunction with plasma treatments, refers to increasing the reactive properties (e.g. hydrophilic properties) on an object's surface.

[0038] While similar terms used in the following descriptions describe similar components, it is understood that because the terms carry slightly different

connotations, one of ordinary skill in the art would not consider any one of the following terms to be purely interchangeable with any other term used to describe a common component.

[0039] **Figure 1a** is a perspective view of one embodiment of a treatment apparatus **100**. The treatment apparatus **100** includes a hopper **105**. Agricultural matter for treatment is placed in hopper **105**. As shown, hopper **105** is a cone with an upper opening, a lower opening, and a side wall that connects the upper and lower openings. In an alternative embodiment (not shown), the hopper is pyramidal. In another alternative embodiment, the hopper can be made airtight.

[0040] Hopper **105** connects to load lock seal **110** and chamber **120**. Load lock seal **110** allows agricultural matter from hopper **105** to travel to chamber **120** without breaking vacuum conditions in chamber **120**. In an alternative embodiment (not shown), a valve, such as a four-way valve, replaces the load lock seal. It should be understood that many valves are suitable. Examples of suitable valves include without limitation, quarter-turn valves, sliding gate valves, and solenoid valves all applicable valves.

[0041] Apparatus **100** further comprises a housing **115** that surrounds chamber **120**. Housing **115** supports an airtight cylinder that defines the boundaries of chamber **120**. In an alternative embodiment (not shown), the housing does not define the boundaries of the chamber. As an example, additional components could be disposed between the housing and the chamber. In additional embodiments, the

housing and/or chamber are prisms. In further embodiments, the housing includes an energy shield. As one of ordinary skill in the art will understand, a variety of shapes may be used for the housing and/or chamber.

[0042] As shown, a plurality of first inserts **125** are disposed within chamber **120**. The first inserts **125** are circular and have a diameter that substantially coincides with the cross-sectional area of chamber **120**. The diameter of the first inserts **125** substantially coincides with the cross-sectional area of chamber **120** such that agricultural matter cannot pass between the edge of the first inserts **125** and a chamber wall. In an alternative embodiment (not shown), the first inserts have a cross-sectional area between about 75–95% of the cross-sectional area of the chamber. In another embodiment, the first inserts have a cross-sectional area between about 50–70% of the cross-sectional area of the chamber.

[0043] In one embodiment, the first inserts **125** are inclined or angled with respect to the horizon (**Figure 2b** and **Figure 2e** depict inclined inserts). Suitable inclination angles include, without limitation, 5–60° with respect to the horizon. In an alternative embodiment (not shown), only a portion of a first insert is inclined. In another embodiment, a first insert is curved with respect to a horizontal plane.

[0044] The first inserts **125** feature apertures **130** (as shown in **Figure 1b**). Agricultural matter passes through apertures **130** as its progresses through chamber **120**. As one of ordinary skill in the art will understand, a wide variety of cross-sectional shapes are suitable for apertures **130**. Additionally, apertures **130** can be

tuned to accommodate different applications. For example, the cross sectional area of aperture **130** can be decreased to slow the passage of material through chamber **120**. Conversely, the cross sectional area of apertures **130** can be increased to promote the passage of material through chamber **120**. In the embodiment shown in **Figure 1a**, apertures **130** are disposed at the edges of the first inserts **125**. In an alternative embodiment (not shown), the apertures are disposed on an interior portion of the plates. In additional alternative embodiments, apertures are scattered across the inserts. In another embodiment, the apertures are omitted so that the apparatus lacks apertures and only has edges allowing agricultural matter to spill off an edge.

[0045] In addition to the first inserts **125**, a plurality of second inserts **135** are disposed within chamber **120**. As shown in **Figure 1c**, the second inserts **135** are inclined or curved and contain an inner ring that allows agricultural matter to pass through chamber **120** near the center (i.e., the core) of the chamber. When the first inserts **125** and the second inserts **135** are both curved, the second inserts **135** may be curved opposite of the first inserts **125**. In another embodiment (not shown), the second inserts are flat.

[0046] In **Figure 1a**, first and second inserts **125**,**135** are arranged in alternating fashion. When the first and second inserts are inclined and interspersed, material is directed between the periphery and the core of the apparatus **100** as it proceeds through the apparatus. In embodiments where the inserts are flat, movement produced by, without limitation, vibration, rocking, or gas diffusion, is used to direct

material to proceed through the apparatus. For embodiments utilizing mechanical movement, an axis running through the apparatus could be used as a driving shaft for the mechanical motion. Additionally, mechanical arms or appendages may be used to direct material over the inserts or through the chamber.

[0047] The first and second inserts are not permanently attached as to allow for removal and maintenance. The first and second inserts may be made from a variety of materials, including, without limitation, dielectrics, metals, and metals coated with dielectric.

[0048] Apparatus **100** further comprises a vacuum **140**, which removes gas from apparatus **100**. In one embodiment, the vacuum removes gas from the apparatus to a pressure between 0.01 and 730 torr. In another embodiment, the vacuum removes gas from the apparatus to a pressure of between 0.01 and 10 torr. In yet another embodiment, the vacuum removes gas from the apparatus to a pressure of between about 500 and 1,000 mTorr.

[0049] In the embodiment shown in **Figure 1a**, vacuum **140** connects to chamber **120** via a hose and port and removes gas from chamber **120**. As one of ordinary skill in the art will understand, vacuum **140** may evacuate gas from chamber **120** via various airtight pathways (including intermediate pathways) between chamber **120** and vacuum **140**. In an alternative embodiment (not shown), the apparatus further includes a valve that seals the port. In an embodiment where the hopper **105** is

airtight, the vacuum may also connect to the hopper **105**. In yet another embodiment, the vacuum is provided separately from the apparatus.

[0050] Apparatus **100** further comprises a gas supply **145**. Gas supply **145** connects to chamber **120** via a hose and port and provides gas to chamber **120**. In one embodiment, the gas supply provides a variety of gasses to the chamber, including without limitation, air, water vapor, nitrogen, oxygen, argon, hydrogen, noble gasses, and various combinations thereof. In another embodiment, the gas supply provides nitrogen and oxygen in various combinations. In a different embodiment, the gas supply provides ambient gas to the chamber.

[0051] As one of ordinary skill in the art will understand, the gas supply may provide gas to the chamber via various airtight pathways (including intermediate pathways) between the gas supply and chamber. In an alternative embodiment (not shown), the apparatus further includes a valve that seals the port. In another alternative embodiment, the gas supply and vacuum share a port. In yet another embodiment, the gas supply is provided separately from the apparatus. An exemplary flow rate is, without limitation, 0–2,000 sccm.

[0052] Apparatus **100** further comprises at least a first electrode **150** and a second electrode **155**. First electrode **150** and second electrode **155** are powered by an RF generator. The electrodes are located on an opposite sides of exterior surface of chamber **120**. The RF frequency generated ranges from 0.2 to 220 MHz, corresponding to a plasma density between about $n_e \times 10^8 - n_e \times 10^{12}$ or power

density of 0.001 to 0.4 W/cm^3. The electrodes may be used to generate capacitively coupled plasma, helicon, inductively coupled plasma, or a combination of the aforementioned. The electrodes are used in conjunction with a plasma control unit and RF circuit matching network (discussed below). In an alternative embodiment (not shown), the electrodes are separate from the apparatus and do not form a part of the apparatus.

[0053] Apparatus **100** further comprises a temperature control unit **160**. In **Figure 1a**, temperature control unit **160** is depicted as a block temperature display; one of ordinary skill in the art will understand that temperature control unit **160** comprises a temperature sensor **165**, a processor **170** that regulates temperature, and a temperature control element **175** (temperature control element **175**, which is shown in **Figures 2a–c**, is omitted from **Figure 1**). In one embodiment, the temperature control unit holds temperature within the chamber and on most surfaces between room temperature (20–26°C) and 50°C. In another embodiment, the temperature control unit holds temperature within the chamber between room temperature and 45°C. In a different embodiment, the temperature control unit holds temperature within the chamber between 0°C and room temperature.

[0054] Temperature sensor **165** senses the temperature in chamber **120**. Suitable sensors include, without limitation, analog and digital sensors. In an alternative embodiment (not shown), the temperature sensor senses the temperature of a

component of the apparatus, such as a chamber wall, which is then used to estimate the temperature in the chamber.

[0055] Processor **170** is programmed to control the temperature of the chamber. A desired chamber temperature is selected and then input into the processor **170**. Processor **170** obtains or receives the temperature from temperature sensor **165**, and then compares the temperature to the desired chamber temperature. If the desired chamber temperature is lower than the sensed temperature, then processor **170** sends a signal to temperature control element **175** to adjust the temperature utilizing the control devices in the system. If the desired chamber temperature is higher than the sensed temperature, then processor **170** sends a signal to temperature control element **175** to turn off (passive cooling). In an alternative embodiment, if the desired chamber temperature is higher than the sensed temperature, then processor **170** sends a signal to temperature control element **175** to remove energy from the system (active cooling). In another embodiment, the processor sends a signal to the temperature control element without receiving the sensed temperature.

[0056] Apparatus **100** further includes a collector **180**. Collector **180** channels agricultural matter that has passed through chamber **120**. As shown, collector **180** is a cone-shaped funnel. In an alternative embodiment (not shown), the collector is a pyramid-shaped funnel. In another embodiment, the collector is a rectangular receptacle. As one of ordinary skill in the art will understand, a variety of structures may be used for the collector.

[0057] Apparatus **100** further includes a second load lock seal **185**. Collector **180** bridges load lock seal **185** and chamber **120**, although collector **180** need not bridge the second load lock seal **185** and chamber **120**. Similar to load lock seal **110**, second load lock seal **185** allows agricultural matter to exit chamber **120** without breaking vacuum conditions in chamber **120**.

[0058] Apparatus **100** further comprises an actuator **190**. In one embodiment, actuator **190** ultrasonically vibrates at least one first insert **125**, a plurality of first inserts **125**, at least one second insert **135**, a plurality of second inserts **135**, or a combination of the inserts. In a second embodiment, actuator **190** moves apparatus **100** or any subpart, thus promoting the movement of agricultural material through apparatus **100**. As one of ordinary skill in the art will understand, in this embodiment, actuator **190** may be configured to, without limitation, rock, vibrate, or rotate apparatus **100**. Apparatus **100** and actuator **190** may also be configured so that certain components of apparatus **100** move while other components remain still or relatively still. In additional alternative embodiments, the chamber or components of the apparatus are vibrated mechanically.

[0059] Apparatus **100** further comprises a hood **195**. Hood **195** prevents ambient matter from interacting with matter exiting chamber **120**. Hood **195** is an inverted cone. In an alternative embodiment (not shown), the hood further comprises a bag attachment. In additional embodiments, the hood is a pyramid-shaped funnel or a

rectangular chute. As one of ordinary skill in the art will understand, a variety of structures may be used for the hood.

[0060] **Figure 1b** is a perspective view of one embodiment of a first insert **125** with an aperture **130**.

[0061] **Figure 1c** is a perspective view of one embodiment of a second insert **130**. Second insert **130** features a slope to a central collection exit point that directs agricultural material movement to the next insert below.

[0062] **Figure 1d** is a perspective view of one embodiment of an apparatus **100** that features a coil **C**. The coil winds around the chamber and is used in applications utilizing inductive plasma generation techniques. Various elements depicted in **Figure 1a** are omitted for simplification.

[0063] **Figure 2a** is a perspective view of an embodiment of the temperature control element **175** for use in the apparatus **100** shown in **Figure 1a**. While inserts **125**, **135** from apparatus **100** are shown, various elements depicted in **Figure 1a** are omitted for simplification.

[0064] Temperature control element **175** features at least one supply line **205a**. Supply line **205a** runs vertically and contains a circulating bath fluid (the connection between the line at the top of the apparatus and the line on the side of the apparatus is not shown). Optionally, a second supply line **205b** may be used to deliver a circulating bath medium. In an alternative embodiment (not shown), a supply line spirals with respect to the vertical direction. One of ordinary skill in the art will

understand that a suitable medium for the circulating bath includes, without limitation, liquid, steam, or gas.

[0065] Temperature control element **175** further features a plurality of feeder paths **210**. The feeder paths **210** extend annularly from the supply lines **205** into the chamber. In one embodiment, the feeder paths extend linearly from a supply line until forming an annulus. In another embodiment, the feeder paths extend annularly. The elements of the temperature control element **175**, such as the supply line **205** or the feeder paths **210**, may be used to support the inserts.

[0066] In a specific embodiment (not explicitly shown in **Figure 2a**), at least one supply line **205** or one feeder path **210** of the temperature control element **175** connects into at least one first insert **125**. Alternatively, a plurality of feeder paths **210** connect into a plurality of first inserts **125.** The supply line **205** or feeder paths **210** may also connect into at least one second insert **135** or a plurality of second inserts **135**.

[0067] In another embodiment (also not shown), the fluid in a temperature-controlled circulating bath can be run through or around, without limitation, a volume associated with the housing, the chamber, and the inserts.

[0068] **Figure 2b** is a front elevational view of an alternative embodiment of the temperature control element **175** shown in **Figure 2a**. In comparison to **Figure 2a**, the feeder path **210** shown in **Figure 2b** connects into at least one first insert **125**.

Thus, in this embodiment, the fluid within the feeder path also circulates into at least one first insert **125**.

[0069] **Figure 2c** is an isometric view of an alternative embodiment of the temperature control element shown in **Figure 2a**. In comparison to **Figure 2a**, the feeder path **210** shown in **Figure 2c** runs down the center of the apparatus.

[0070] **Figure 2d** is a perspective view of an alternative embodiment of select components utilized in a treatment apparatus **200**. Various elements from the apparatus **100** depicted in **Figure 1a** are omitted for simplification.

[0071] In **Figure 2d**, apparatus **200** features a first connection **215** and a second connection **220** that extend from apparatus **200**. First connection **215** and second connection **220** are connected to an RF generator (not shown). First connection **215** also connects to first line **225**, which extends axially down an outer section of apparatus **200** (the connection between first connection **215** and first line **225** is not depicted). Second connection **220** also connects to second line **230**, which extends axially down an outer section of apparatus **200**. In the illustrated embodiment, connections **215**, **220** and lines **225**, **230** are made of conductive materials. Like first electrode **150** and second electrode **155**, the first line **225** and second line **230** may be used in connection with other components to generate plasma.

[0072] In another embodiment, the first inserts **125** connect to the first line **225**, and the first inserts **125** are utilized for an internal RF connection, to generate plasma. When connected in this manner, the first inserts **125** are charged independently of the

second inserts **135**. Optionally, the second line **230** may be connected to the second inserts **235** for plasma generation purposes. As one of ordinary skill in the art will understand, connections to ground have been omitted for simplicity.

[0073] **Figure 2e** is a front elevational view of an alternative embodiment of the select components utilized in a treatment apparatus **200** shown in **Figure 2d**. In comparison to **Figure 2d**, only the first line **225** is shown, and it is shown as connecting to a first insert **125** at connection **240**.

[0074] **Figure 2f** is an isometric view of an alternative embodiment of the select components utilized in a treatment apparatus **200** shown in **Figure 2d**. In comparison to **Figure 2d**, only the first line **225** is shown, and it is shown as running down the center of apparatus **200**.

[0075] **Figure 3** is a perspective view of one embodiment of a modular treatment apparatus **300**. Modular treatment apparatus **300** comprises, *inter alia*, treatment modules **305**. Each treatment module **305** may include any of the components discussed above. As shown, modular treatment apparatus **300** features three treatment modules **305**. In an alternative embodiment (not shown), the modular treatment apparatus features two treatment modules. In another embodiment, the modular treatment apparatus features four treatment modules. In additional embodiments, the modular treatment apparatus features five or more treatment modules. In a different embodiment, the modular treatment apparatus features a single (replaceable) treatment module. As one of ordinary skill in the art will

understand, the treatment modules in modular treatment apparatus need not be identical.

[0076] Modular treatment apparatus **300** features a holding receptacle **310**. Agricultural matter is placed into holding receptacle **310**. Holding receptacle **310** is a simple receptacle with no sensors, agitators, or regulators. In an alternative embodiment (not shown), the holding receptacle features a sensor that measures the amount of agricultural material in the receptacle. The sensor may be digital or analog. In another embodiment, the holding receptacle features an agitator that agitates agricultural material in the receptacle. Examples of agitators include, without limitation, stirrers, vibratory actuators, and pneumatic agitators. In yet another embodiment, the holding receptacle includes a regulator, such as a wheel, that regulates the amount of agricultural material that enters a treatment module. In further embodiments, the holding receptacle contains a combination of sensors, agitators, and regulators.

[0077] Modular treatment apparatus **300** further comprises a first seal **315**. First seal **315** is resealable, airtight, and distal to treatment module **305**. First seal **315**, as shown, is disposed between holding receptacle **310** and treatment module **305**. In an alternative embodiment (not shown), the first seal is incorporated into at least one treatment module. In another embodiment, the first seal is incorporated into the holding receptacle.

[0078] Module **305** further comprises an inlet **320** and a chamber **325**. Inlet **320**, as shown, is a cylindrical passageway disposed between holding receptacle **310** and chamber **325** of treatment module **305**. Inlet **320** is airtight and distal to treatment module **305**. Optionally, inlet **320** may be sealable. In an alternative embodiment (not shown), the inlet is formed in a treatment module wall and does not extend from the treatment module. In another embodiment, the cross sectional area of the inlet opening is adjustable. As one of ordinary skill in the art will understand, the inlet may be made of a variety of materials, including without limitation, ceramic, glass, plastic, quartz, rubber, or zirconia.

[0079] As shown, chamber **325** is an airtight cylinder, yet chamber **325** is not limited to a cylindrical form. Regardless of the shape of chamber **325**, chamber **325** is durable enough to withstand low pressure environments and the creation and containment of plasma. Suitable materials for chamber **325** include, without limitation, quartz, glass, plastic, ceramic, and metal. In an alternative embodiment (not shown), the chamber further includes a cage. In another embodiment, the chamber further includes an opening that allows access to the chamber.

[0080] Treatment module **305** features porous discs **330**. The perimeter of each porous disc **330** is coextensive with the interior of the chamber **325**, but the perimeter of porous disc **330** does not need to be coextensive with the interior of chamber **325**. Porous discs **330** are suspended within the interior of chamber **325**, and porous discs **330** may be secured by attachment to an internal, axial column (not shown). In an

alternative embodiment, the porous discs rest on cantilevers. The cantilevers may extend into the chamber from an external wall or an internal, axial column. In yet another embodiment, the porous discs slide into a structure having compartments that is disposed within the treatment module or chamber.

[0081] Each porous disc **330** is sloped so that gravity pulls agricultural matter through the chamber. Varying the slope of the porous disc between adjacent plates allows agricultural matter to be directed through different regions of the chamber (e.g., from an interior toward a perimeter, and vice versa). Likewise, varying the slope of the porous disc allows agricultural matter to pass through the chamber at different rates. In an alternative embodiment (not shown), each porous disc is flat and motion is applied to modular treatment apparatus **300** so that agricultural material passes through the pores of the porous discs.

[0082] Each treatment module **305** contains a plurality of porous discs **330**. While **Figure 3** shows each treatment module **305** having multiple porous discs, treatment module **305** does not require a specific number of porous discs, and different treatment modules within modular treatment apparatus **300** can have varying numbers of porous discs. In an alternative embodiment (not shown), at least one solid disc is disposed between two porous discs. In yet another embodiment, the plurality of discs is replaced with a plurality of spokes disposed throughout the chamber.

[0083] Each treatment module **305** features at least one pair of electrodes **335**. Electrodes **335** are positioned on the exterior of treatment module **305**. In the embodiment shown, electrodes **335** are permanently attached to treatment module **305** and connected to the RF power source. In an alternative embodiment (not shown), the electrodes are separate from the treatment module and do not form a part of the treatment module. In another embodiment, multiple electrode pairs are individually associated with two or more treatment modules within the modular treatment apparatus.

[0084] As shown, each treatment module **305** also features a port **340**. Port **340** is positioned distal to treatment module **305**, although it could be positioned anywhere on treatment module **305**. In an alternative embodiment (not shown), each treatment module contains two ports—preferably disposed at opposite distal ends of the chamber. In another embodiment, only one treatment module in the modular treatment apparatus contains a port. In a different embodiment, only two treatment modules in the modular treatment apparatus contain ports. As one of ordinary skill in the art will understand, a port can be used to remove gas from the chamber or add gas to the chamber.

[0085] Each treatment module **305** also features an egress **345**. In the illustrated embodiment, egress **345** is a funnel that is positioned distal to the chamber. Optionally, egress **345** may be sealable. In another embodiment (not shown), the egress is a cylindrical passageway disposed between the chamber and an exterior of

treatment module. In an alternative embodiment, the egress is formed in a treatment module wall and does not extend from the treatment module wall. In another embodiment, the cross sectional area of a portion of the egress is adjustable. As one of ordinary skill in the art will understand, the egress may be made of a variety of materials, including without limitation, glass, plastic, rubber, or metal.

[0086] Modular treatment apparatus **300** further comprises a second seal **350**. Second seal **350** is resalable, airtight, and distal to treatment module **305**. Second seal **350**, as shown, is disposed between an egress and an exterior of treatment module **305** or modular treatment apparatus **300**. In an alternative embodiment (not shown), the second seal is incorporated into at least one treatment module. In another embodiment, the second seal is incorporated into a base.

[0087] Modular treatment apparatus **300** also features a base **355**. The base provides stability to modular treatment apparatus **300**. Agricultural material may exit modular treatment apparatus **300** through the bottom of base **355** or via a side chute (not shown). As one of ordinary skill in the art will understand, a variety of structures may be used for the base, and the base may also be used to house or store various components or materials used in connection with modular treatment apparatus **300**.

[0088] When multiple treatment modules **305** are used in modular treatment apparatus **300**, as shown in **Figure 3**, inlet **320** connects to egress **345** to form an airtight pathway between adjacent chambers **325**. Inlet **320** and egress **345** feature

smooth surfaces (which may be lubricated, for example, with vacuum grease). In an alternative embodiment (not shown), the inlet and egress screw together. In another embodiment, a bridge passage, such as a tube, is used to join adjacent chambers. The bridge may be rigid or flexible, and it may be sealable.

[0089] **Figures 4a–h** are top views of discs and plates **405**, which are two types of encumbrance structures.

[0090] As shown in **Figure 4a**, the apertures **410** in disc **405** are uniform, circular holes. The apertures **410** are disposed along an interior perimeter of disc **405**, and the dimensions of apertures **410** may be selected so that multiple seeds of a given plant species can simultaneously pass through an aperture **410**. Alternatively, the dimensions of the apertures may be selected so that only one seed of a given plant species can pass through an aperture at a given time. In an alternative embodiment (not shown), the apertures are randomly disposed throughout the disc.

[0091] As shown in **Figure 4b**, the apertures **410** in disc **405** may vary in size. The large pores allow multiple seeds within a single seed species to pass through the disc, while the small holes allow a single seed within a single seed species to pass through the disc. When the variation in seed size is large between plant species, the disc shown in **Figure 4b** can be used to accommodate treating multiple plant species without having to change discs **405**, because larger seeds will pass over the smaller apertures without passing through a plate. In an alternative embodiment (not shown), all of the apertures are the same size.

[0092] As shown in **Figure 4c**, the apertures **410** in disc **405** are slits. In alternative embodiments (not shown), the slits may be triangular, rectangular, trapezoidal, or any other similar elongated shape. In an alternative embodiment, two thin discs with slits are stacked on top of each other. At least one disc is rotatable in relation to the other disc, such that the size of apertures may be adjusted. This arrangement allows a user to adjust the apertures without substantial modifications or replacement of various components.

[0093] As shown in **Figure 4d**, the apertures **410** in disc **405** are disposed along an interior ring **415**. The interior ring **415** may form part of internal, axial column. Disposing the apertures along an interior ring allows the agricultural material, such as seeds, to move from an outer edge of a disc to an interior edge of the disc. Further, interspersing discs having apertures disposed along an interior ring with discs having apertures disposed along an outer perimeter allows the agricultural material to move across the discs, thus facilitating movement of material.

[0094] As shown in **Figure 4e**, the apertures **410** in disc **405**, along with disc **405**, may be ovals. Interior ring **415** may also be an oval.

[0095] As shown in **Figure 4f**, disc **405** may be a square. Disc **405** may also be solid, as shown. When disc **405** is solid, seeds may pass through the disc via a passage along an interior edge ring (not shown) or along an exterior edge ring (also not shown).

[0096] As shown in **Figure 4g**, disc **405** is triangular and contains hexagonal apertures **410**. The edges of angular discs, such as the example shown in **Figure 4g**, may also be rounded.

[0097] As shown in **Figure 4h**, disc **405** is rectangular and has an interior square **420**. Similar to the interior edge ring discussed above, an internal, axial column may be disposed within interior square **420**. Alternatively, the area of interior square **415** may be left void.

[0098] **Figures 5a–5d** are block diagrams depicting various RF power source systems used to create and maintain capacitively coupled or inductively coupled plasma environments. The RF frequencies generated by RF power sources of **Figures 5a–5d** may range from about 0.2–220 MHz. In one embodiment, a plasma ionization device generates plasma at a frequency range between 11–16 MHz. In another embodiment, the plasma ionization device generates plasma at a frequency range between 0.2–2.0 MHz. In yet another embodiment, the plasma ionization device generates plasma at a frequency range between 25–30 MHz. In a different embodiment, the plasma ionization device generates plasma at a frequency range between 38–50 MHz. Additional frequencies may be utilized with shielding equipment.

[0099] In **Figure 5a**, RF power source system **500a** features a controller **505** that controls RF generator **510** and matching network **515**. RF generator **510** provides the voltage source to strike gas into plasma. Matching network **515** provides impedance

matched to the impedance of the RF generator. As one of ordinary skill in the art will understand, matching the impedance of the network to the impedance of the RF generator optimizes power transfer.

[0100] RF power source system **500a** strikes the gas within reactor **520** into plasma. Plasma within reactor **520**, in turn, is monitored by the controller **505**. Similarly, the impedance of matching network **515** is also monitored by controller **505**.

[0101] In the embodiment depicted in **Figure 5b**, RF power source system **500b** creates plasma within a first reactor **520a**, a second reactor **520b**, and a third reactor **520c**. The first, second, and third reactors **520a–c** can be operated in series or in parallel.

[0102] In the depicted configuration, RF generator **510** and matching network **515** provide a power source that power splitter **525** splits between first reactor **520a**, second reactor **520b**, and third reactor **520c**. Controller **505** monitors the RF generator, the matching network **515**, and the reactors **520a–c** to ensure optimal plasma conditions at each reactor.

[0103] **Figure 5c** depicts an RF power source system **500c** with additional matching networks that allow for further control functions. In the illustrated embodiment, three matching networks are shown—first matching network **515a**, second matching network **515b**, and third matching network **515c**. In this embodiment, power splitter **525** is disposed between RF generator **510** and the

matching networks **515a–c**. Each matching network **515a–c** pairs with a reactor **520a–c**. Matching networks **515a–c** and reactors **520a–c** may be connected in series or in parallel with the controller **505.**

[0104] **Figure 5d** depicts an RF power source system **500d** featuring a controller **505** and a power oscillator **530**. When power oscillator **530** is utilized, reactor **520** forms a part of the resonant circuit. In this embodiment, controller **505** mitigates efficiency and frequency control issues.

[0105] **Figures 6a–6b** are flowcharts describing generalized processes for treating agricultural matter.

[0106] In **Figure 6a**, method **600a** starts with setting and regulating **610** the temperature in the treatment compartment. In setting and regulating step **610**, a temperature control unit is activated. Setpoint regulation, or feedback control, is used to ensure that the temperature remains within a desired range.

[0107] Method **600a** continues with loading **620** agricultural matter into a treatment compartment. In loading step **620**, matter may be loaded from a source external to the treatment compartment or from a source connected to the treatment compartment.

[0108] Method **600a** then continues with evacuating **630** gas from the treatment compartment. In evacuating step **630**, a vacuum is used to remove existing gas from the treatment compartment.

[0109] Method **600a** then continues with providing **640** a specific gas to the treatment compartment. Exemplary gases and the pressures at which they are provided are discussed above.

[0110] After providing step **640** occurs, method **600a** continues with creating **650** a plasma environment. In creating step **650**, the plasma environment is created using the RF power source systems and electrodes.

[0111] Once a plasma environment is created in creating step **650**, the matter within the plasma environment is agitated **660**. In agitating step **660**, the matter may be stirred within the treatment compartment. Alternatively, the matter may be agitated by, without limitation, rocking, vibrating, rotating, or tilting the treatment chamber.

[0112] In agitating step **660**, the matter within the treatment compartment is treated with plasma. In one embodiment, the surface of the matter is activated such that the contact angle of the matter is increased. In another embodiment, the surface of the matter is activated such that the contact angle of the matter is decreased.

[0113] Method **600a** then continues, and concludes with, unloading **670** the matter from the treatment compartment. In unloading step **670**, material may be, without limitation, directed into packaging or storage, set aside for testing, or directed into another treatment compartment.

[0114] **Figure 6b** shows an alternative embodiment of method **600a**. In method **600b**, loading step **620**, evacuating step **630**, and providing step **640** are performed

prior to creating step **650**. Loading step **620**, evacuating step **630**, and providing step **640** may be performed in any order prior to creating step **650**, and they may also be performed concurrently. Agitating step **660** and unloading step **670** are then performed subsequent to creating step **650**. In method **600b**, setting and regulating step **610** (shown in dashed lines) is optional. Setting and regulating step **610** may be performed at any time in connection with method **600b**.

[0115] **Figure 7a** and **Figure 7b** are flowcharts describing processes for treating agricultural matter using a cascade treatment apparatus.

[0116] In **Figure 7a**, method **700a** starts with providing **705** seeds to a cascade treatment apparatus. In providing step **705**, seeds may be provided (continuously or semi-continuously) to a storage receptacle or directly to a treatment chamber.

[0117] Method **700a** continues with monitoring and regulating **710** the temperature in the cascade apparatus. In one embodiment, the temperature in the treatment chamber may be monitored and regulated. In another embodiment, a temperature sensor senses the temperature of a component of the apparatus, such as a treatment chamber wall, which is then used to estimate and regulate the temperature in the treatment chamber.

[0118] Method **700a** then continues with evacuating step **715**, introducing step **720**, and ionizing step **725**. Evacuating step **715**, introducing step **720**, and ionizing step **725** are substantially similar to evacuating step **630**, providing step **640**, and

creating step **650**. After ionizing step **725**, method **700a** continues with monitoring and regulating **730** the ionizing energy used in ionizing step **725**.

[0119] Once a plasma environment is created, seeds are introduced **735** into a treatment chamber. In one embodiment of introducing step **735**, seeds are introduced in batches. In an alternative embodiment, seeds are introduced continually.

[0120] As seeds are introduced in introducing step **735**, the flow of seeds within the chamber is hindered **740** with the use of encumbrance structures such as inserts or porous discs. Optionally, gas may be injected **745** through an encumbrance structure to generate a force that momentarily opposes gravity. This force further hinders the flow of seeds within the chamber. Likewise, an optional agitation step **750** may also be practiced as the seeds are introduced or hindered. Agitation step **750** is substantially similar to agitating step **660**.

[0121] Method **700a** then continues, and concludes with, removing **755** seeds from the cascade treatment apparatus. In removing step **755**, material may be, without limitation, directed into packaging or storage, set aside for testing, or directed into another treatment compartment. The material may be removed, directed, or set aside continuously or semi-continuously.

[0122] **Figure 7b** shows an alternative embodiment, **method 700b**, of method **700a**. Like method **600b**, method **700b** shows that various steps in method **700a** may be performed concurrently or in more than one order.

[0123] **Figure 8a** is a simplified side view of one embodiment of a treatment apparatus **800**. The treatment apparatus **800** includes a first compartment **805**. Agricultural matter for treatment is placed in first compartment **805**. The compartment may be, without limitation, a hopper, canister, or tube.

[0124] First compartment **805** connects to load lock seal **810** and a treatment compartment **815**. Load lock seal **810** allows agricultural matter from first compartment **805** to travel to the treatment compartment **815** without breaking vacuum. In an alternative embodiment (not shown), a valve, such as a four-way valve, replaces the load lock seal. It should be understood that many valves are suitable. Examples of suitable valves include without limitation, quarter-turn valves, sliding gate valves, and solenoid valves all applicable valves.

[0125] As shown, a first ridged sheet **820a** is disposed within treatment compartment **815**. The first ridged sheet **820a** is planar (through the body of the sheet, and on the bottom surface) and has ridges **830** that extend from a top surface of the sheet. **Figure 8e** is a perspective view of one embodiment of a ridged sheet as depicted in **Figure 8a**; various components from **Figure 8a** have been omitted for simplicity.

[0126] With continued reference to **Figure 8a**, the ridges extend between two edges of a tray. Each ridge has a height, **H**, and is separated from an adjoining ridge by a peak-to-peak distance, **D**. In general, the distance between adjoining ridges is equal or larger than ridge height. In one specific embodiment, the height-to-distance

ratio is between 1:1 and 1:10. In another embodiment, the height-to-distance ratio is between 1:1 and 2:5. **Figure 8f** is a close-up perspective view of one embodiment of a ridged sheet as depicted in **Figures 8e**.

[0127] In addition to the first ridged sheet **820a**, treatment compartment **815** may also feature a second ridged sheet **820b**. As shown, second ridged sheet **820b** is disposed under first ridged sheet **820a** so that second ridged sheet **820b** catches seeds falling from first ridged sheet **820a**. In an alternative embodiment, an inverter is used to invert seeds passing between ridged sheets. As one of ordinary skill in the art will understand, multiple ridged sheets may be used. The ridged sheets may be made from a variety of materials, including, without limitation, dielectrics, metals, and metals coated with dielectric. **Figure 8b** is a perspective view of an alternative embodiment of the modular treatment apparatus depicted in **Figure 8a**; the embodiment shown in **Figure 8b** comprises multiple ridged sheets—**820a**, **820b**, and **820c**. Various components described herein are omitted for simplicity. **Figure 8c** and **Figure 8d** are side views of one embodiment of an apparatus as depicted in **Figure 8b.**

[0128] With reference to **Figure 8a**, in the illustrated embodiment, first actuator **825a** is connected to the first ridged sheet **820a**, and it moves the first ridged sheet **820a** linearly. The first actuator **825a** can operate continuously or intermittently. In alternative embodiments, the first actuator **825a**, without limitation, vibrates, rocks, or swirls the first ridged sheet **820a**. As one of ordinary skill in the art will

understand, moving a ridged sheet will cause agricultural matter to move progressively through the treatment chamber; the ridges on a ridged sheet will inhibit backward movement of the agricultural matter.

[0129] In addition to the first actuator **825a**, as shown, second actuator **825b** is connected to the second ridged sheet **820b**. Second actuator **825b** is substantially similar to first actuator **825a**. As one of ordinary skill in the art will understand, multiple actuators can be used with multiple ridged sheets. In an alternative embodiment, a single actuator may be used with two or more ridged sheets.

[0130] Apparatus **800** further comprises a vacuum **835**, which removes gas from apparatus **800**. In one embodiment, the vacuum removes gas from the apparatus to a pressure between 0.01 and 730 torr. In another embodiment, the vacuum removes gas from the apparatus to a pressure of between 0.01 and 10 torr. In yet another embodiment, the vacuum removes gas from the apparatus to a pressure of between about 500 and 1,000 mTorr.

[0131] In the embodiment shown in **Figure 8**, vacuum **835** connects to treatment compartment **815** and removes gas from treatment compartment **815**. As one of ordinary skill in the art will understand, vacuum **835** may evacuate gas from treatment compartment **815** via various airtight pathways (including intermediate pathways) between treatment compartment **815** and vacuum **835**. In an alternative embodiment (not shown), the apparatus further includes a valve that seals the port. In an embodiment where first compartment **805** is airtight, the vacuum may also connect

to the first compartment **805**. In yet another embodiment, the vacuum is provided separately from the apparatus.

[0132] Apparatus **800** further comprises a gas supply **840**. Gas supply **840** connects to treatment compartment **815** via a hose and port and provides gas to treatment compartment **815**. In one embodiment, the gas supply provides a variety of gasses to the treatment compartment, including without limitation, air, water vapor, nitrogen, oxygen, argon, hydrogen, noble gasses, and various combinations thereof. In another embodiment, the gas supply provides nitrogen and oxygen in various combinations. In a different embodiment, the gas supply provides ambient gas to the treatment compartment.

[0133] As one of ordinary skill in the art will understand, the gas supply may provide gas to the treatment compartment via various airtight pathways (including intermediate pathways) between the gas supply and treatment compartment. In an alternative embodiment (not shown), the apparatus further includes a valve that seals the port. In another alternative embodiment, the gas supply and vacuum share a port. In yet another embodiment, the gas supply is provided separately from the apparatus. An exemplary flow rate is, without limitation, 0–2,000 sccm.

[0134] Apparatus **800** further comprises at least a first electrode **845** and a second electrode **850**. First electrode **845** and second electrode **850** are powered by an RF generator **860**. Collectively, the first electrode **845** and second electrode **850** form a plasma ionizer. The electrodes are located on an opposite sides of exterior surface of

treatment compartment **815**. The RF frequency generated ranges from 0.2 to 920 MHz, corresponding to a plasma density between about $n_e \times 10^8 - n_e \times 10^{12}$ or power density of 0.001 to 0.4 W/cm^3. The electrodes may be used to generate capacitively coupled plasma, helicon, inductively coupled plasma, or a combination of the aforementioned. The electrodes are used in conjunction with a plasma control unit and RF circuit matching network (discussed below). In an alternative embodiment (not shown), the electrodes are separate from the apparatus and do not form a part of the apparatus.

[0135] Apparatus **800** further features an RF Generator **855**, a matching network **860**, and a controller **865**. The RF Generator **855**, matching network **860**, and controller **865** are substantially similar to the RF Generator, matching network, and controller of **Figures 5a–b**.

[0136] Apparatus **800** further comprises a temperature control unit **870**. In **Figure 8**, temperature control unit **870** is depicted as a bar; one of ordinary skill in the art will understand that temperature control unit **870** comprises a temperature sensor, a processor that regulates temperature, and a temperature control element (not shown). In one embodiment, the temperature control unit holds temperature within the treatment compartment and on most surfaces between room temperature (20–26°C) and 50°C. In another embodiment, the temperature control unit holds temperature within the treatment compartment between room temperature and 45°C.

In a different embodiment, the temperature control unit holds temperature within the treatment compartment between 0°C and room temperature.

[0137] Apparatus **800** further includes a third compartment **875**. Third compartment **875** collects agricultural matter from treatment compartment **815**. As one of ordinary skill in the art will understand, a variety of structures may be used for the third compartment.

[0138] Apparatus **800** further includes a second load lock seal **880**. Third compartment **875** bridges load lock seal **880** and treatment compartment **815**, although third compartment **875** need not bridge the second load lock seal **880** and treatment compartment **815**. Similar to load lock seal **810**, second load lock seal **880** allows agricultural matter to exit treatment compartment **815** without breaking vacuum conditions in treatment compartment **815**. Matter exits at egress **885**. In an alternative embodiment (not shown), the egress further comprises a bag attachment. In additional embodiments, the egress is a pyramid-shaped funnel or a rectangular chute. As one of ordinary skill in the art will understand, a variety of structures may be used for the egress.

[0139] **Figure 9** is a side view of one embodiment of a modular treatment apparatus 900. Modular treatment apparatus 900 comprises, *inter alia*, modules **905a** and **905b**. Each module **905** may include any of the components discussed above. In an alternative embodiment (not shown), the modular treatment apparatus features three modules. In another embodiment, the modular treatment apparatus features

four or more treatment modules. In a different embodiment, the modular treatment apparatus features a single (replaceable) treatment module. As one of ordinary skill in the art will understand, the modules in modular treatment apparatus need not be identical.

[0140] Modular treatment apparatus 900 features a hopper **910**. Agricultural matter is placed into hopper **910**. Hopper **910** is a simple receptacle with no sensors, agitators, or regulators. In an alternative embodiment (not shown), the hopper features a sensor that measures the amount of agricultural material in the receptacle. The sensor may be digital or analog. In another embodiment, the hopper features an agitator that agitates agricultural material in the receptacle. Examples of agitators include, without limitation, stirrers, vibratory actuators, and pneumatic agitators. In yet another embodiment, the hopper includes a regulator, such as a feeder or wheel, that regulates the amount of agricultural material that enters a treatment module. In further embodiments, the hopper contains a combination of sensors, agitators, and regulators.

[0141] Modular treatment apparatus 900 further comprises a first seal **915**. First seal **915** is re-sealable, airtight, and distal to treatment module **905a**. First seal **915**, as shown, is disposed between hopper **910** and treatment module **905a**. In an alternative embodiment (not shown), the first seal is incorporated into at least one treatment module. In another embodiment, the first seal is incorporated into the hopper.

[0142] Module **905a** further comprises a treatment compartment **920**. As shown, treatment compartment **920** is an airtight rectangular prism (but treatment compartment **920** is not limited to a rectangular form). Regardless of the shape of treatment compartment **920**, treatment compartment **920** is durable enough to withstand low pressure environments and the creation and containment of plasma. Suitable materials for treatment compartment **920** include, without limitation, quartz, glass, plastic, ceramic, and metal. In another embodiment, the treatment compartment further includes an opening that allows access to the treatment compartment.

[0143] Module **905a** features a first tray **925a** and a first actuator **930a**. As shown, first tray **925a** is substantially flat. Agricultural matter entering the treatment compartment deposits on first tray **925a**. First actuator **930a** moves tray **925a**, which causes agricultural matter on first tray **925a** to move through the treatment compartment. In the illustrated embodiment, additional agricultural matter may be used to hinder backward movement of agricultural matter deposited on the first tray **925a**. In an alternative embodiment, the rate of reverse translation of the sheet can be set to exceed the rate of forward translation, which would also hinder backward movement of agricultural matter deposited on the tray.

[0144] As shown, module **905a** also features second and third trays, **925b** and **925c**, and second and third actuators, **930b** and **930c**. The second and third trays and second and third actuators are substantially similar to the first tray **925a** and first

actuator **930a**. As depicted, the second tray receives agricultural matter from the first tray, and the third tray receives agricultural matter from the second tray. As one of ordinary skill in the art will understand, multiple trays and actuators may be provided within a module. In alternative embodiments (not shown), at least one of the trays features ridges, which hinder backward movement of agricultural matter deposited on the tray.

[0145] Module **905a** also features a first port **935** and a second port **940**. The ports allow connection to a vacuum or gas supply. In an alternative embodiment, the ports are replaced with an integrated vacuum or gas supply. In another embodiment, only one module in apparatus features at least one port.

[0146] Module **905a** also features electrodes **945** and **950**. The electrodes **945** and **950** are disposed on an external surface of module **905a**. In the illustrated embodiment, the electrodes are used to induce RF plasma. In an alternative embodiment, the electrodes are separate from (and not integrated into) the module. In another alternative embodiment, the electrodes are disposed on an internal surface of the module. The electrodes are used in conjunction with an RF Generator, a matching network, and a controller (not shown).

[0147] In **Figure 9**, temperature control unit **955** is depicted as a bar; one of ordinary skill in the art will understand that temperature control unit **955** comprises a temperature sensor, a processor that regulates temperature, and a temperature control element (not shown).

[0148] After passing through treatment chamber **920**, agricultural matter leaves module **905a** and enters module **905b** via conduit **960**. Agricultural matter then proceeds through module **905b**, where it eventually accumulates at collector **965**. Load lock seal **970** allows agricultural matter leave module **905b** without breaking vacuum.

[0149] **Figure 10** is a flowchart describing processes for treating agricultural matter. Various steps in method **1000** may be performed concurrently or in more than one order.

[0150] In **Figure 10**, method **1000** starts with setting and regulating **1010** the temperature in the treatment compartment. In setting and regulating step **1010**, a temperature control unit is activated. Setpoint regulation, or feedback control, is used to ensure that the temperature remains within a desired range.

[0151] Method **1000** continues with loading **1020** agricultural matter into a treatment compartment. In loading step **1020**, matter may be loaded from a source external to the treatment compartment or from a source connected to the treatment compartment.

[0152] Method **1000** then continues with evacuating **1030** gas from the treatment compartment. In evacuating step **1030**, a vacuum is used to remove existing gas from the treatment compartment.

[0153] Method **1000** then continues with providing **1040** a specific gas to the treatment compartment. Exemplary gases and the pressures at which they are provided are discussed above.

[0154] After providing step **1040** occurs, method **1000** continues with creating **1050** a plasma environment. In creating step **1050**, the plasma environment is created using the RF power source systems and electrodes.

[0155] Once a plasma environment is created in creating step **1050**, trays or ridged sheets within the plasma environment are agitated **1060**. In agitating step **1060**, trays or ridged sheets may translate with actuators. As one of ordinary skill in the art will understand, translating the trays or ridged sheets is substantially linear movement. Alternatively, the matter may be agitated by, without limitation, rocking, vibrating, rotating, or tilting the trays or ridged sheets.

[0156] In an optional step (not shown) where trays with ridges are used, the inclination of the ridges can be varied to increase or decrease the processing time. Likewise, in an optional step where the trays are translated, the rate of reverse translation may be set greater than the rate of forward translation.

[0157] In conjunction with agitating step **1060**, the matter within the treatment compartment is treated with plasma. In one embodiment, the surface of the matter is activated such that the contact angle of water on the surface of the matter is increased. In another embodiment, the surface of the matter is activated such that the contact angle of the matter is decreased.

[0158] Method **1000** then continues, and concludes with, unloading **1070** the matter from the treatment compartment. In unloading step **1070**, material may be, without limitation, directed into packaging or storage, set aside for testing, or directed into another treatment compartment.

[0159] In an optional step, unprocessed, or partially processed material is reloaded **1080**. In reloading step **1080**, unprocessed or partially processed material is reloaded into the treatment compartment for further processing. As one of ordinary skill in the art will appreciate, this optional step allows for continual system flow processing.

[0160] To the extent that the term "includes" or "including" is used in the specification or the claims, it is intended to be inclusive in a manner similar to the term "comprising" as that term is interpreted when employed as a transitional word in a claim. Furthermore, to the extent that the term "or" is employed (e.g., A or B) it is intended to mean "A or B or both." When the applicants intend to indicate "only A or B but not both" then the term "only A or B but not both" will be employed. Thus, use of the term "or" herein is the inclusive, and not the exclusive use. See, Bryan A. Garner, A Dictionary of Modern Legal Usage 624 (2d. Ed. 1995). Also, to the extent that the terms "in" or "into" are used in the specification or the claims, it is intended to additionally mean "on" or "onto." Furthermore, to the extent the term "connect" is used in the specification or claims, it is intended to mean not only "directly connected

to," but also "indirectly connected to" such as connected through another component or components.

[0161] While the present disclosure has been illustrated by the description of embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the disclosure, in its broader aspects, is not limited to the specific details, the representative apparatus and method, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of the applicant's general inventive concept.

CLAIMS

What is claimed is:

1. An apparatus for processing agricultural matter comprising:

a first compartment, for receiving agricultural matter from an external source, a second compartment, for processing agricultural matter, and a third compartment, for receiving processed agricultural matter;

a first re-sealable airtight seal, disposed between the first compartment and the second compartment, and a second re-sealable airtight seal, disposed between the second compartment and third compartment, through which agricultural matter passes;

a vacuum, operably connected to the second compartment, that evacuates air from at least the second compartment;

a gas supply, operably connected to at least the second compartment, that provides gas to the second compartment;

a plasma ionizer, operably associated with the second compartment, that ionizes gas in the second compartment into a plasma;

an RF generator configured to provide a plasma striking voltage and operating power;

an RF matching network, configured to match the impedance of the RF generator, a plasma controller, operably associated with the second compartment, that controls plasma flow within the second compartment, and;

a first ridged sheet, operably connected to an actuator, that moves agricultural matter within the second chamber;

and a second ridged sheet, operably connected to an actuator, that moves agricultural matter within the second chamber.

2. The apparatus of claim 1, further comprising an inverter that inverts agricultural matter within the second chamber.

3. The apparatus of claim 1, further comprising a power density controller that maintains density in the second compartment between electron density $n_e \times 10^8 - n_e \times 10^{12}$ or power density of 0.001 to 0.4 W/cm^3.

4. The apparatus of claim 1, wherein the first and second re-sealable airtight seals are screw-in valves.

5. The apparatus of claim 1, wherein the first and second re-sealable airtight seals are load lock seals.

6. The apparatus of claim 1, wherein the distance between adjoining ridges is equal or larger than ridge height.

7. The apparatus of claim 1, wherein the actuator is a vibrator.

8. A plasma treatment module comprising:

a hopper, for holding seeds for treatment;

a first load lock seal, partitioning the exterior of the apparatus from an interior vacuum chamber, the chamber being plasma-tolerant;

a feeder, for dispensing seeds from the hopper at a predetermined rate;

a first tray, disposed within the vacuum chamber, that receives seeds from the feeder;

a second tray, disposed within the vacuum chamber, that receives seeds from the first tray;

at least one linear actuator that moves at least one of the trays;

at least one pair of electrodes, disposed about the chamber, capable of generating a plasma environment;

a temperature regulator comprising a temperature sensor, a temperature control unit, a temperature control element;

a second load lock seal, partitioning the interior of the apparatus from an exterior vacuum chamber.

9. The module of claim 8, wherein the first tray further comprises inclined ridges.

10. The module of claim 8, wherein the first tray is porous.

11. The module of claim 8, wherein the at least one linear actuator is connected to the first tray and a second linear actuator is connected to the second tray.

12. The module of claim 8, further comprising a third tray, disposed within the vacuum chamber, that receives seeds from the second tray.

13. The module of claim 8, further comprising an inverting slide disposed between the first tray and the second tray.

14. The module of claim 8, wherein the first load lock seal is a double valve gate.

15. A method for treating agricultural matter comprising:

providing seeds to a linear processing apparatus;

introducing seeds into a chamber in the linear processing apparatus;

moving seeds linearly within the chamber with actuators;

evacuating gas from the chamber;

introducing gas to the chamber;

ionizing gas introduced into the chamber;

monitoring and regulating ionizing energy within the chamber;

monitoring and regulating temperature within the chamber;

removing seeds from the linear processing apparatus.

16. The method of claim 15, wherein gas introduced into the chamber is ionized by inductively coupled plasma discharge.

17. The method of claim 15, wherein trays are translated to move seeds within the chamber.

18. The method of claim 17, wherein the trays further comprise inclined ridges.

19. The method of claim 17, wherein the inclination of the ridges is adjusted in proportion to a given processing time.

20. The method of claim 17, wherein the rate of reverse translation is greater than the rate of forward translation.

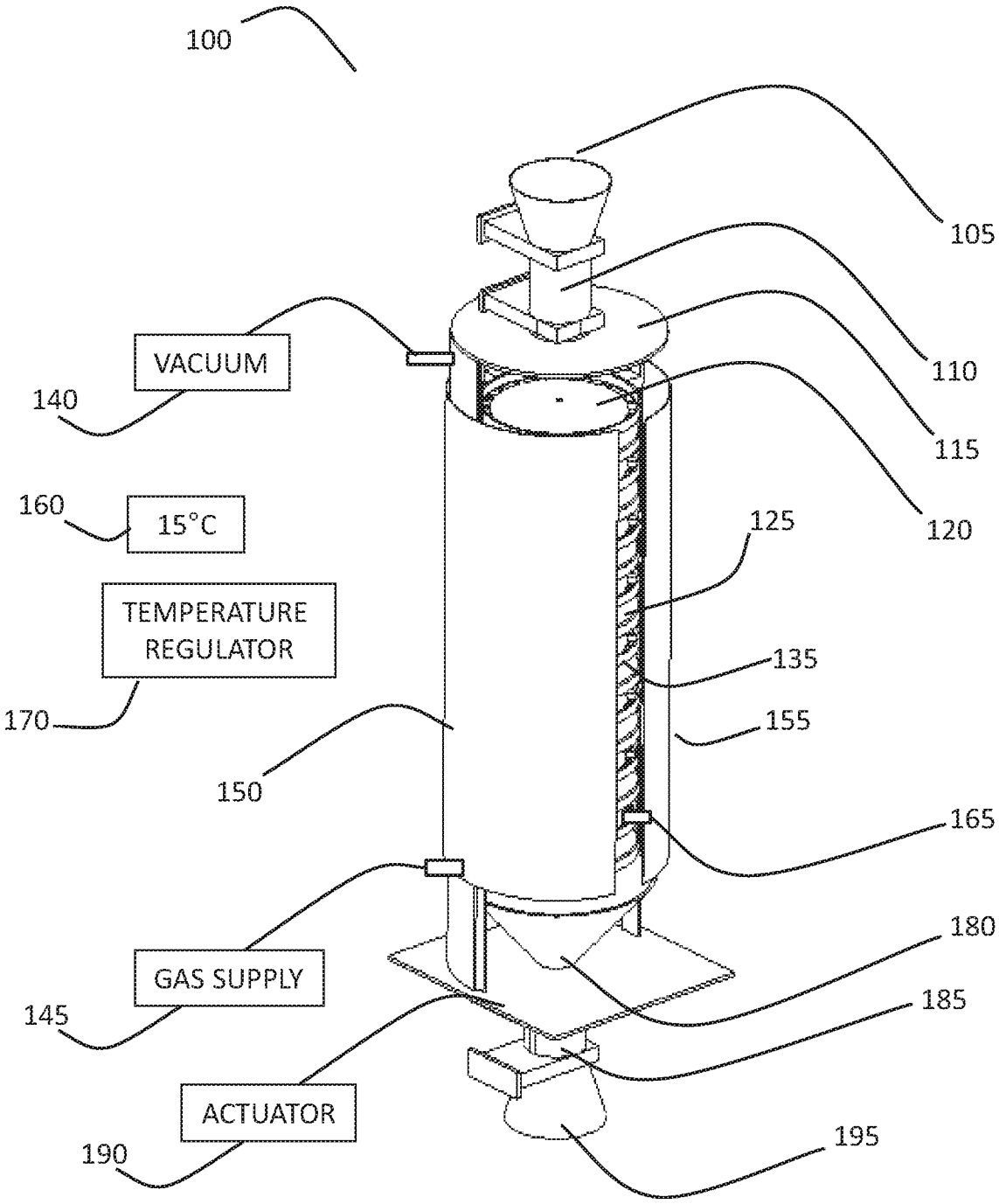

100
105
110
115
120
VACUUM
140
160
15°C
TEMPERATURE REGULATOR
170
125
135
155
150
165
180
185
GAS SUPPLY
145
ACTUATOR
190
195

FIG. 1a

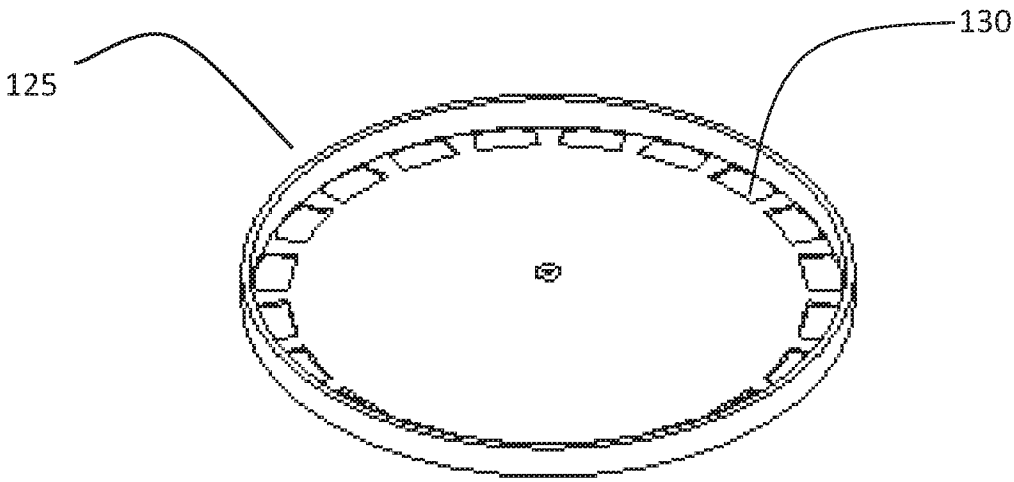


FIG. 1b

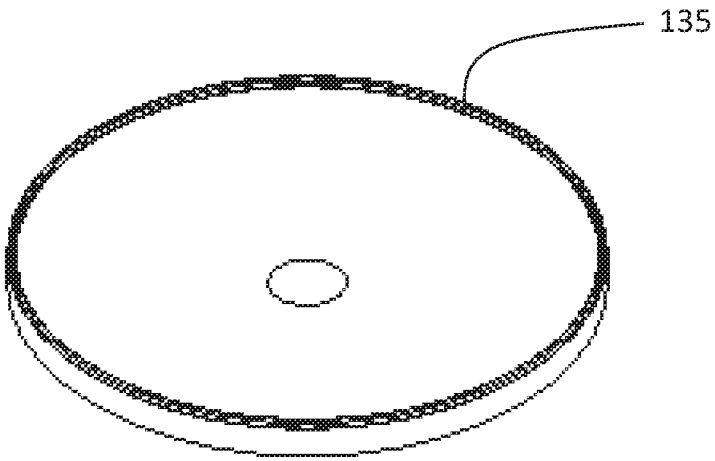


FIG. 1c

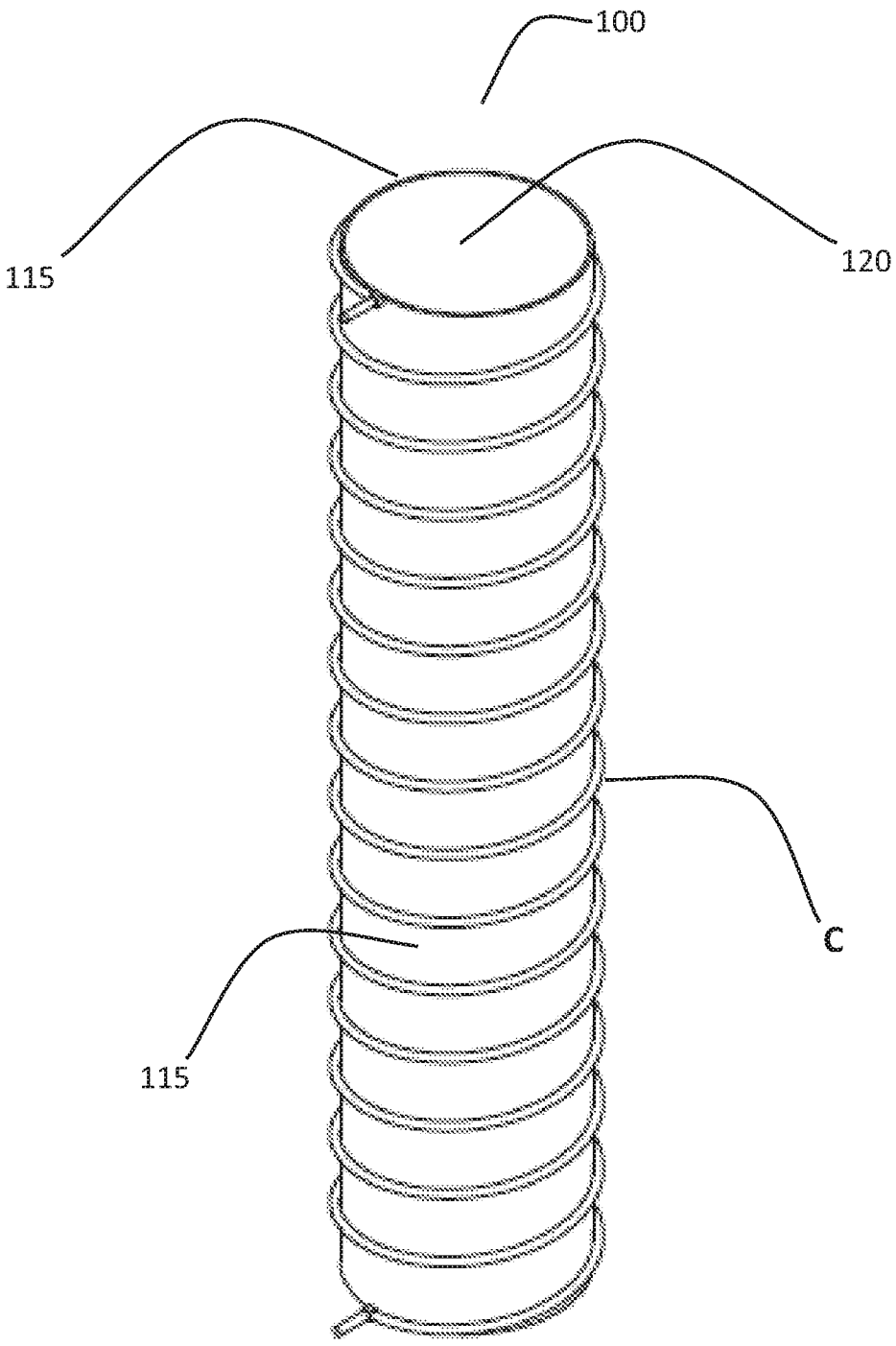


FIG. 1d

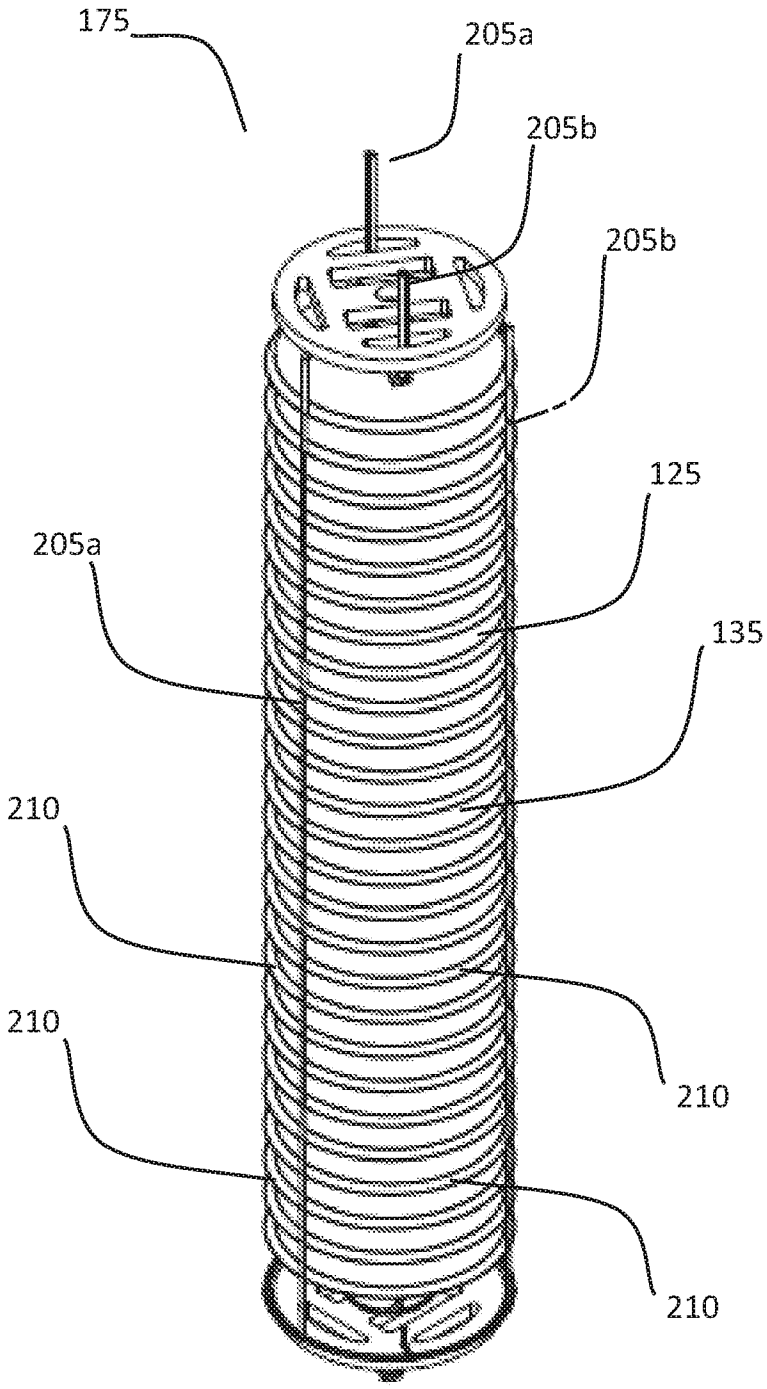


FIG. 2a

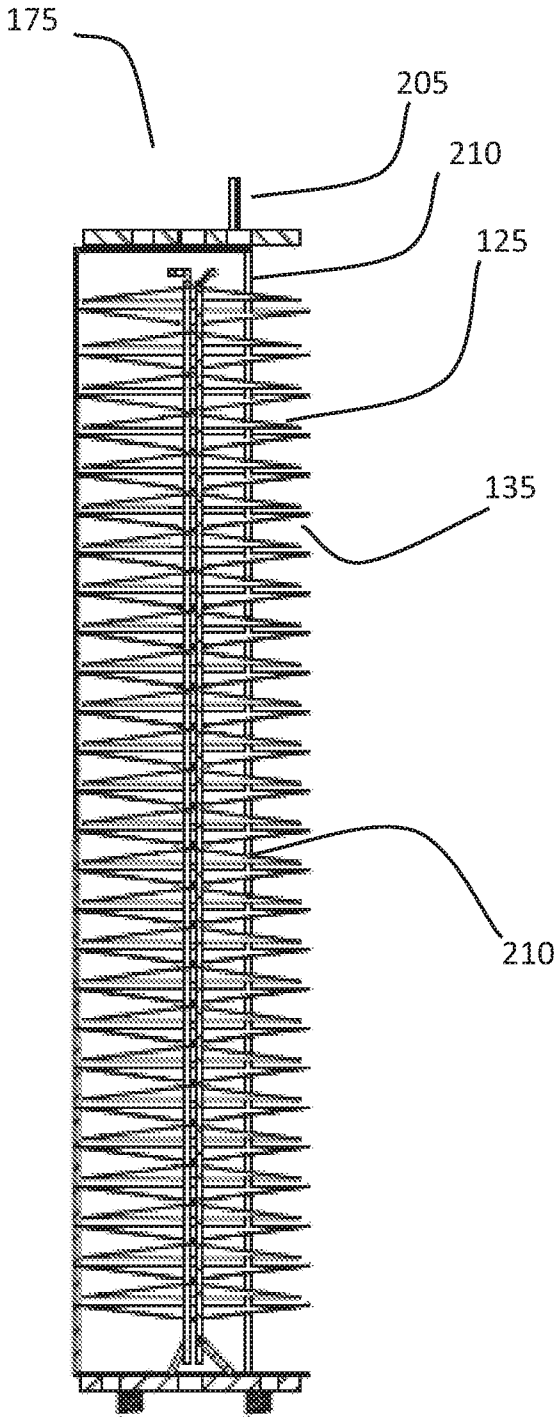


FIG. 2b

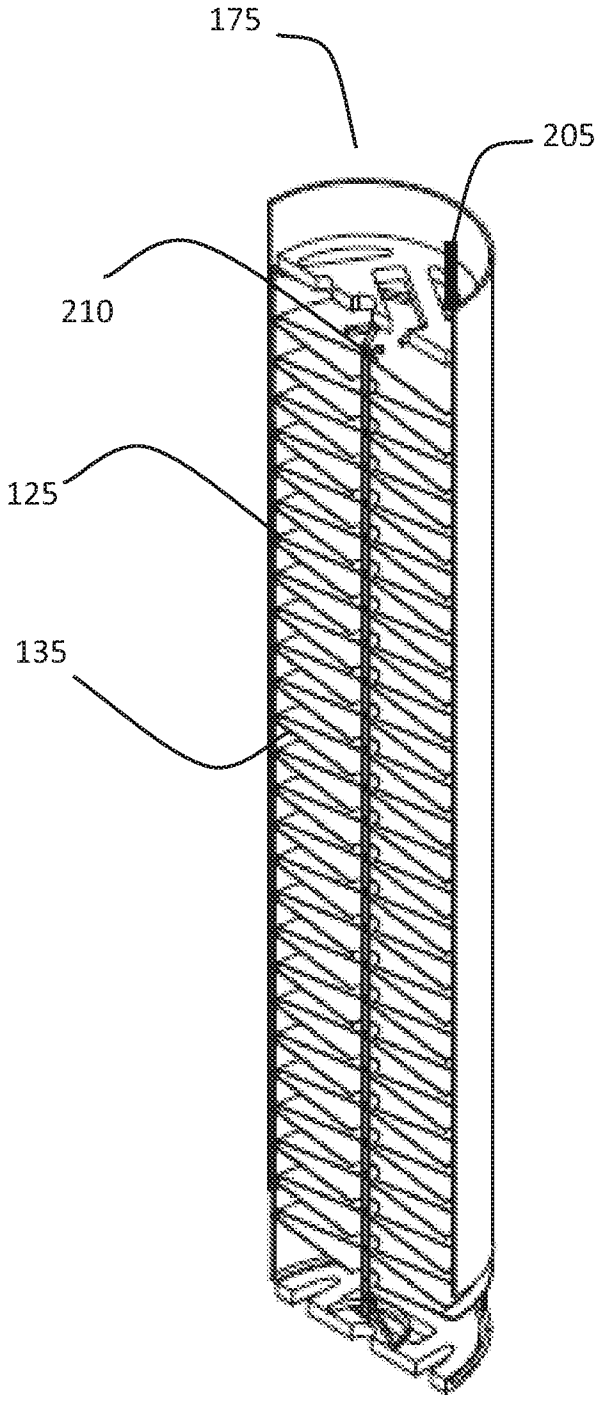


FIG. 2c

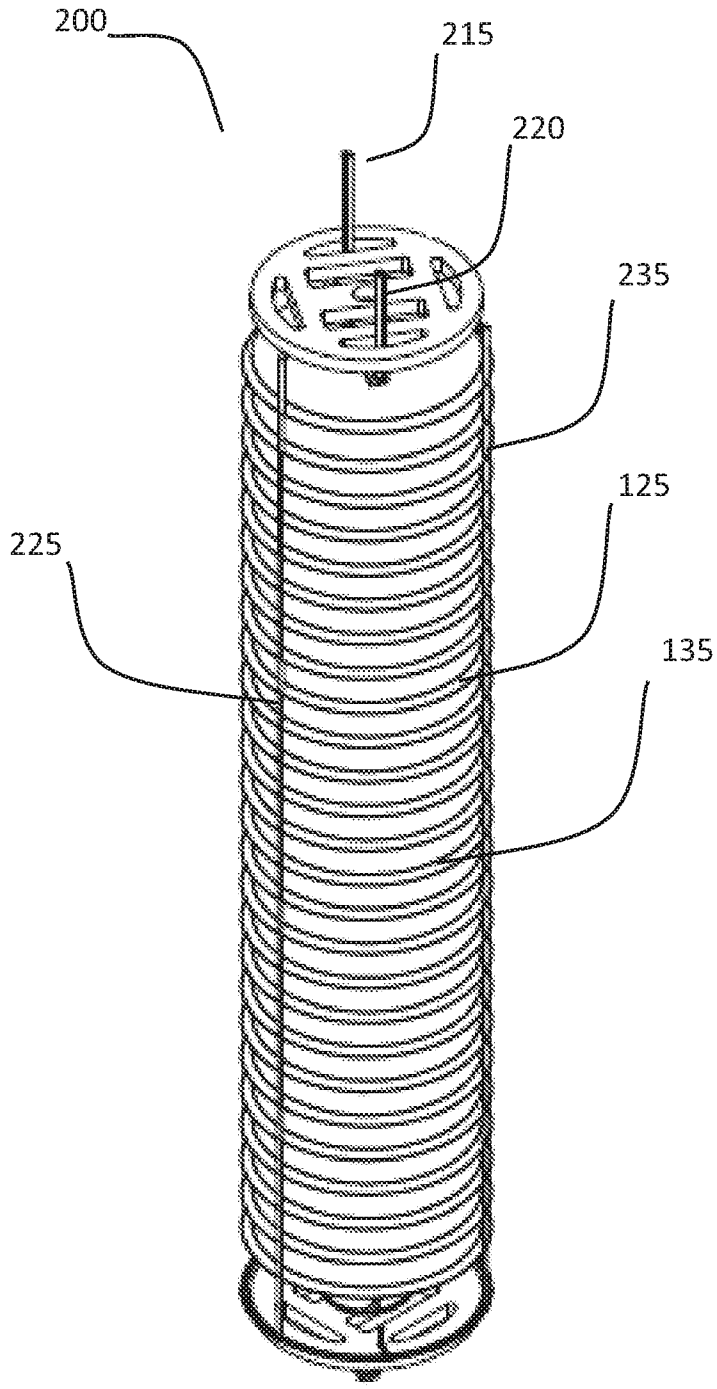


FIG. 2d

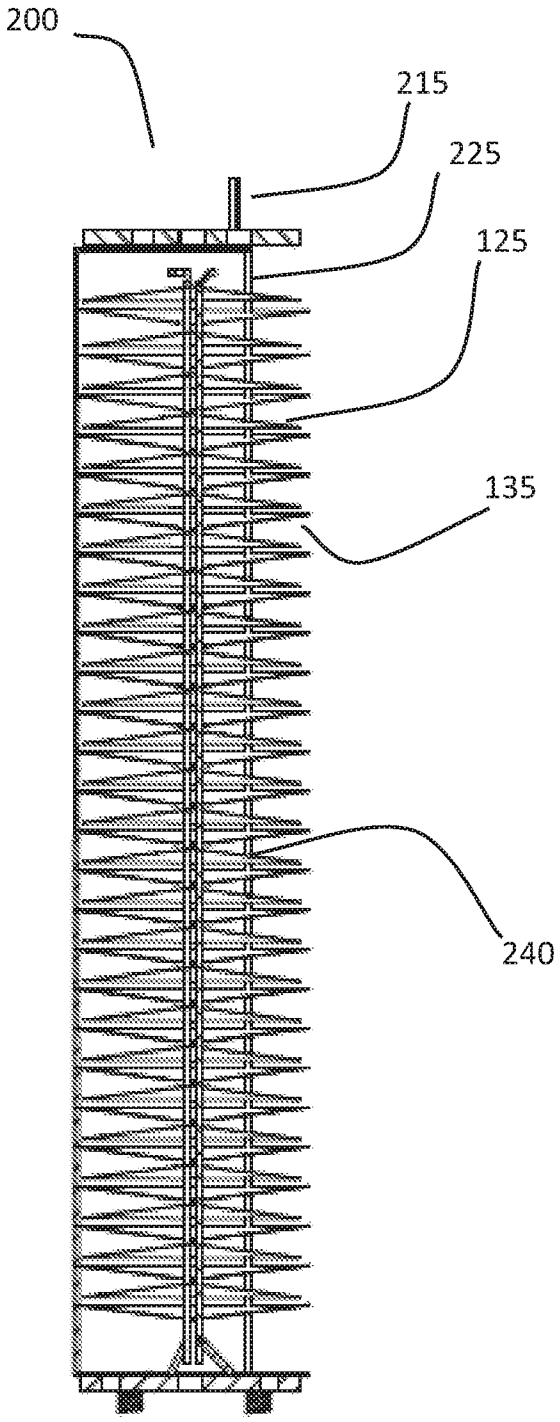


FIG. 2e

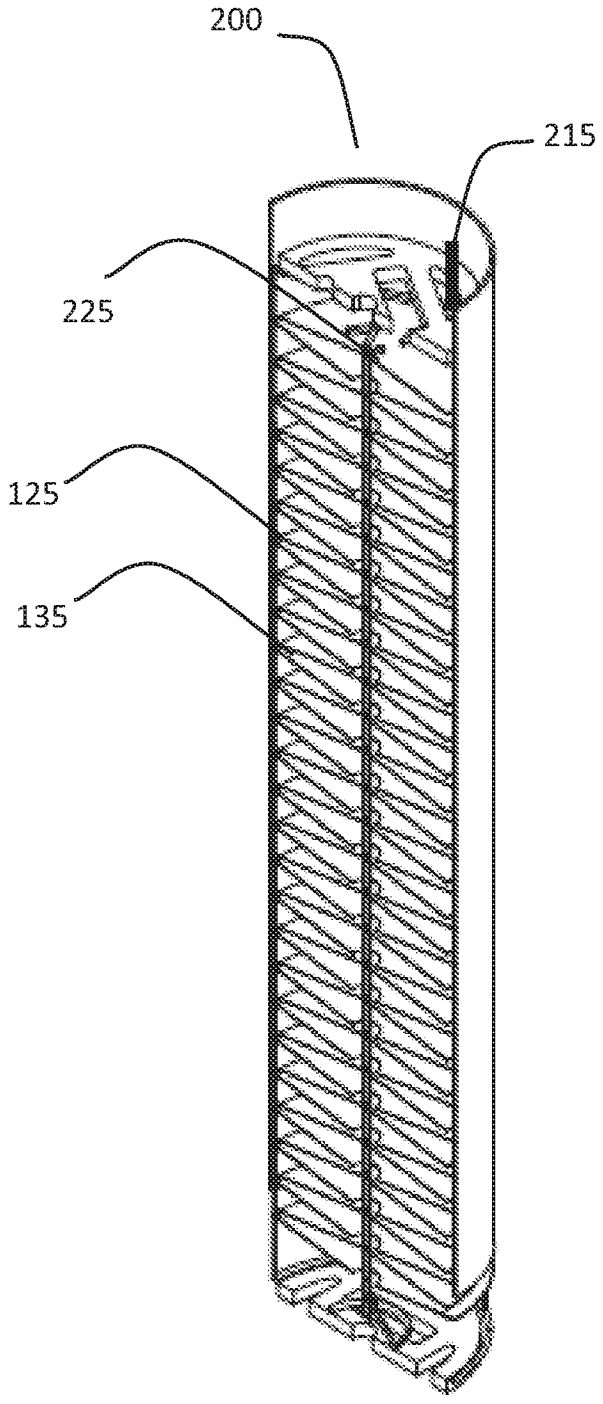


FIG. 2f

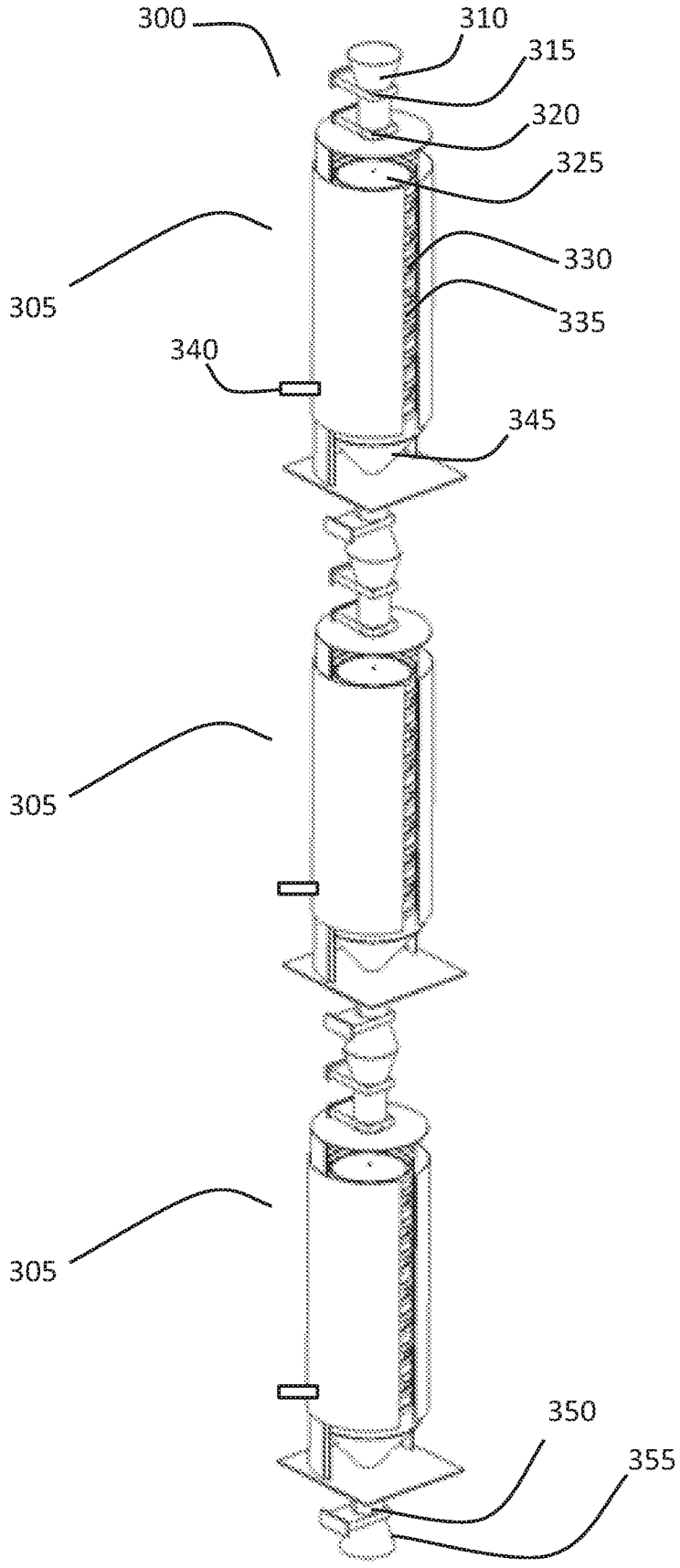


FIG. 3

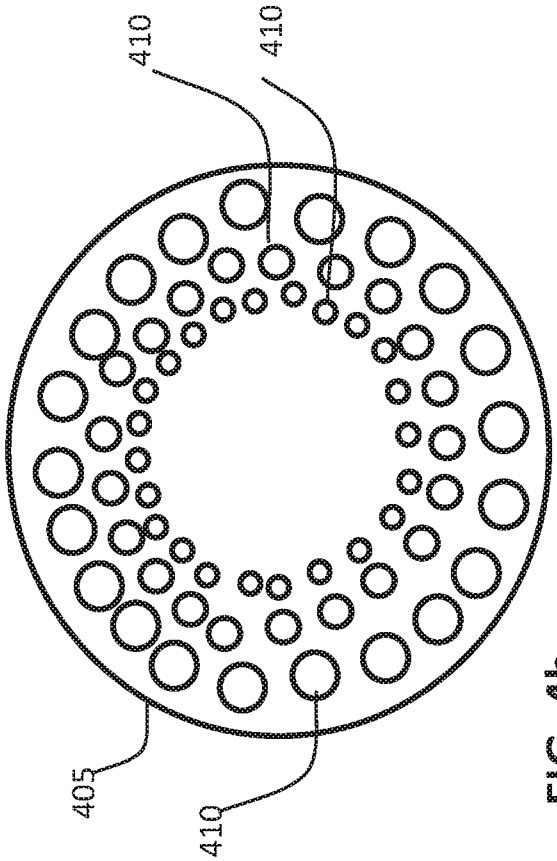


FIG. 4b

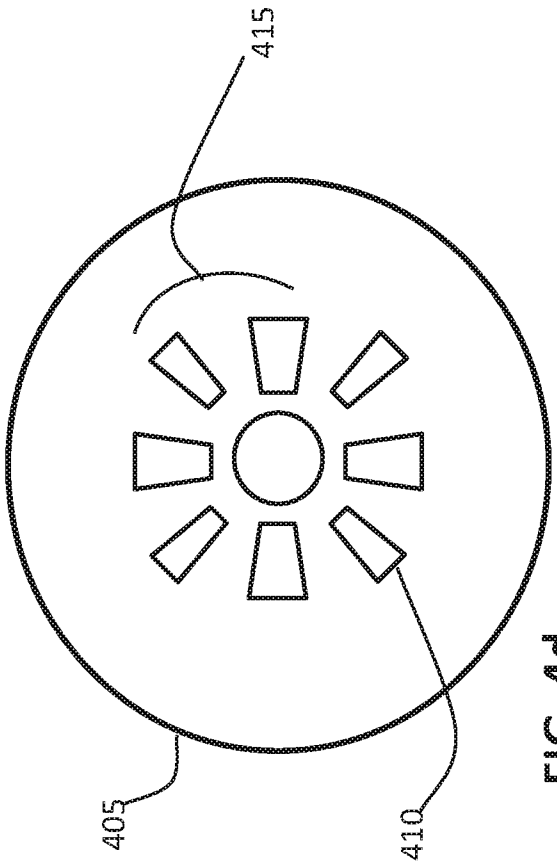


FIG. 4d

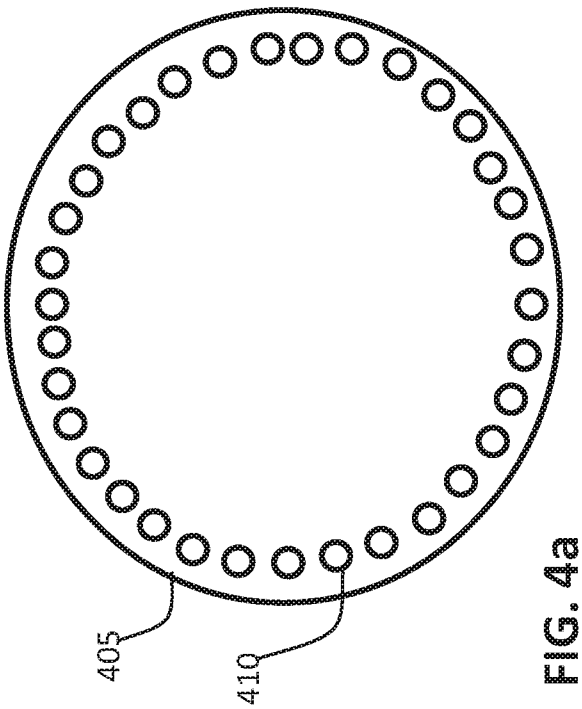


FIG. 4a

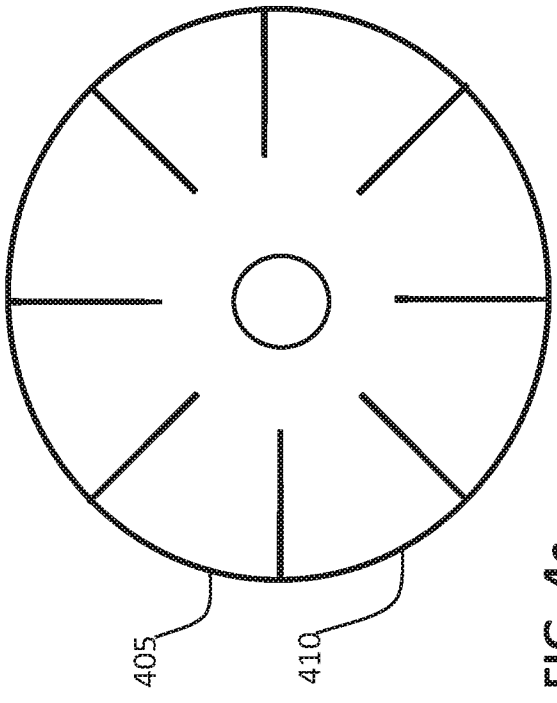


FIG. 4c

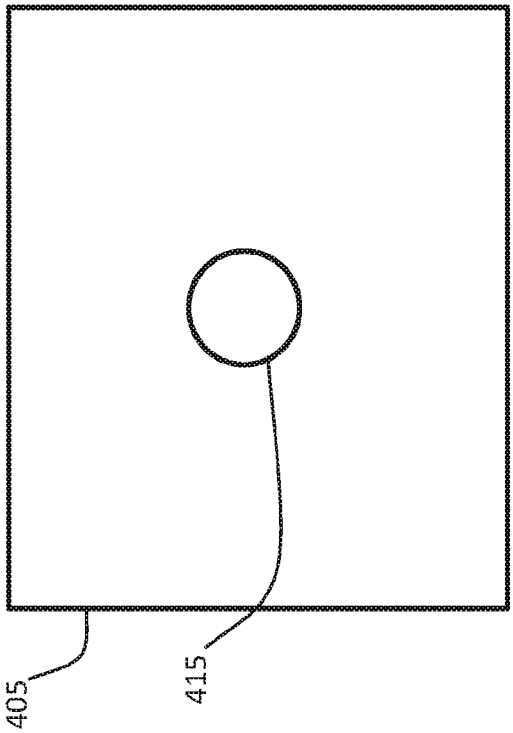


FIG. 4f

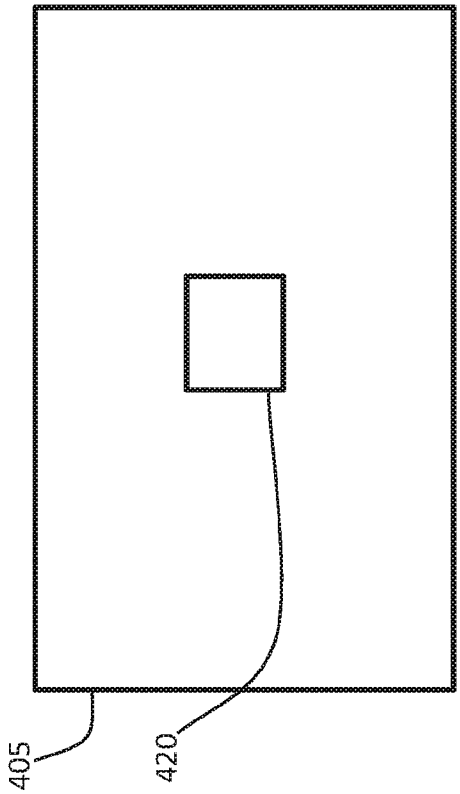


FIG. 4h

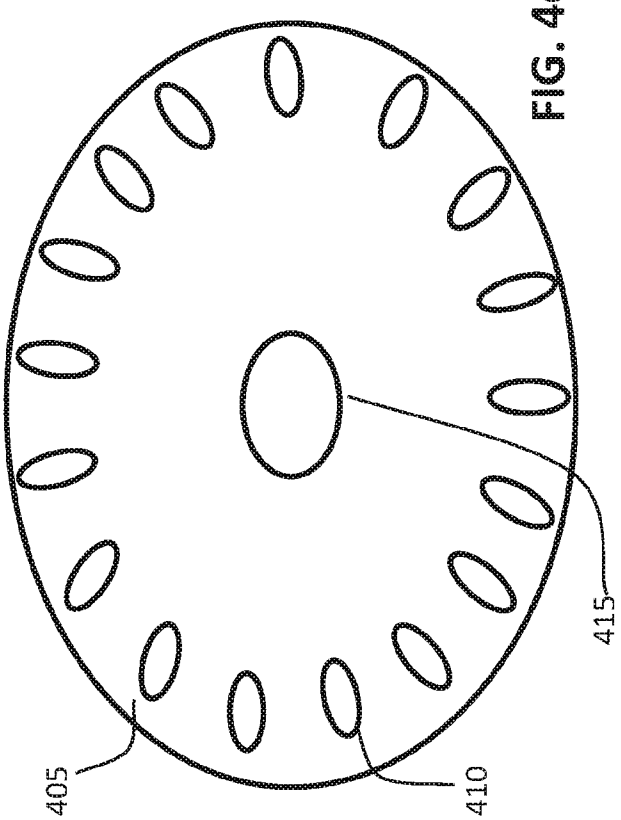


FIG. 4e

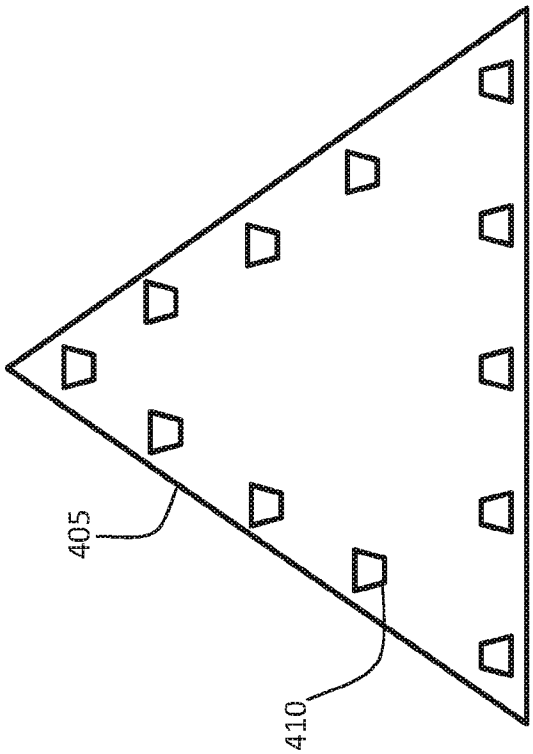


FIG. 4g

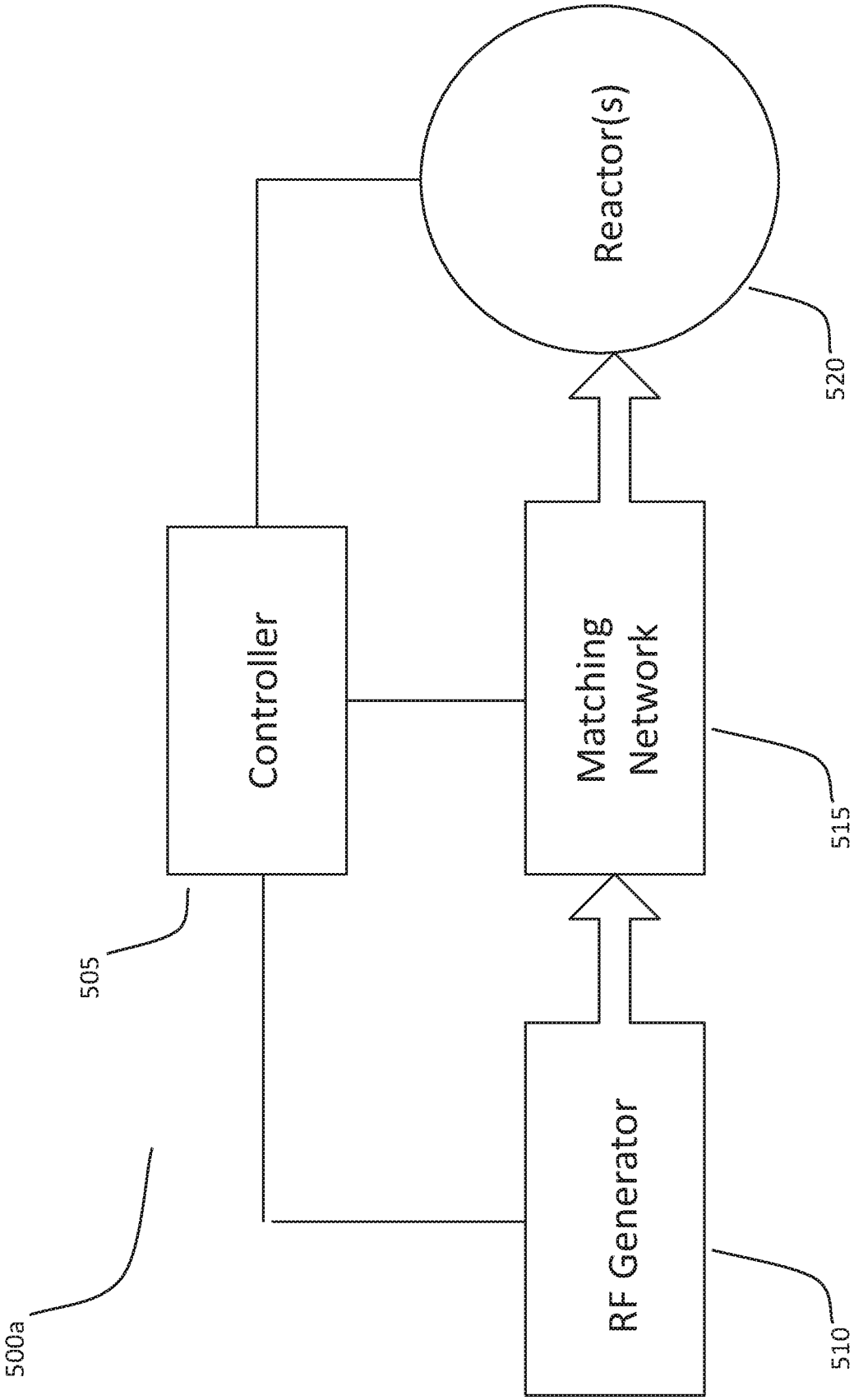

Reactor(s)
520
Controller
Matching Network
515
505
RF Generator
510
500a

FIG. 5a

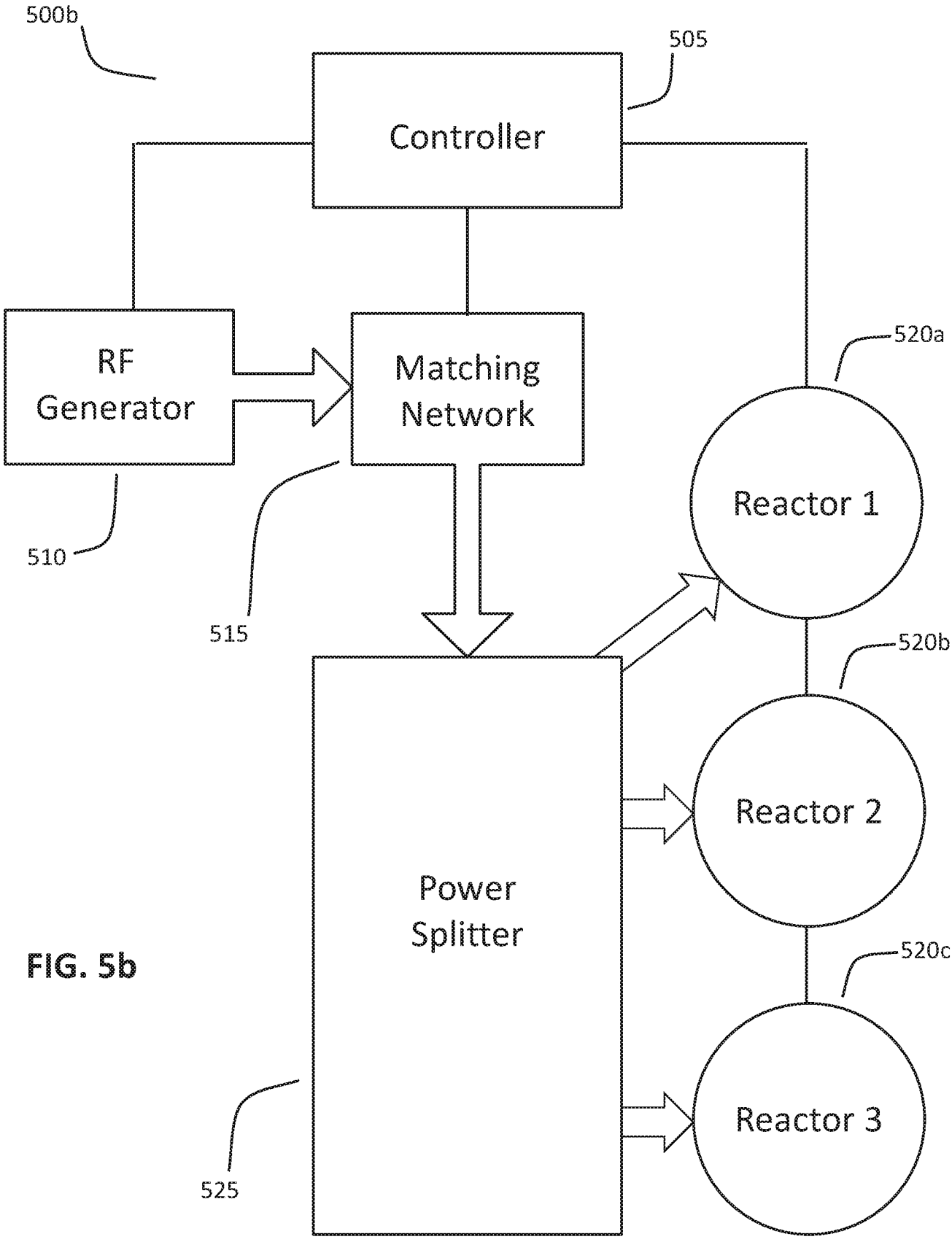

500b
505
Controller
RF Generator
Matching Network
520a
Reactor 1
510
515
520b
Reactor 2
Power Splitter
520c
Reactor 3
525

FIG. 5b

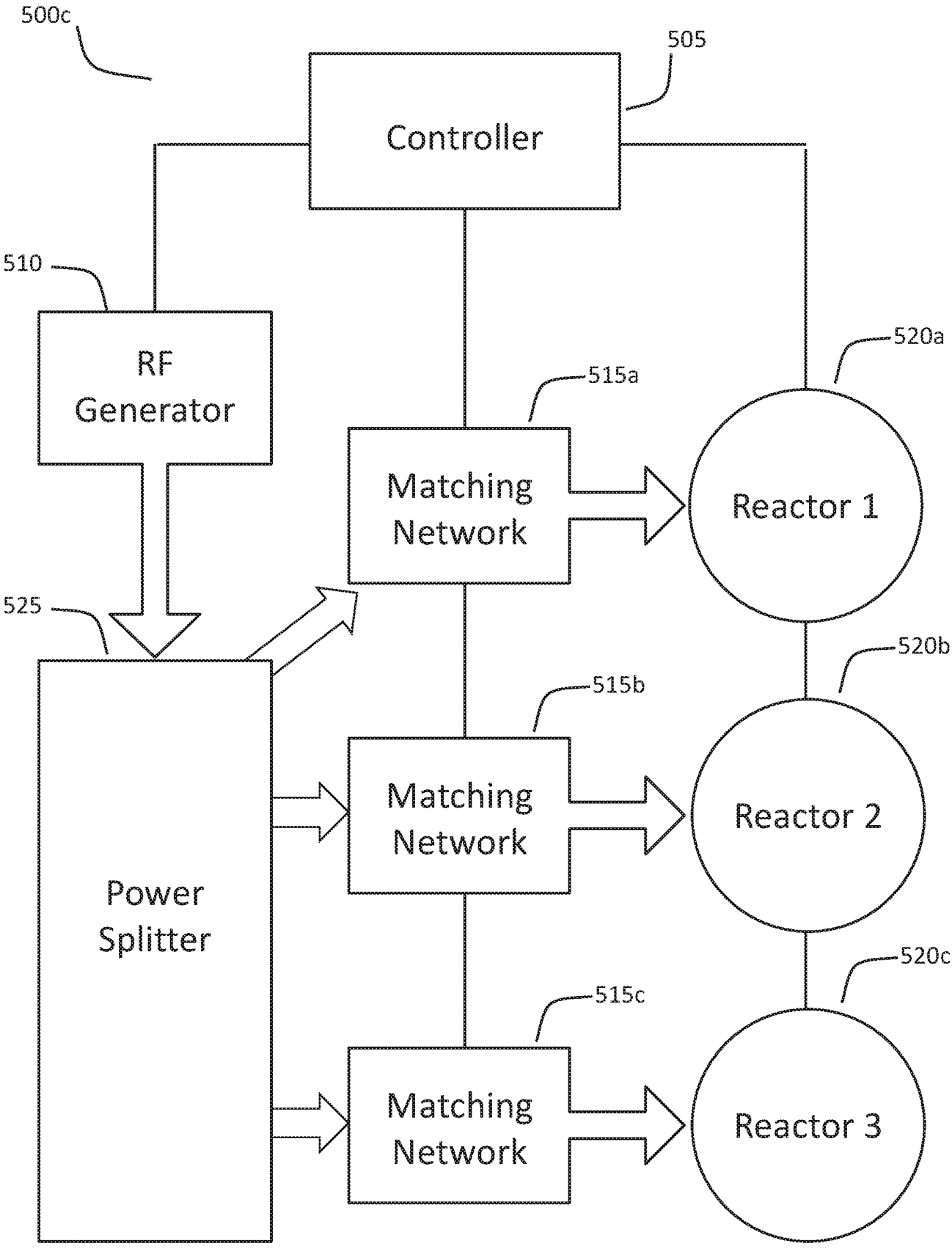

500c
505
Controller
510
RF Generator
520a
515a
Matching Network
Reactor 1
525
520b
515b
Matching Network
Reactor 2
Power Splitter
520c
515c
Matching Network
Reactor 3

FIG. 5c

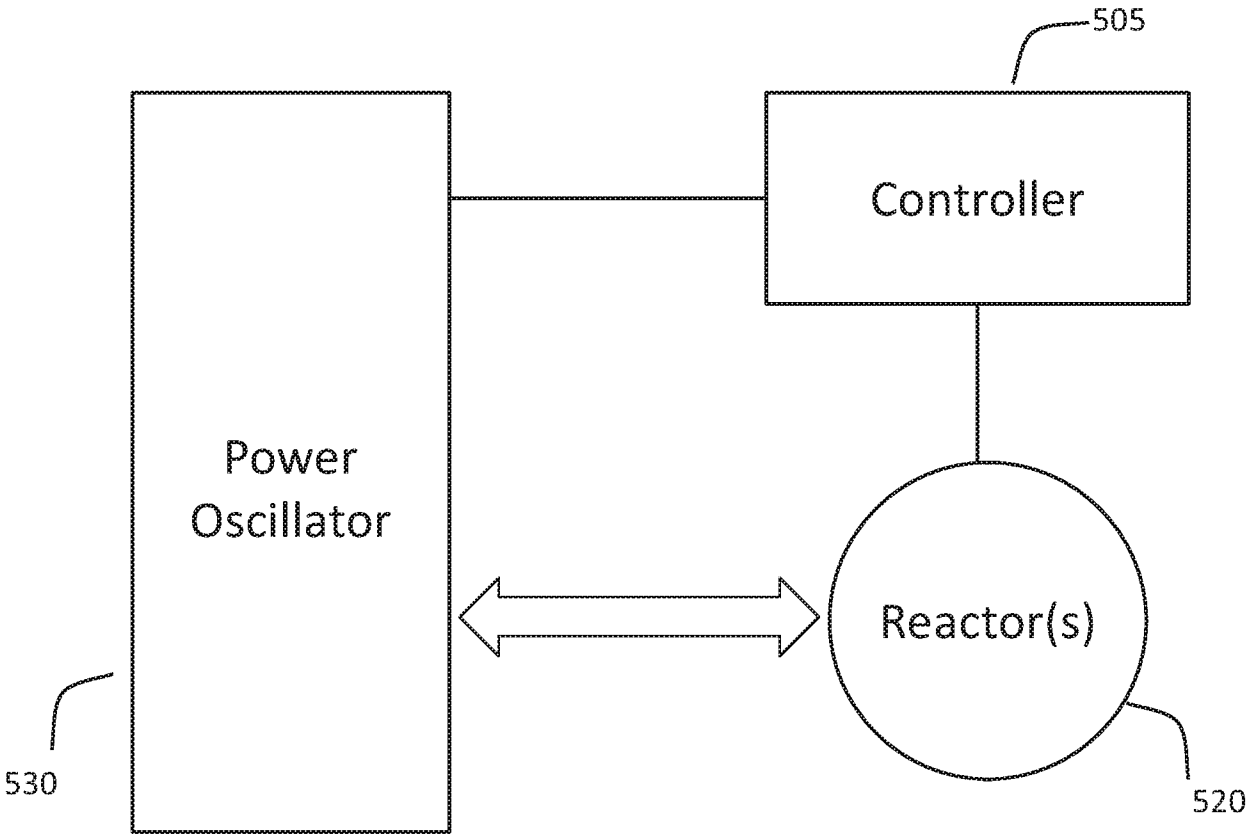


FIG. 5d

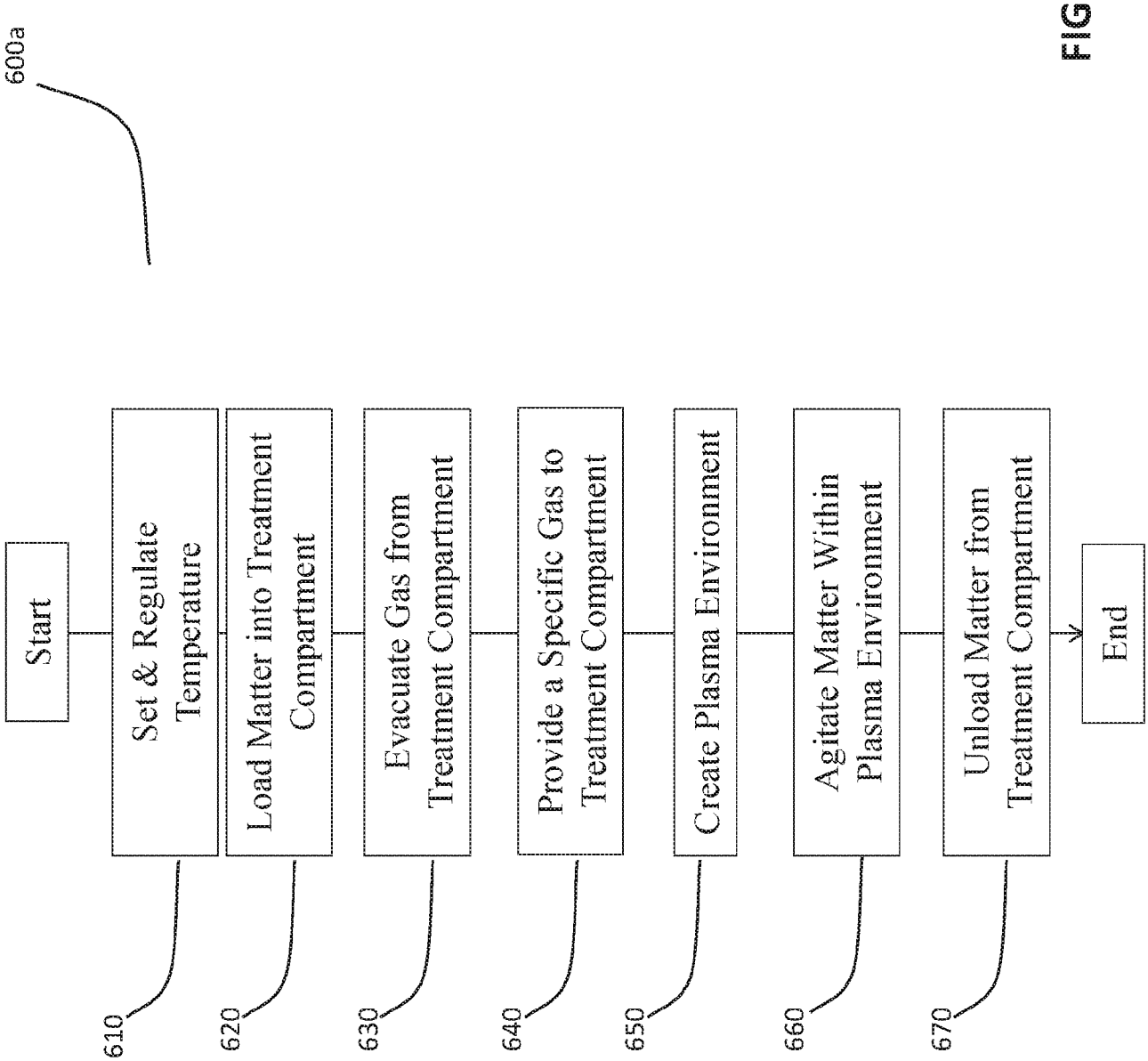

600a
Start
Set & Regulate Temperature
Load Matter into Treatment Compartment
Evacuate Gas from Treatment Compartment
Provide a Specific Gas to Treatment Compartment
Create Plasma Environment
Agitate Matter Within Plasma Environment
Unload Matter from Treatment Compartment
End
610
620
630
640
650
660
670

FIG. 6a

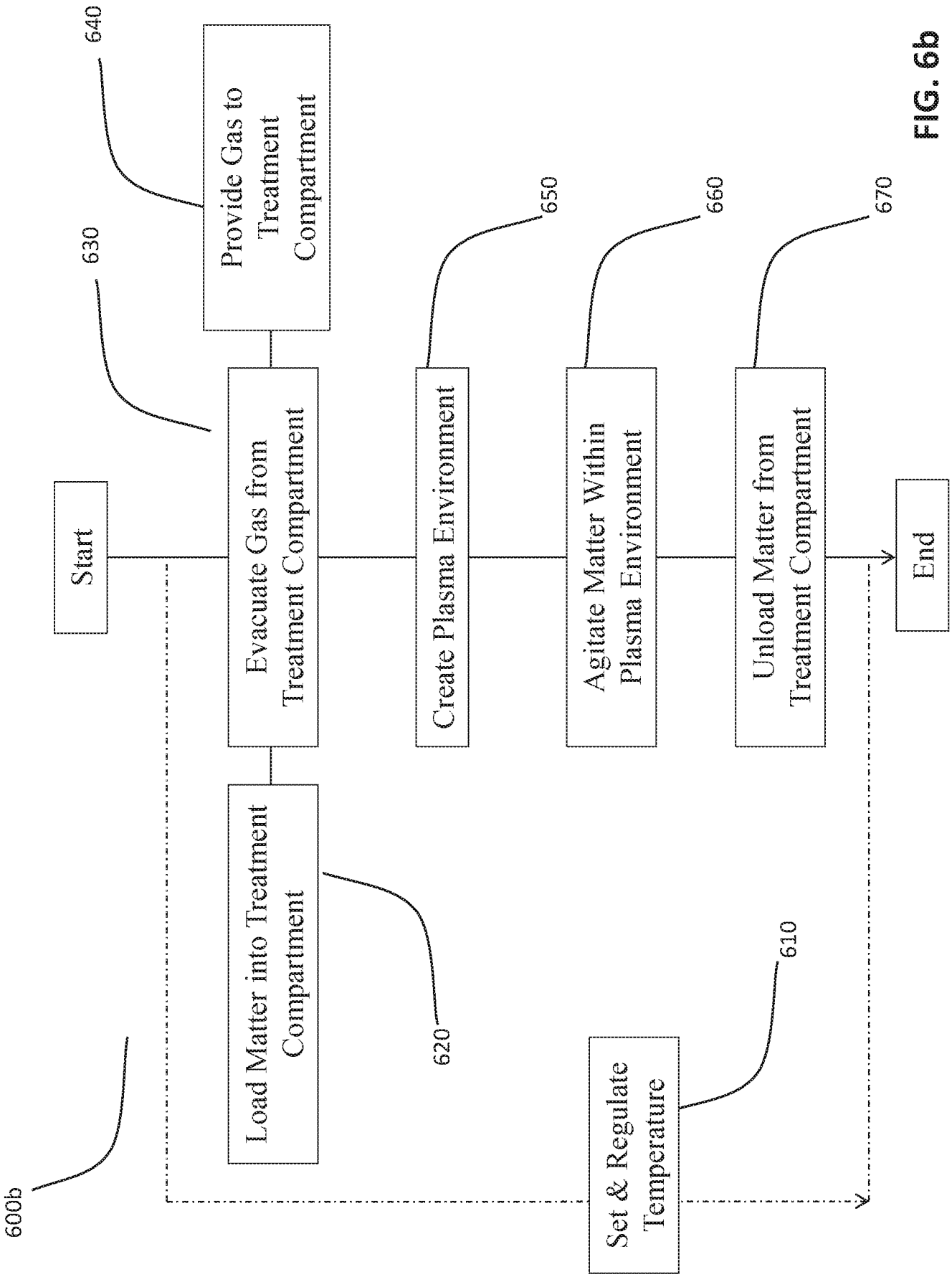

600b
Start
Load Matter into Treatment Compartment
620
Evacuate Gas from Treatment Compartment
630
Provide Gas to Treatment Compartment
640
Set & Regulate Temperature
610
Create Plasma Environment
650
Agitate Matter Within Plasma Environment
660
Unload Matter from Treatment Compartment
670
End

FIG. 6b

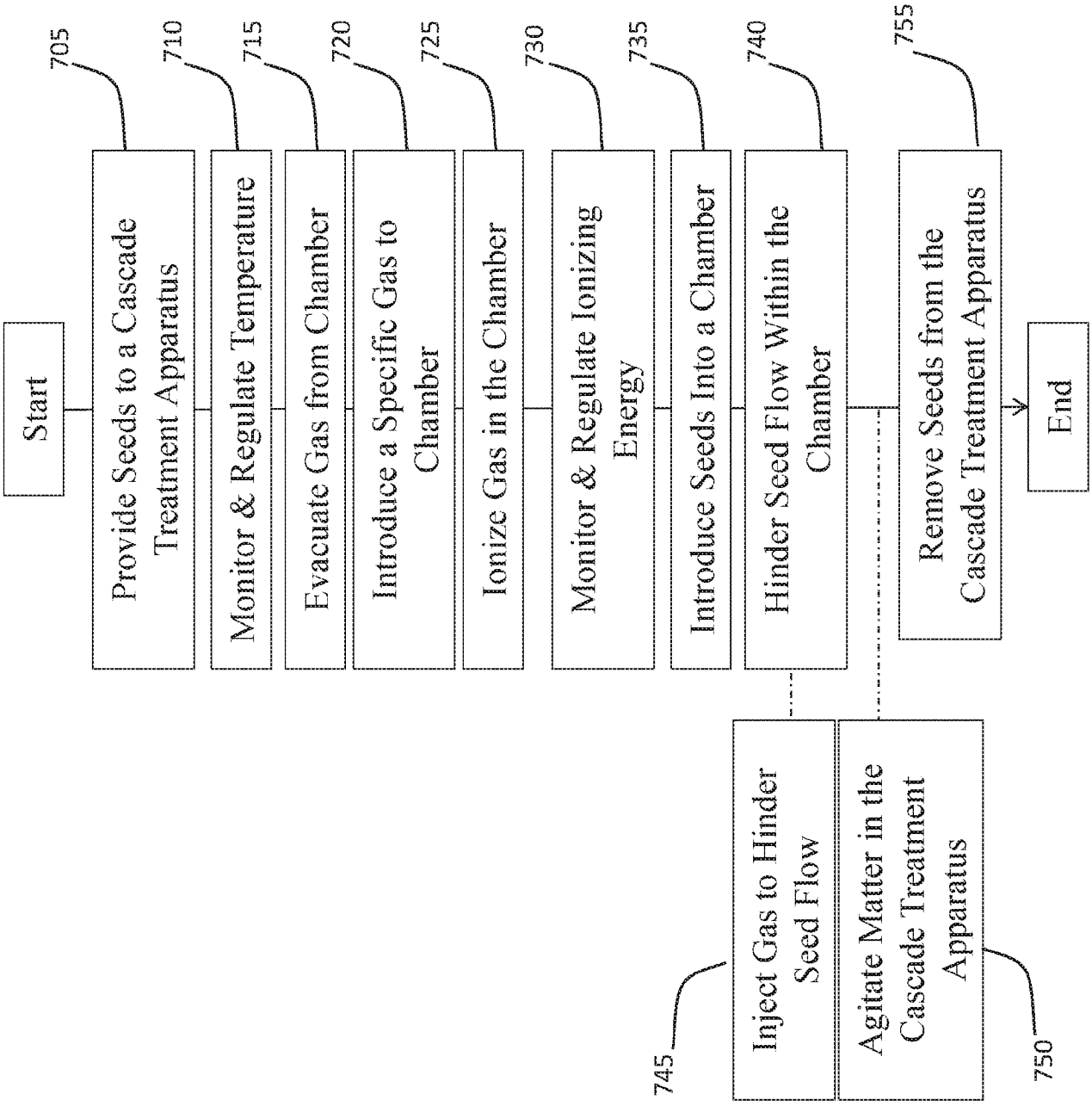

Start
Provide Seeds to a Cascade Treatment Apparatus
Monitor & Regulate Temperature
Evacuate Gas from Chamber
Introduce a Specific Gas to Chamber
Ionize Gas in the Chamber
Monitor & Regulate Ionizing Energy
Introduce Seeds Into a Chamber
Hinder Seed Flow Within the Chamber
Remove Seeds from the Cascade Treatment Apparatus
End
Inject Gas to Hinder Seed Flow
Agitate Matter in the Cascade Treatment Apparatus
705
710
715
720
725
730
735
740
745
750
755

FIG. 7a

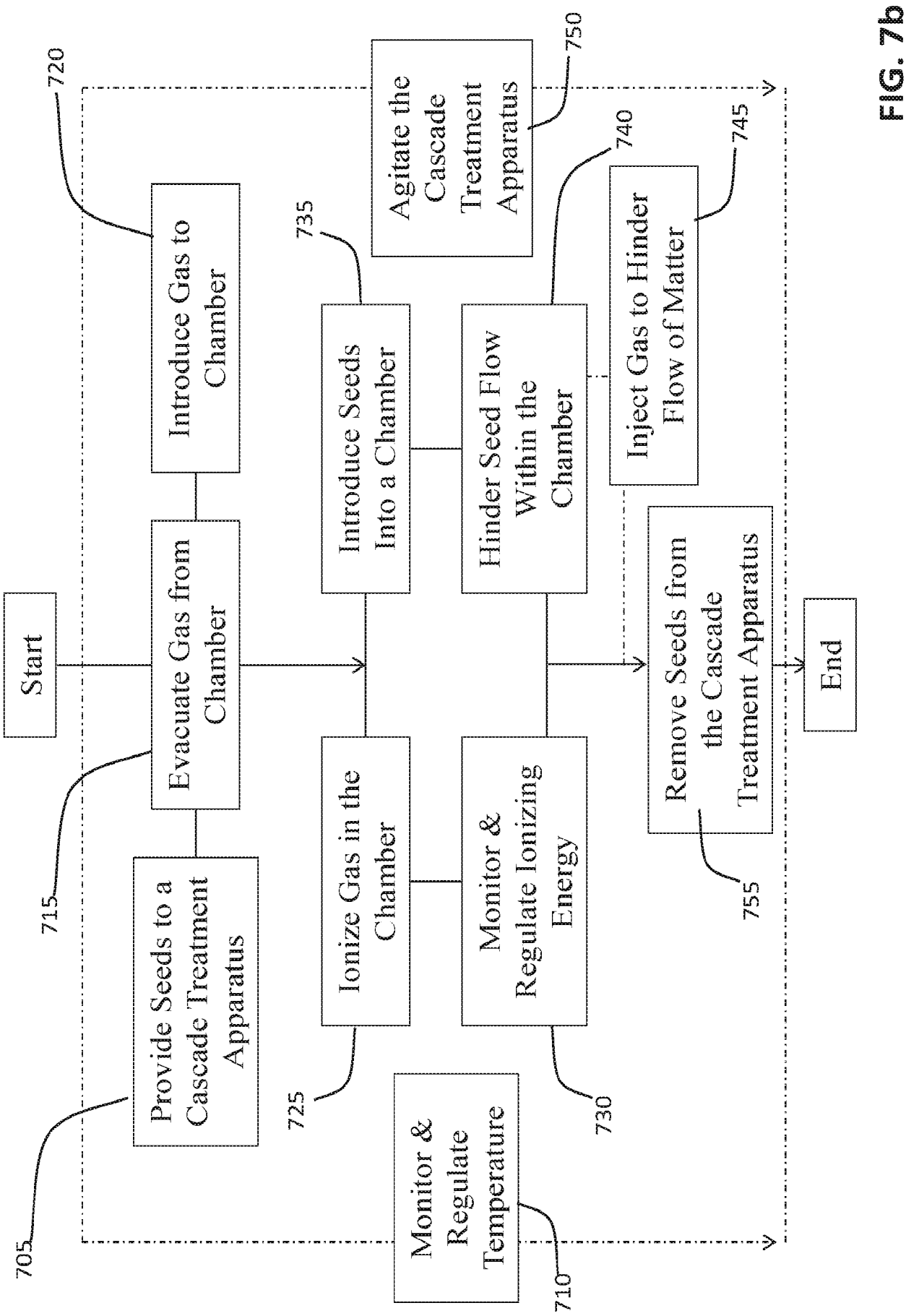

Start
Provide Seeds to a Cascade Treatment Apparatus
Evacuate Gas from Chamber
Introduce Gas to Chamber
Ionize Gas in the Chamber
Introduce Seeds Into a Chamber
Monitor & Regulate Temperature
Monitor & Regulate Ionizing Energy
Hinder Seed Flow Within the Chamber
Agitate the Cascade Treatment Apparatus
Inject Gas to Hinder Flow of Matter
Remove Seeds from the Cascade Treatment Apparatus
End
705
710
715
720
725
730
735
740
745
750
755

FIG. 7b

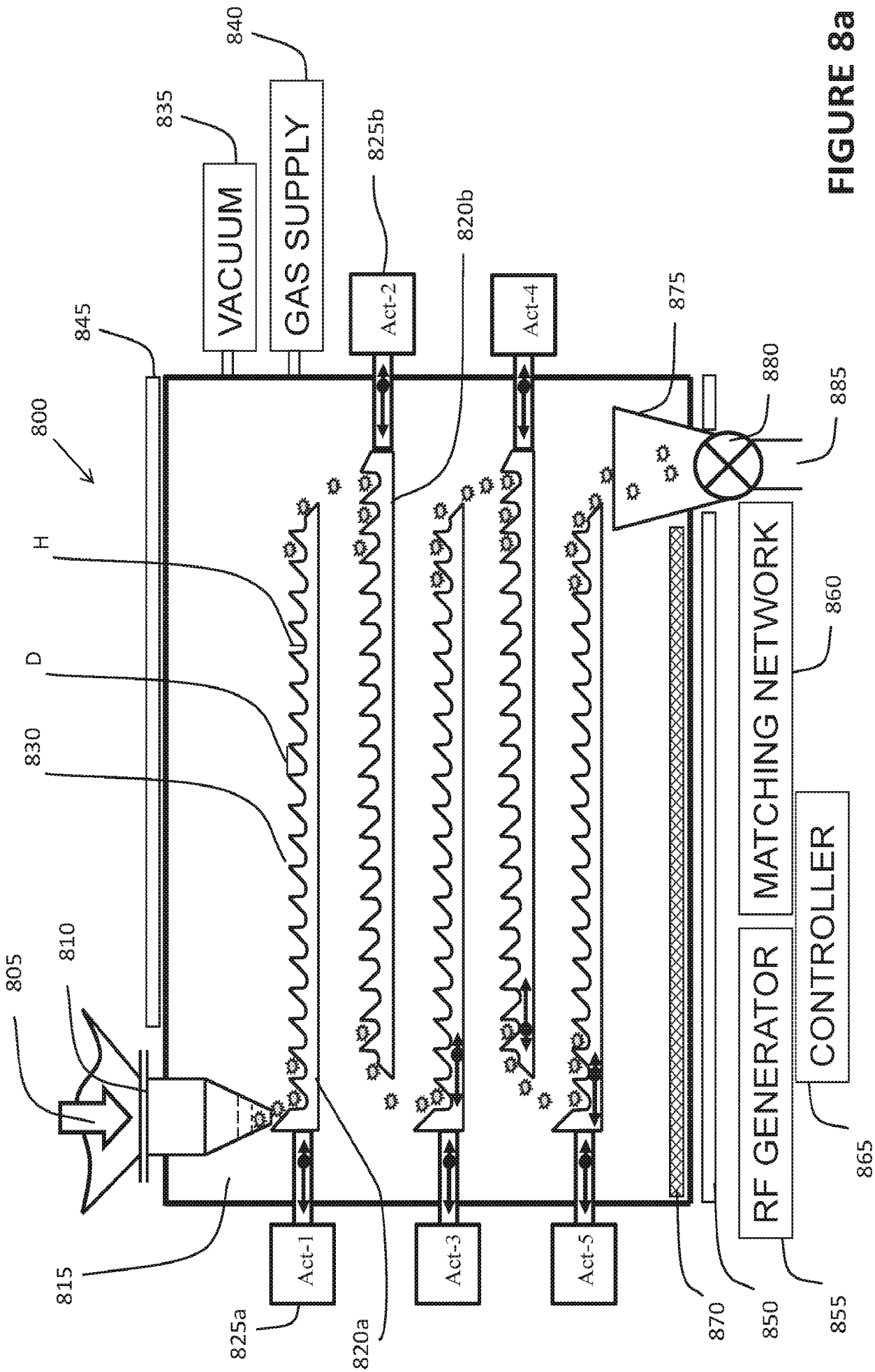

840
835
VACUUM
GAS SUPPLY
825b
820b
845
800
Act-2
Act-4
875
880
885
H
D
830
860
805
810
MATCHING NETWORK
RF GENERATOR
CONTROLLER
865
815
Act-1
Act-3
Act-5
825a
820a
870
850
855

FIGURE 8a

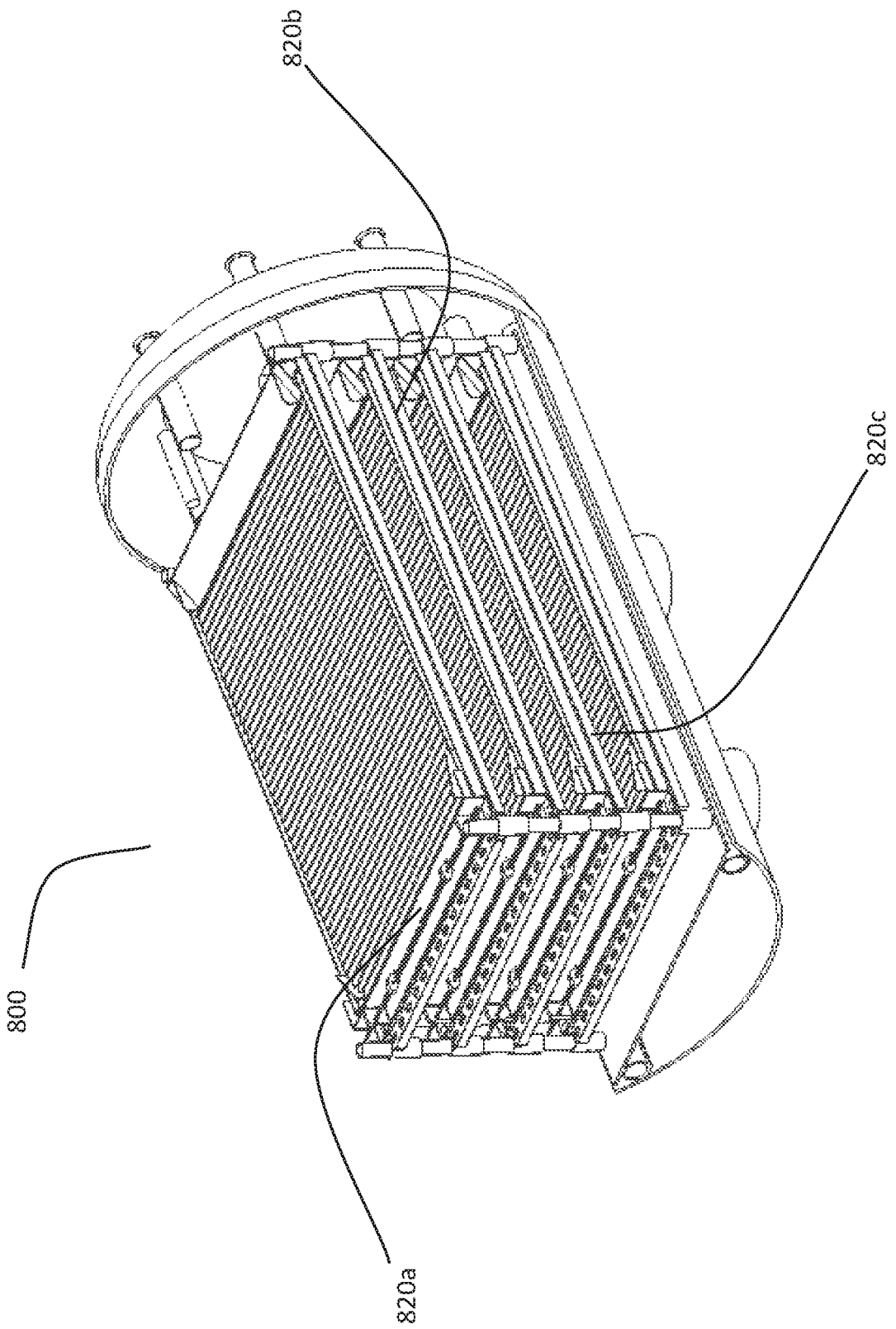


FIGURE 8b

FIGURE 8c

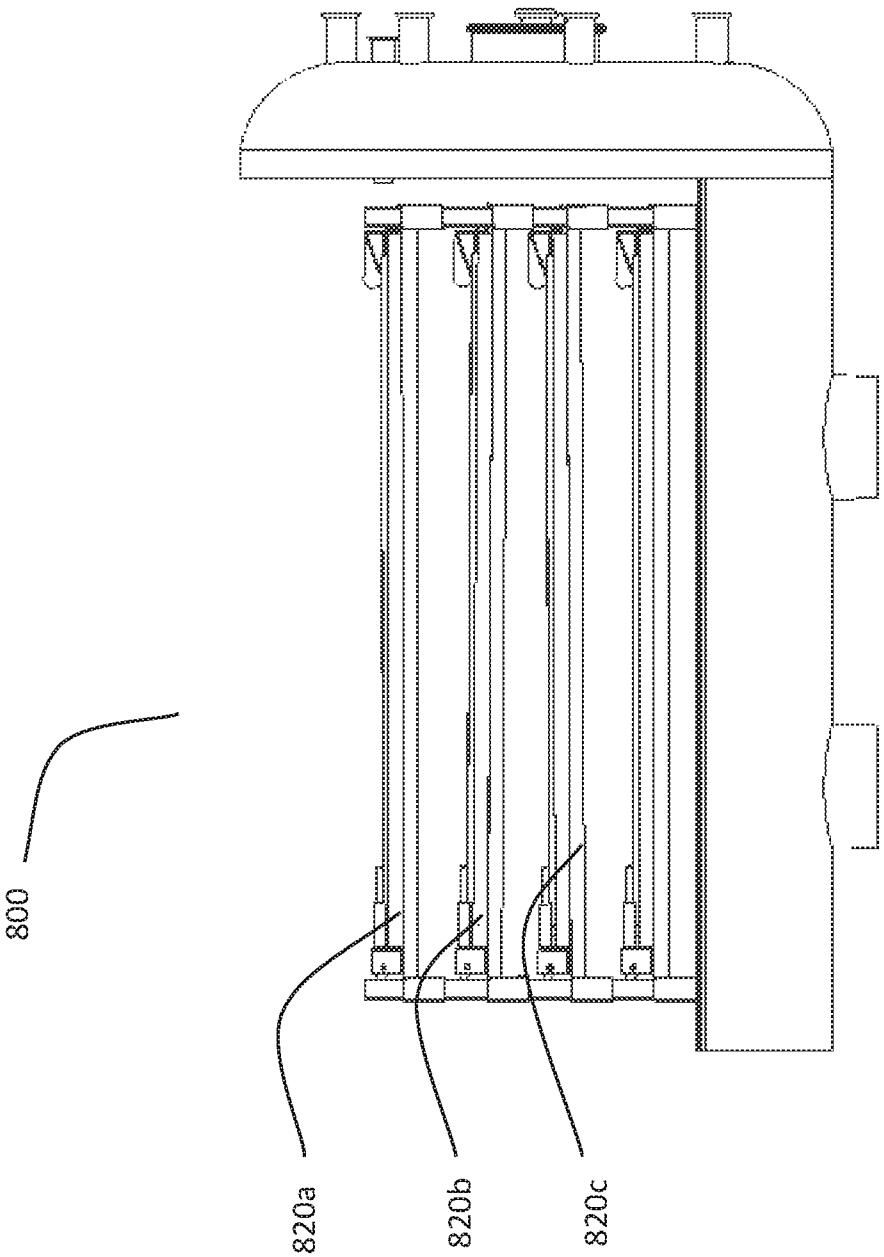
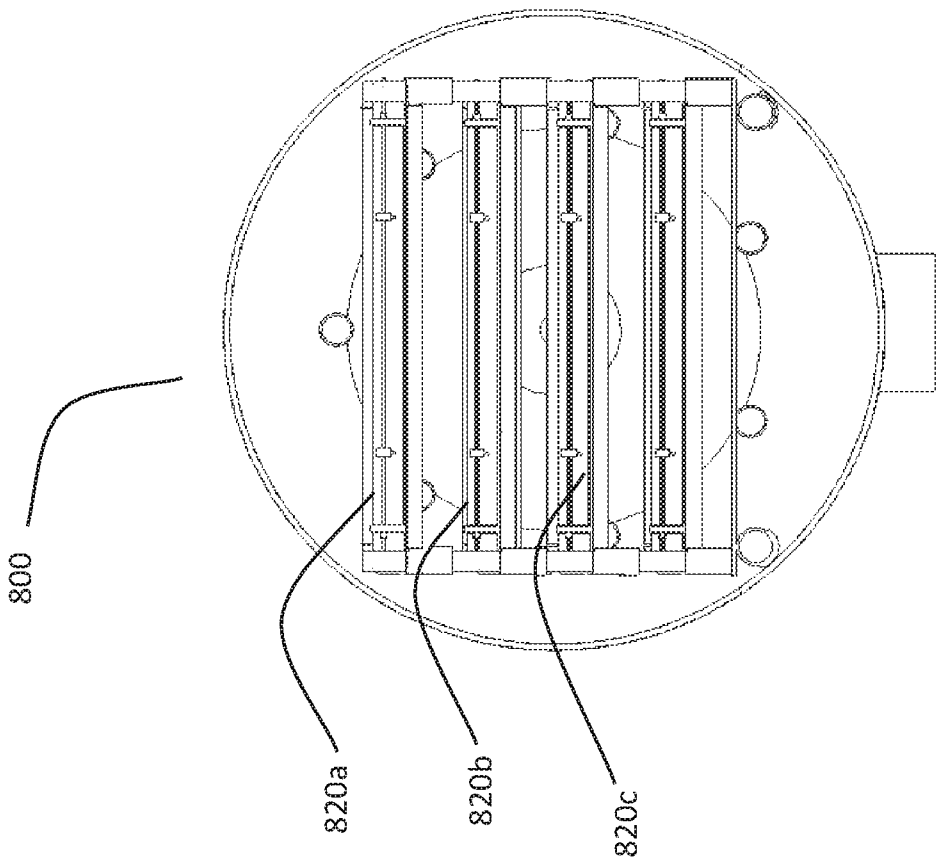


FIGURE 8d



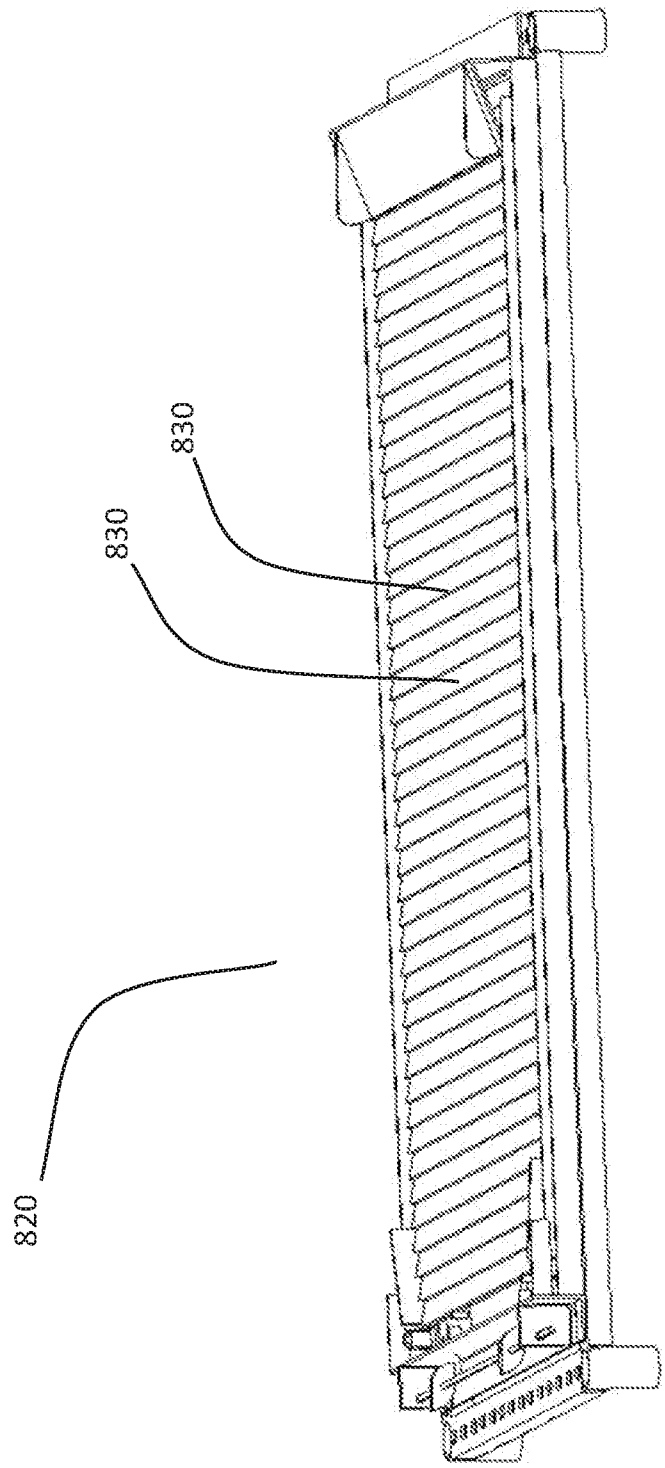
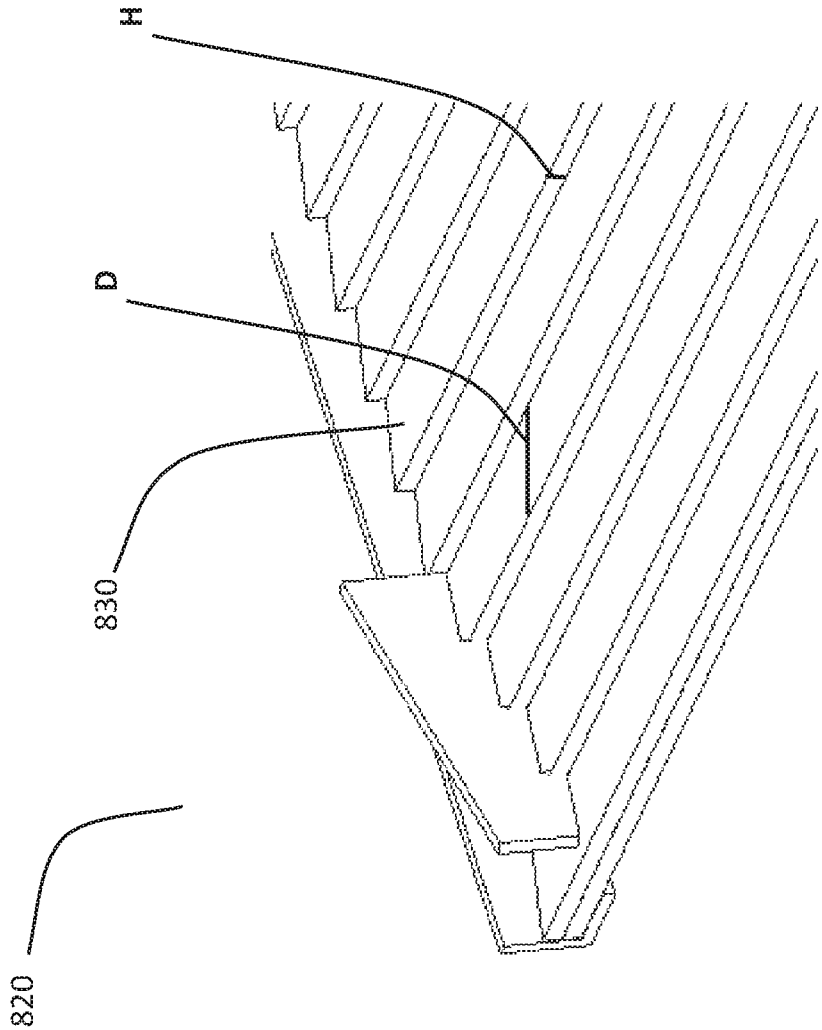


FIGURE 8e

FIGURE 8f



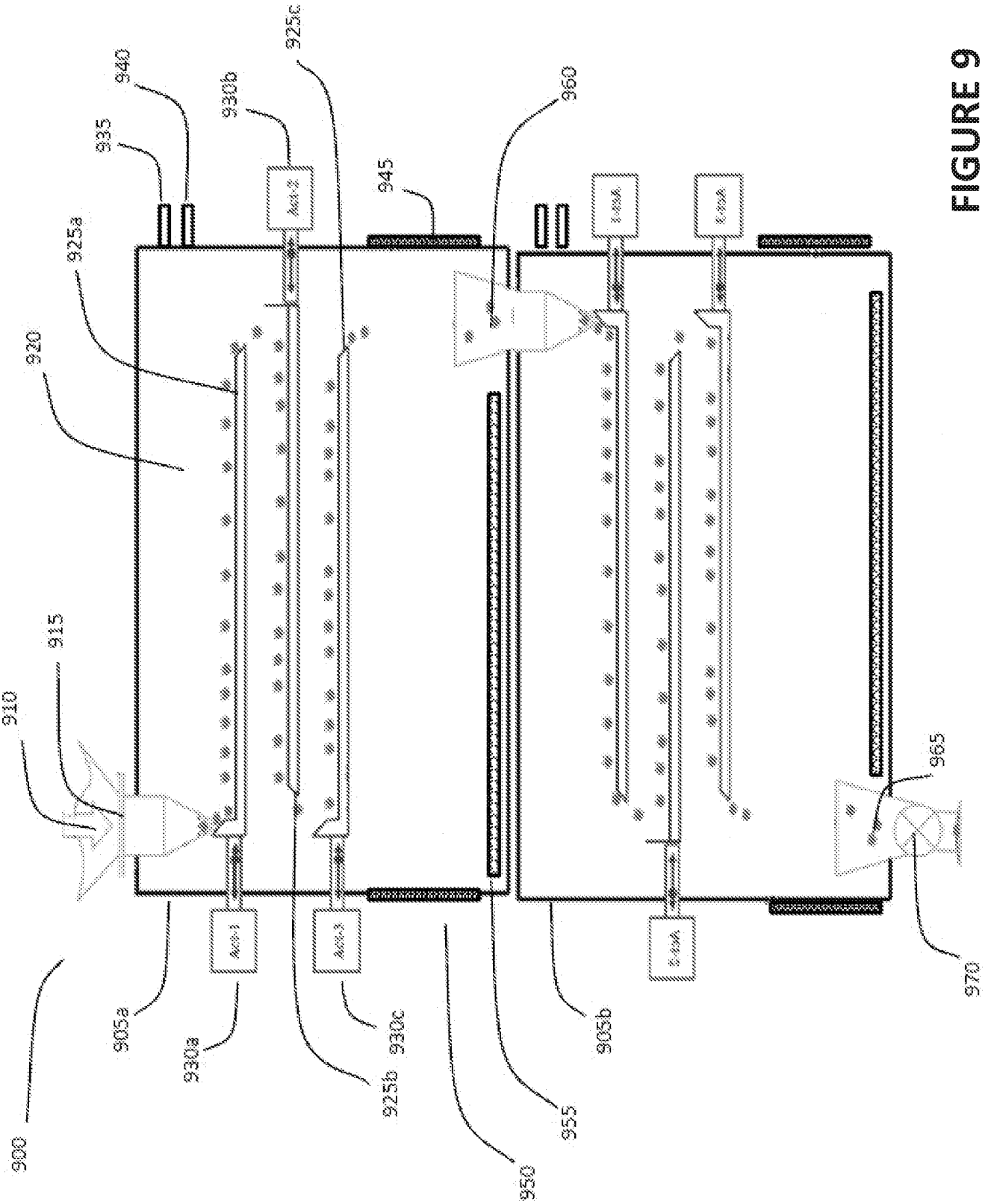

900
905a
905b
910
915
920
925a
925b
925c
930a
930b
930c
935
940
945
950
955
960
965
970

FIGURE 9

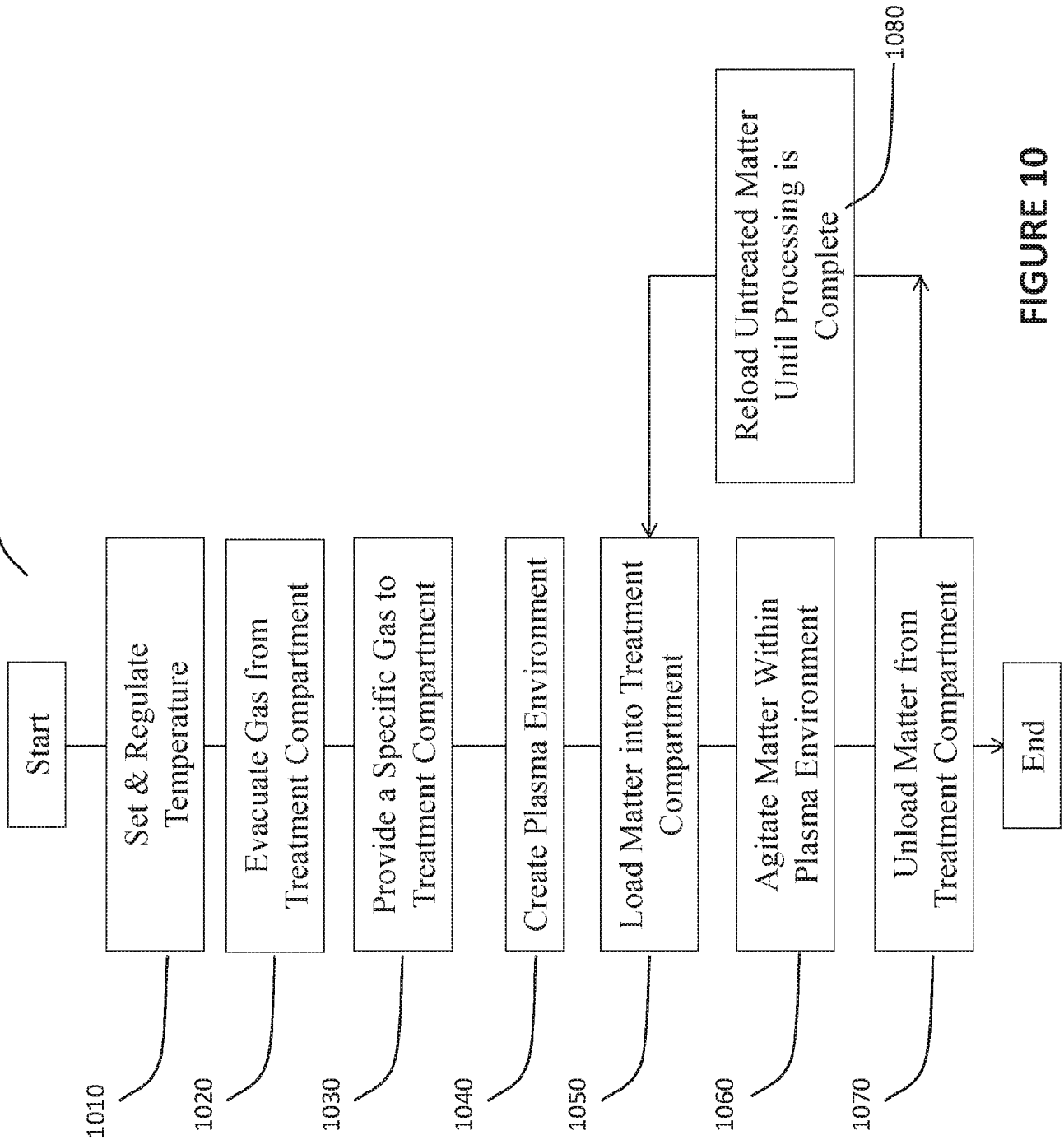

1000
Start
Set & Regulate Temperature
Evacuate Gas from Treatment Compartment
Provide a Specific Gas to Treatment Compartment
Create Plasma Environment
Load Matter into Treatment Compartment
Agitate Matter Within Plasma Environment
Unload Matter from Treatment Compartment
End
Reload Untreated Matter Until Processing is Complete
1080
1010
1020
1030
1040
1050
1060
1070

FIGURE 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/056289

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A01C 1/04; A01C 1/00; A01D 57/06 (2016.01)
CPC - A01C 1/044; A01C 1/00; A01D 57/06 (2016.11)
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 - A01C 1/00; A01C 1/04; A01D 57/06; H05F 3/00
CPC - A01C 1/00; A01C 1/04; A01C 1/044; A01D 57/06; H05F 3/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 56/181; 204/164 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Patbase, Google Patents , Google
Search terms used: plasma, seed, conveyor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2015/0101082 A1 (ARIEL-UNIVERSITY RESEARCH AND DEVELOPMENT COMPANY, LTD) 09 April 2015 (09.04.2015) entire document	1-20
Y	US 2006/0081567 A1 (DOUGHERTY et al) 20 April 2006 (20.04.2006) entire document	1-20
Y	US 3,146,730 A (WHITE) 01 September 1964 (01.09.1964) entire document	2, 8-14
Y	US 2008/0276591 A1 (TIPPERY et al) 13 November 2008 (13.11.2008) entire document	6
Y	US 2011/0241488 A1 (KIMURA) 06 October 2011 (06.10.2011) entire document	7
Y	US 2002/0050582 A1 (ETTINGER et al) 02 May 2002 (02.05.2002) entire document	14
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