



- (51) International Patent Classification:
B03C 3/41 (2006.01) *B03C 3/12* (2006.01)
B03C 3/86 (2006.01) *B03C 3/47* (2006.01)
B03C 3/06 (2006.01) *B03C 3/49* (2006.01)
B03C 3/08 (2006.01)
- (21) International Application Number: PCT/US2014/030006
- (22) International Filing Date: 15 March 2014 (15.03.2014)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
61/800,500 15 March 2013 (15.03.2013) US
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- (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, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME,

[Continued on next page]

(54) Title: OIL-COLLECTING ELECTROSTATIC PRECIPITATOR

(57) Abstract: An apparatus and a method are provided for removing droplets from a droplet-laden gas by means of an electrostatic precipitator.

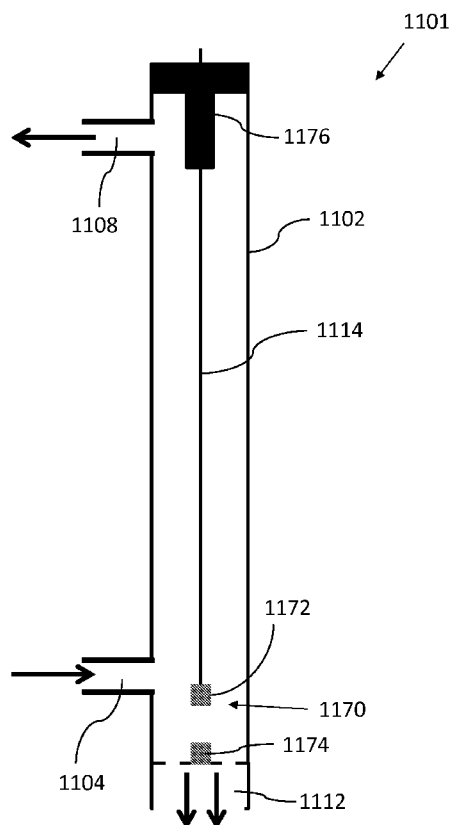


FIG. 11



MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, 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.

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, KM, ML, MR, NE, SN, TD, TG).

Published:

(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,

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

OIL-COLLECTING ELECTROSTATIC PRECIPITATOR**CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims priority from U.S. Provisional Patent Application Nos. 61/800,619, filed on March 15, 2013, and 61/800,500, filed on March 15, 2013, each of which is incorporated by reference herein in its entirety.

BACKGROUND

[0002] In certain chemical processes, it may be desirable to remove liquid droplets from the process flow of gases and vapors. To collect desired liquid droplets, such as bio-oil droplets from a flow of non-condensable gas (NCG) in the pyrolysis of bio mass, it may be necessary or desirable to employ material separation techniques.

[0003] Methods, systems, and apparatuses are needed for removing liquid droplets from NCG.

SUMMARY

[0004] In one embodiment, an electrostatic precipitator is provided, the electrostatic precipitator comprising: a tube, wherein the tube comprises an interior surface and a polarity; a gas flow inlet; a gas flow outlet; at least one corona wire extending within the tube from an isolator to a terminator, wherein the corona wire comprises a polarity; at least one power supply and controller assembly; and a liquid outlet; wherein the polarity of the tube is opposite the polarity of the corona wire.

[0005] In another embodiment, an electrostatic precipitator is provided, the electrostatic precipitator comprising: a tube, wherein the tube comprises an interior surface and a polarity; a gas flow inlet; a gas flow outlet; at least one corona wire extending within the tube from a corona wire holder to a terminator, wherein the corona wire comprises a polarity; at least one

power supply and controller assembly; and a liquid outlet; wherein the polarity of the tube is opposite the polarity of the corona wire.

[0006] In one embodiment, an isolator is provided, the isolator comprising: at least one corona wire magnet operatively connected to a corona wire in an electrostatic precipitator, wherein the corona wire extends through at least a portion of a tube; and at least one base magnet operatively connected to the tube; wherein the corona wire magnet and the base magnet are attracted to one another via a magnetic force.

[0007] In one embodiment, a corona wire holder is provided, the corona wire holder comprising: an elongated electrically insulating body; an insert comprising a flared end; and at least one offset spacer comprising at least one anchor tab, wherein the at least one offset spacer is configured to substantially maintain the insert along a longitudinal axis of an electrostatic precipitator tube, and wherein the at least one anchor tab is configured to limit the movement of the corona wire holder when the corona wire holder is placed in the electrostatic precipitator tube.

[0008] In one embodiment, an upper corona wire terminator is provided, the terminator comprising: a tensioning element configured to apply tension to a corona wire; a tension spring; a contact spring; a high voltage electrode; and a guide; wherein the high voltage electrode, the contact spring, the tensioning element, the guide, and the corona wire are electrically connected.

[0009] In one embodiment, a method for removing droplets from a droplet-laden gas using an electrostatic precipitator is provided, the method comprising: introducing a droplet-laden gas into an electrostatic precipitator via a gas flow inlet; applying a current to at least one corona wire; directing the droplet-laden gas near the at least one corona wire to ionically charge droplets in the droplet-laden gas; directing the ionically charged droplets and gas

through a tube, wherein the ionically charged droplets are attracted to an interior surface of the tube; directing a gas out of the electrostatic precipitator via a gas flow outlet; and collecting droplets adhering to the interior surface of the tube after the droplets agglomerate and flow down the interior surface of the tube and out a liquid outlet.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The accompanying figures, which are incorporated in and constitute a part of the specification, illustrate example methods, systems, and apparatuses, and are used merely to illustrate example embodiments.

[0011] FIG. 1 illustrates an example arrangement of an electrostatic precipitator system.

[0012] FIG. 2 illustrates an example arrangement of an electrostatic precipitator system.

[0013] FIG. 3 illustrates an example arrangement of a corona wire holder.

[0014] FIG. 4 illustrates an example arrangement of a corona wire holder.

[0015] FIG. 5 illustrates an example arrangement of a corona wire holder.

[0016] FIG. 6 illustrates an example arrangement of a corona wire holder.

[0017] FIG. 7 illustrates an example arrangement of an upper corona wire terminator.

[0018] FIG. 8 illustrates an example arrangement of an upper corona wire terminator.

[0019] FIG. 9 illustrates an example arrangement of a power supply and controller assembly.

[0020] FIG. 10 illustrates an example method for using an electrostatic precipitator.

[0021] FIG. 11 illustrates an example arrangement of an electrostatic precipitator.

[0022] FIG. 12 illustrates an example arrangement of an electrostatic precipitator.

[0023] FIG. 13 illustrates an example arrangement of an electrostatic precipitator.

[0024] FIG. 14 illustrates an example arrangement of an electrostatic precipitator.

DETAILED DESCRIPTION

[0025] In certain chemical processes, it may be desirable to remove liquid droplets from the process flow of gases and vapors. Such gases and vapors may be referred to herein as droplet-laden gas. One such chemical process is pyrolysis of biomass for the extraction of bio oils.

[0026] Pyrolysis processes may include fast pyrolysis of biomass material at temperatures of about 500 °C. When biomass undergoes pyrolysis, three groups of components may be created, including: non-condensable gases (“NCG”), vapor that may be quenched into bio oil, and solids known as char. NCG may contain liquid droplets (e.g., bio oil droplets) and, as such, may be a droplet-laden gas. As the extraction of bio oils from biomass may be the objective of pyrolysis, it may be desirable to remove bio oil droplets from NCG to maximize product yield.

[0027] FIG. 1 illustrates an example arrangement of an electrostatic precipitator system 100. In one embodiment, electrostatic precipitator system 100 is configured to process droplet-laden gas having liquid droplets. In another embodiment, electrostatic precipitator system 100 is configured to process NCG having bio oil droplets. In another embodiment, electrostatic precipitator system 100 is configured to collect bio oil droplets from NCG. In another embodiment, electrostatic precipitator system 100 is configured to continuously remove droplets from a stream of droplet-laden gas (e.g., NCG) without having to shut down electrostatic precipitator system 100 to recover the aggregate liquid. The aggregate liquid may be collected in a storage vessel for further processing or use.

[0028] In one embodiment, electrostatic precipitator system 100 operates to bombard the liquid droplets with ions that charge the droplets of the droplet-laden gas. The ions may be

generated by a corona wire. The charged droplets may then strike and adhere to a collection surface, effectively removing the charged droplets from the droplet-laden gas. In one embodiment, the collection surface is the interior surface of a tube through which the droplet-laden gas travels.

[0029] Electrostatic precipitator system **100** may comprise at least one electrostatic precipitator **101**. Electrostatic precipitator **101** may comprise a tube **102**. System **100** may comprise a gas flow inlet **104**, an inlet manifold **106**, a gas flow outlet **108**, an outlet manifold **110**, and a liquid outlet **112**, each of which is operatively connected to at least one electrostatic precipitator **101**. Each electrostatic precipitator **101** may comprise at least one corona wire **114**, at least one corona wire holder **116**, and a power supply and controller assembly **118**.

[0030] System **100** may comprise a plurality of electrostatic precipitators **101**. In one embodiment, system **100** comprises a plurality of electrostatic precipitators **101** operating in parallel. In another embodiment, system **100** comprises a plurality of electrostatic precipitators **101** operating in parallel and supplied with droplet-laden gas by a common gas flow inlet **104**. Gas flow inlet **104** may direct droplet-laden gas to inlet manifold **106**, which substantially divides the droplet-laden gas into multiple streams—one per electrostatic precipitator **101**. In one embodiment, system **100** comprises a plurality of electrostatic precipitators **101** sharing a common gas flow outlet **108**, wherein gas flows from electrostatic precipitators **101** into outlet manifold **110**, which directs gas to gas flow outlet **108** as a single stream.

[0031] In one embodiment, electrostatic precipitator **101** comprises a single-stage electrostatic precipitator wherein droplet charging and collection occur within tube **102**. Tube **102** may comprise a substantially circular cross-section. Tube **102** may comprise any

of a variety of materials suited for processing of droplet-laden gas, including a metal, an alloy, a ceramic, or a polymer. In one embodiment, tube **102** is electrically grounded. In one embodiment, tube **102** comprises a polarity that is opposite from the polarity of corona wire **114**.

[0032] In one embodiment, droplet-laden gas enters gas flow inlet **104** and travels to inlet manifold **106** wherein the droplet-laden gas is divided into one stream per electrostatic precipitator **101**. In one embodiment, each electrostatic precipitator **101** operates independently of the others. In another embodiment, each electrostatic precipitator **101** operates dependently with the others. In one embodiment, each electrostatic precipitator **101** is powered and controlled by its respective power supply and controller assembly **118**.

[0033] The droplet-laden gas may advance within tube **102** upwardly past corona wire holder **116** and about corona wire **114**. Corona wire holder **116** may constrain the lower end of corona wire **114**, which is axially oriented within tube **102**. Corona wire **114** may generate ions that radiate outward and bombard the droplets of the droplet-laden gas.

[0034] Corona wire **114** may comprise any of a variety of apparatuses configured to create a corona. A corona is a process by which an electrical current flows from an electrode with a high potential into a neutral fluid (e.g., a droplet-laden gas) by ionizing the fluid so as to create a region of plasma around the electrode. Droplets in the fluid may thus become charged. In one embodiment, corona wire **114** comprises a polarity that is opposite the polarity of tube **102**. Corona wire **114** may be electrically insulated from tube **102**. In one embodiment, corona wire holder **116** is configured to electrically insulate corona wire **114** from tube **102**.

[0035] In one embodiment, charged droplets are acted upon by magnetic forces to strike and adhere to a collection surface. In one embodiment, the collection surface is the interior

surface of tube **102**. In another embodiment, charged droplets are acted upon by magnetic forces and move along the electric field established within electrostatic precipitator **101** to strike and adhere to the interior surface of tube **102**. In another embodiment, charged droplets are acted upon by electromagnetic forces and move along the electric field established within electrostatic precipitator **101** to strike and adhere to the interior surface of tube **102**. In one embodiment, charged droplets comprise a polarity that is opposite the polarity of tube **102**.

[0036] In one embodiment, droplets adhering to the interior surface of tube **102** agglomerate and fall, as a flowing liquid, down the interior surface of tube **102** due to gravitational forces. In one embodiment, the flowing liquid proceeds down the interior surface of tube **102**, into inlet manifold **106**, and out liquid outlet **112**. In another embodiment, a collection vessel (not shown) is operatively connected to or positioned below liquid outlet **112** to collect the flowing liquid. In one embodiment, the flowing liquid is substantially bio oil.

[0037] In one embodiment, the processed gas proceeds upwards through tube **102**, into outlet manifold **110** and out of gas flow outlet **108**.

[0038] **FIG. 2** illustrates an example arrangement of an electrostatic precipitator system **200**. Electrostatic precipitator system **200** may comprise at least one electrostatic precipitator **201**. Electrostatic precipitator **201** may comprise a tube **202**. System **200** may comprise a gas flow inlet **204**, an inlet manifold **206**, a gas flow outlet **208**, an outlet manifold **210**, and a liquid outlet **212**, each of which is operatively connected to at least one electrostatic precipitator **201**. Each electrostatic precipitator **201** may comprise a power supply and controller assembly **218**.

[0039] FIG. 3 illustrates an example arrangement of a corona wire holder 316. In one embodiment, corona wire holder 316 is configured to locate a corona wire (such as corona wire 114 illustrated in FIG. 1) along an axis of an electrostatic precipitator tube (such as tube 102 illustrated in FIG. 1). In another embodiment, corona wire holder 316 is configured to anchor one end of a corona wire. In another embodiment, corona wire holder 316 is configured to anchor one end of a corona wire in tension.

[0040] In one embodiment, corona wire holder 316 is highly electrically insulating. In another embodiment, corona wire holder 316 is electrically insulating to at least 10 kV. In another embodiment, corona wire holder 316 is electrically insulating to more than 10 kV. In some embodiments, an electrostatic precipitator may operate at 10 kV or greater.

[0041] Corona wire holder 316 may comprise an elongated electrically insulating body 320. In one embodiment, an insert 322 extends through at least a portion of elongated body 320. Insert 322 may be comprised of any of a variety of materials, including a metal, an alloy, or a ceramic. In one embodiment, insert 322 comprises a stainless steel.

[0042] Electrical insulators may eventually lose resistive characteristics if exposed to intense electric fields over prolonged periods. In one embodiment, insert 322 is configured to reduce the electric field strength to which corona wire holder 316 is exposed. In one embodiment, insert 322 comprises the same potential as a corona wire extending through insert 322 (such as corona wire 114 illustrated in FIG. 1), but the larger radius of insert 322 compared to the corona wire significantly reduces the electric field strength to which corona wire holder 316 is exposed.

[0043] Insert 322 may be substantially cylindrical with a longitudinal aperture extending along its length. In one embodiment, insert 322 comprises a rounded end (visible in FIG. 3) and a flared end (oriented within elongated body 320). A corona wire may extend through

the interior of insert **322** and be anchored thereto. The flared end of insert **322** may be configured to keep insert **322** oriented within corona wire holder **316** when a corona wire is under tension.

[0044] Corona wire holder **316** may comprise at least one offset spacer **324** configured to substantially maintain insert **322** along the central longitudinal axis of an electrostatic precipitator tube (such as **102** illustrated in **FIG. 1**). In one embodiment, at least one offset spacer **324** is oriented radially outwardly of elongated body **320**. In one embodiment, corona wire holder **316** comprises at least two offset spacers **324**. In another embodiment, corona wire holder **316** comprises at least three offset spacers **324**. In another embodiment, corona wire holder **316** comprises a plurality of offset spacers **324**.

[0045] In one embodiment, offset spacer **324** is configured to allow a droplet-laden gas to advance upwardly past corona wire holder **316**. In another embodiment, offset spacer **324** is configured to allow a flowing liquid to advance downwardly past corona wire holder **316** along the interior surface of an electrostatic precipitator tube. The gaps created between offset spacers **324** may be configured to allow the passage of droplet-laden gas and flowing liquid past corona wire holder **316**.

[0046] Corona wire holder **316** may comprise at least one anchor tab **326** configured to limit the movement of corona wire holder **316** when placed in an electrostatic precipitator tube (such as **102** illustrated in **FIG. 1**). In one embodiment, at least one anchor tab **326** is oriented on at least one offset spacer **324**. In another embodiment, each offset spacer **324** comprises at least one anchor tab **326**. In another embodiment, at least one anchor tab **326** is oriented radially outwardly of elongated body **320**.

[0047] **FIG. 4** illustrates a tube **402** containing a corona wire holder **416**. Corona wire holder **416** may comprise at least one anchor tab **426** configured to prevent corona wire

holder **416** from advancing completely into tube **402**. Corona wire holder **416** may be oriented at a joint between sections of tube **402**.

[0048] FIG. 5 illustrates a plurality of electrostatic precipitators **501** comprising tubes **502**. A corona wire **514** may extend along a longitudinal axis within tube **502**, anchored at one end by corona wire holder **516**. Corona wire holder **516** may be oriented at a joint between sections of tube **502**. In one embodiment, corona wire holder **516** is configured such that it cannot advance completely into tube **502** when tension is applied to corona wire **514**.

[0049] FIG. 6 illustrates an electrostatic precipitator **601** comprising a tube **602**. A corona wire **614** may extend along a longitudinal axis within tube **602**. Corona wire **614** may be anchored at one end by corona wire holder **616**.

[0050] Corona wire holder **616** may comprise an elongated body **620**, an insert **622**, at least one offset spacer **624**, and at least one anchor tab **626**. Corona wire holder **616** may additionally comprise a threaded plug **628**. Plug **628** may comprise any of a variety of materials, including a ceramic or a polymer. Plug **628** may be removed to allow corona wire **614** to be inserted through corona wire holder **616**. Plug **628** may be inserted to prevent droplet-laden gas from entering within corona wire holder **616**.

[0051] Corona wire holder **616** may be oriented at a joint between sections of tube **602**. In one embodiment, a gasket **630** is oriented at the joint between sections of tube **602** radially outwardly of corona wire holder **616**. Gasket **630** may be configured to prevent ambient air from entering the interior of tube **602**. Ambient air may react negatively with pyrolysis products such as droplet-laden gas. In one embodiment, substantially all joints and flanges of electrostatic precipitator **601** comprise gaskets, O-rings, or both to at least substantially preclude the entry of ambient air into the electrostatic precipitator system.

[0052] In one embodiment, the droplets of droplet-laden gas comprise a bio oil. A bio oil may be very acidic and electrically conducting. In one embodiment, corona wire holder **616** is configured to at least substantially prevent the conducting of electricity between corona wire **614**, or insert **622**, and grounded tube **602**. Offset spacer **624** may be beveled down and away from corona wire **614** so as to at least substantially prevent bio oil from approaching corona wire **614** as it contacts corona wire holder **616** while flowing down the inner surface of tube **602**.

[0053] In one embodiment, electrostatic precipitator **601** is configured to operate in continuous mode for extended periods of time. During operation, electrostatic precipitator **601** may be expected to operate continuously without maintenance intervention for long periods of time. Accordingly, corona wire holder **616** may be configured so as to allow the running of electrostatic precipitator **601** for extended periods of time.

[0054] Corona wire holder **616** may be comprised of any of a variety of materials, including a polymer, a ceramic, a metal, or an alloy. In one embodiment, corona wire holder **616** comprises polytetrafluoroethylene (PTFE). In another embodiment, corona wire holder **616** comprises Teflon®. In another embodiment, corona wire holder **616** comprises a material that is highly electrically insulating, even at high voltages. In another embodiment, corona wire holder **616** comprises a material that does not chemically interact with pyrolysis products, such as NCG laden with bio oil droplets.

[0055] In one embodiment, corona wire holder **616** comprises a material that may creep over time. Accordingly, corona wire **614** tension may be kept at a minimum to minimize the creep of corona wire holder **616**. Additionally, stress points in corona wire holder **616** may be broadly distributed (including over insert **622**) so as to minimize creep of corona wire holder **616**.

[0056] FIG. 7 illustrates an electrostatic precipitator tube 702, through which a corona wire 714 extends. The uppermost portion of tube 702 may comprise an upper corona wire terminator 740. Terminator 740 may comprise a tensioning element 742, a tension spring 744, a contact spring 746, and a high voltage electrode 748. Terminator 740 may additionally comprise a guide 750 through which corona wire 714 may extend. Terminator 740 may comprise at least one seal 752 configured to prevent ambient air from entering the electrostatic precipitator.

[0057] Terminator 740 may comprise any of a variety of materials, including a polymer, a metal, an alloy, or a ceramic. In one embodiment, terminator 740 comprises a non-conductive material. In another embodiment, terminator 740 comprises a material capable of withstanding high voltage. In another embodiment, terminator 740 comprises an acetal. In another embodiment, terminator 740 comprises Delrin®. In one embodiment, substantially all of the bio oil is separated from the gas as it contacts terminator 740, and terminator 740 does not necessarily comprise a chemically resistant material.

[0058] Tensioning element 742 may be connected to corona wire 714 and may be configured to apply a desired amount of tension to corona wire 714. Tension spring 744 may be configured to press upward on tensioning element 742 to apply a desired amount of tension to corona wire 714. Tensioning element 742 may comprise a nut and bolt assembly configured to cinch corona wire 714 and at least substantially constrain it. Contact spring 746 may be configured to make an electrical connection between tensioning element 742 and high voltage electrode 748.

[0059] High voltage electrode 748 may be electrically connected to corona wire 714. In one embodiment, high voltage electrode 748 accepts a current and directs the current into

corona wire **714**. To energize the electrostatic precipitator, each corona wire **714** may comprise its own dedicated high voltage power source.

[0060] Guide **750** may comprise any of a variety of materials, including a metal, an alloy, a ceramic, or a polymer. In one embodiment, guide **750** comprises a stainless steel. The use of stainless steel in guide **750** may be configured to reduce the electric field intensity to which terminator **740** and its electrically insulating portions are exposed.

[0061] In one embodiment, high voltage electrode **748**, contact spring **746**, tensioning element **742**, guide **750**, and corona wire **714** are electrically connected.

[0062] FIG. 8 illustrates an electrostatic precipitator system **800** comprising a plurality of terminators **840**. Each terminator **840** may be oriented on top of an electrostatic precipitator tube. Each terminator **840** may comprise a high voltage electrode **848**.

[0063] FIG. 9 illustrates an example arrangement of an electrostatic precipitator system **900**. System **900** comprises a plurality of tubes **902**, a gas flow outlet **908**, an outlet manifold **910**, and at least one power supply and controller assembly **918**.

[0064] Assembly **918** may contain a terminator **940**. In one embodiment, assembly **918** substantially encases terminator **940** to isolate terminator **940** from a user in order to prevent unintended contact with the high voltage electrode (not shown) of terminator **940**.

[0065] Terminator **940** may be electrically insulated from contact by a user by a cover **960**. Cover **960** may be configured to substantially prevent unintended contact between a user and the high voltage electrode (not shown) of terminator **940**.

[0066] In one embodiment, each corona wire (not shown) comprises its own dedicated assembly **918**. Assembly **918** may comprise a controller **962**. Controller **962** may comprise a circuit board, circuitry, and/or a computer.

[0067] Assemblies **918** may compensate for slight geometric variations among each electrostatic precipitator in system **900**. Assembly **918** may comprise a DC-to-DC converter module capable of operating from a 24 VDC source and supplying up to 15 kV. In one embodiment, each module is adjustable and controller **962** allows for local setting of output voltage and maximum output current. In one embodiment, controller **962** comprises a remote control, such as a programmable logic controller.

[0068] In one embodiment, assembly **918** comprises at least one display configured to display output voltage in kV and output current in μA .

[0069] **FIG. 10** illustrates an example method **1000** for removing droplets from droplet-laden gas using an electrostatic precipitator. The method includes introducing a droplet-laden gas into an electrostatic precipitator (e.g., electrostatic precipitator **101**) via a gas flow inlet (e.g., gas flow inlet **104**) (step **1002**). A current is applied to at least one corona wire (e.g., corona wire **114**) (step **1004**). The at least one corona wire is configured to ionically charge droplets in the droplet-laden gas by directing the droplet-laden gas near the at least one corona wire (step **1006**). The ionically charged droplets and gas are directed through a tube (e.g., tube **102**) wherein ionically charged droplets are attracted to an interior surface of the tube (step **1008**). Gas is directed out of the electrostatic precipitator via a gas flow outlet (e.g., gas flow outlet **108**) (step **1010**). Droplets adhering to the interior surface of the tube (e.g., tube **102**) agglomerate and fall, as a flowing liquid, down the interior surface of the tube due to gravitational forces, and out a liquid outlet (e.g., liquid outlet **112**) (step **1012**).

[0070] **FIG. 11** illustrates an example arrangement of an electrostatic precipitator **1101**. Electrostatic precipitator **1101** may include a tube **1102**, a gas flow inlet **1104**, a gas flow outlet **1108**, and a liquid outlet **1112**. Electrostatic precipitator **1101** may include a corona wire **1114**.

[0071] Electrostatic precipitator **1101** may include an isolator **1170**. Isolator **1170** may replace a corona wire holder. Isolator **1170** may function to prevent corona wire **1114** from contacting, or coming too close to, tube **1102**. Corona wire **1114** may be kept at a distance from a wall of tube **1102** to substantially prevent electricity from traveling between corona wire **1114** and tube **1102**. Isolator **1170** may function similarly to an electrical insulator. Isolator **1170** may function to keep corona wire **1114** substantially radially centered within tube **1102**.

[0072] Isolator **1170** may function to provide a tension to corona wire **1114**. In one embodiment, isolator **1170** at least partially retains an end of corona wire **1114**. Isolator **1170** may include at least one magnet, including a corona wire magnet **1172**, which may be operatively connected to corona wire **114**. Isolator **1170** may include at least one magnet, including a base magnet **1174**, which may be operatively connected to at least one of a base member and tube **1102**. Isolator **1170** may include both at least one corona wire magnet **1172** and at least one base magnet **1174**. In one embodiment, corona wire magnet **1172** may be oriented so as to be attracted via magnetic forces to base magnet **1174**.

[0073] At least one corona wire magnet **1172** may include any of a variety of magnets, including for example at least one of a permanent magnet, a temporary magnet, and an electromagnet. At least one corona wire magnet **1172** may include any of a variety of materials known to be magnetic, including for example Neodymium Iron Boron, Samarium Cobalt, Alnico, Ceramic, or Ferrite.

[0074] At least one base magnet **1174** may include any of a variety of magnets, including for example at least one of a permanent magnet, a temporary magnet, and an electromagnet. At least one base magnet **1174** may include any of a variety of materials known to be

magnetic, including for example Neodymium Iron Boron, Samarium Cobalt, Alnico, Ceramic, or Ferrite.

[0075] In one embodiment, at least one corona wire magnet **1172** and at least one base magnet **1174** are attracted via magnetic forces without actually making contact with one another. At least one corona wire magnet **1172** and at least one base magnet **1174** may be close enough to adequately attract one another to at least one of partially retain and end of corona wire **1114** and provide a tension to corona wire **1114**. At least one corona wire magnet **1172** and at least one base magnet **1174** may be far enough away from one another, and tube **1102**, to substantially prevent electricity from traveling between corona wire **1114** and tube **1102**.

[0076] In one embodiment, at least one corona wire magnet **1172** may be attracted to a base member (not shown). In one embodiment, at least one base magnet **1174** may be attracted to corona wire **1114**. Attraction between at least one of corona wire magnet **1172** or base magnet **1174**, to a base member or corona wire **1114**, respectively, may at least one of partially retain an end of corona wire **1114** and provide a tension to corona wire **1114**. At least one of corona wire magnet **1172** or base magnet **1174**, and a base member or corona wire **1114**, respectively, may be attracted via magnetic forces without actually making contact with one another. At least one of corona wire magnet **1172** or base magnet **1174**, and a base member or corona wire **1114**, respectively, may be close enough to adequately attract one another to at least one of partially retain and end of corona wire **1114** and provide a tension to corona wire **1114**. At least one of corona wire magnet **1172** or base magnet **1174**, and a base member or corona wire **1114**, respectively, may be far enough away from one another, and tube **1102**, to substantially prevent electricity from traveling between corona wire **1114** and tube **1102**.

[0077] Any of various magnets referenced herein may be of a size, shape, and the like, and may include a magnetic attraction, configured to achieve at least partial retention of an end of corona wire **1114**, and/or tensioning of corona wire **1114**.

[0078] Utilizing a gap between magnets referenced herein, and/or a base member or end of corona wire **1114** may eliminate any direct physical connection between the end of corona wire **1114** and a grounded item, such as tube **1102**. In some instances, a physical connection between a lower end of corona wire **1114** and a grounded item, such as tube **1102**, can allow electricity to travel through a liquid coating that physical connection and make an electrical connection between corona wire **1114** and the grounded item.

[0079] **FIG. 12** illustrates an example arrangement of an electrostatic precipitator **1200**.

[0080] In certain chemical processes, it may be desirable to remove particulates from the process flow of gases and vapors. To maximize the efficiency of processes, including certain chemical processes, or to improve the quality of the output product of a chemical process, it may be necessary to employ material separation techniques. One such chemical process is pyrolysis of biomass for the extraction of bio oils. Pyrolysis of biomass may necessitate removal of particulates from a vapor at a high temperature, low flow rate, or a low pressure. Pyrolysis of biomass may create a char-laden gas. In one embodiment, electrostatic precipitator **1200** is configured to process pyrolysis vapor having one or more of these characteristics.

[0081] Pyrolysis processes may include fast pyrolysis of biomass material at temperatures of about 500 °C. When biomass undergoes pyrolysis, three groups of components may be created, including: non-condensable gases, vapor that may be quenched into bio oil, and solids known as char. In one embodiment, it is desirable to remove the char from the non-condensable gases and vapor before further processing of these components. In one

embodiment, electrostatic precipitator **1200** is configured to remove a char from a non-condensable gas and/or pyrolysis vapor (herein referred to as a char-laden gas).

[0082] In one embodiment, electrostatic precipitator **1200** operates to bombard the char material with ions that charge the particles of the char material. The charged particles may then strike and adhere to a collection surface, effectively removing the charged particles of char from the char-laden gas.

[0083] Electrostatic precipitator **1200** may comprise a housing **1202**, a gas flow inlet **1204**, and at least one pair of corona electrodes **1206**. Each pair of corona electrodes **1206** may be electrically connected by at least one charging wire **1208**. Each corona electrode **1206** may comprise a disk insulator **1210** and/or a rod insulator **1212**. Electrostatic precipitator **1200** may also comprise a plate electrode **1214**, which may be electrically insulated from housing **1202** by a plate insulator **1216**.

[0084] Housing **1202** may comprise any of a variety of materials, including a metal, an alloy, a composite, and a polymer. Housing **1202** may comprise a gas flow inlet **1204** and a gas flow outlet (not shown) configured to permit a gas to flow through housing **1202**. Housing **1202** may be configured to operate at temperatures at or near about 500 °C in a pyrolysis system. In one embodiment, housing **1202** is electrically grounded.

[0085] Corona electrodes **1206** may comprise any of a variety of electrodes configured to create a corona. A corona is a process by which an electrical current flows from an electrode with a high potential into a neutral fluid (e.g., a non-condensable gas or a pyrolysis vapor, either of which may be referred to herein as a char-laden gas) by ionizing the fluid so as to create a region of plasma around the electrode. Particulate matter in the fluid may thus become charged. Corona electrodes **1206** may extend from the outside of housing **1202** to the interior of housing **1202**, while being electrically insulated from housing **1202**. An

electrical current may be applied to corona electrodes **1206**. In one embodiment, the electricity applied to corona electrodes **1206** comprises a relatively high voltage.

[0086] A pair of corona electrodes **1206** may be electrically connected via charging wire **1208**, so as to cause an electrical current to pass through charging wire **1208**. Charging wire **1208** may pass substantially across the flow of char-laden gas entering gas flow inlet **1204**, such that char-laden gas is directed at or near charging wire **1208**.

[0087] In one embodiment, a char-laden gas is directed into gas flow inlet **1204**, wherein the char particles are ionically charged by charging wire **1208**. Charging wire **1208** may emit a corona. Ionically charging the char particles by passing the char-laden gas by charging wire **1208** enables the charged char particles to later strike and adhere to a collector plate.

[0088] Disk insulator **1210** may be oriented between charging wire **1208** and housing **1202**. Disk insulator **1210** may be configured to at least substantially prevent electrical discharge from charging wire **1208** to housing **1202**. In one embodiment, char-laden gas may, at high temperatures, become more conducting to a current than at room temperature. It may be possible for current to pass through the char-laden gas from charging wire **1208** to housing **1202**. In one embodiment, disk insulator **1210** is oriented to at least partially prevent such passing of current through the char-laden gas from charging wire **1208** to housing **1202**. Disk insulator **1210** may comprise any of a variety of electrically insulating materials, including a ceramic. Disk insulator **1210** may comprise a ceramic material comprising high insulating characteristics even at elevated temperatures.

[0089] Rod insulator **1212** may be oriented between corona electrodes **1206** and housing **1202**. In another embodiment, rod insulator **1212** is oriented between charging wire **1208** and housing **1202**. In another embodiment, rod insulator **1212** is oriented between disk insulator **1210** and housing **1202**. Rod insulator **1212** may be configured to at least

substantially insulate electricity-carrying components from housing **1202**. Housing **1202** may be grounded. Rod insulator **1212** may comprise any of a variety of electrically insulating materials, including a ceramic. Rod insulator **1212** may comprise a ceramic material comprising high insulating characteristics even at elevated temperatures.

[0090] FIG. 13 illustrates an example arrangement of an electrostatic precipitator **1300**. Electrostatic precipitator **1300** may comprise a housing **1302**, a gas flow inlet **1304**, and at least one pair of corona electrodes **1306**. Each pair of corona electrodes **1306** may be electrically connected by at least one charging wire **1308**. Each corona electrode **1306** may comprise a disk insulator **1310** and/or a rod insulator **1312**.

[0091] In one embodiment, electrostatic precipitator **1300** comprises a collection plate array **1320** comprising at least two plates comprising different electrical polarity adjacent to one another. In one embodiment, collection plate array **1320** comprises a plurality of interdigitated plates of opposite electrical polarity that create an electrical field between one another. The charged particles in the char-laden gas may pass near or through collection plate array **1320**. In one embodiment, at least one of the plates extends downward from the upper portion of housing **1302**, and such plates are referred to as charged plates. At least one of the plates extends upward from the lower portion of housing **1302**, and such plates are referred to as collection plates. The collection plates may be electrically grounded. The charged plates may be electrically insulated from the rest of housing **1302**, using for example plate insulator **1216** illustrated in FIG. 12. An electric potential may be applied to the charged plates, wherein the electric potential may comprise the same polarity as charging wire **1308**. In this embodiment, charged particles in char-laden gas may be forced away from the charged plates via magnetic forces acting between the charged plates and the charged particles. Charged particles may be attracted to the collection plates, which are grounded, via magnetic forces acting between the collection plates and the charged particles.

[0092] FIG. 14 illustrates an example arrangement of an electrostatic precipitator **1400**. Electrostatic precipitator **1400** may comprise a housing **1402** operatively connected to a plate electrode **1414**.

[0093] Electrostatic precipitator **1400** may comprise a collection plate array **1420** comprising at least one charged plate **1430** extending from plate electrode **1414**. In one embodiment, collection plate array **1420** comprises a plurality of charged plates **1430**. In another embodiment, at least one charged plate **1430** extends downwardly from plate electrode **1414** and is electrically insulated from housing **1402**. In one embodiment, at least one charged plate **1430** and plate electrode **1414** comprise an electric potential having the same polarity as the charging wire (not shown).

[0094] Collection plate array **1420** may comprise at least one collection plate **1434** connected to housing **1402** via at least one collection plate connection member **1436**. In one embodiment, collection plate array **1420** comprises a plurality of collection plates **1434**. In another embodiment, at least one collection plate **1434** extends upwardly from collection plate connection member **1436**. In one embodiment, at least one collection plate **1434** is electrically grounded.

[0095] In one embodiment, char collects on at least one collection plate **1434**. Char may collect on at least one collection plate **1434** to such an extent that char must be removed so that at least one collection plate **1434** may continue to collect char. In one embodiment, electrostatic precipitator **1400** is configured to operate in a batch mode, such that a certain volume of char-laden gas is processed after which electrostatic precipitator is shut down and char may be removed from at least one collection plate **1434**. In another embodiment, electrostatic precipitator **1400** is configured to operate in a continuous mode such that

electrostatic precipitator **1400** may not be shut down to allow manual removal of char from at least one collection plate **1434** by a user.

[0096] In one embodiment, electrostatic precipitator **1400** comprises at least one wiper **1438** and **1440** configured to physically contact at least one collection plate **1434** and remove char from at least one collection plate **1434**. In one embodiment, electrostatic precipitator **1400** comprises at least one upper wiper **1438**. In another embodiment, electrostatic precipitator **1400** comprises at least one lower wiper **1440**. In another embodiment, electrostatic precipitator **1400** comprises at least one upper wiper **1438** and at least one lower wiper **1440**.

[0097] At least one upper wiper **1438** may be operatively connected to an upper corner of at least one collection plate **1434**. At least one upper wiper **1438** may be configured to pivot near its end and travel in an arc about 90 degrees from a position substantially parallel to the upper edge of at least one collection plate **1434** to a position substantially parallel to a side edge of at least one collection plate **1434**. In one embodiment, two upper wipers **1438** may be in a substantially opposed orientation, such that each arcs down away from the center of at least one collection plate **1434** to opposing edges of at least one collection plate **1434**.

[0098] At least one lower wiper **1440** may be operatively connected to at least one collection plate **1434** at a point near the center of the lower edge of at least one collection plate **1434**. At least one lower wiper **1440** may be configured to pivot near its end and travel in an arc about 180 degrees, from a position substantially parallel to the lower edge of at least one collection plate **1434** (e.g., facing toward a first edge of collection plate **1434**), upwardly arcing about the face of at least one collection plate **1434** to a position substantially parallel to the lower edge of at least one collection plate **1434** (e.g., facing toward a second edge of

collection plate **1434**). As illustrated in **FIG. 4**, at least one lower wiper **1440** is oriented in its upward-most position approximately 90 degrees through its arc of movement.

[0099] In one embodiment, each of a plurality of collection plates **1434** comprise at least one upper wiper **1438** and/or at least one lower wiper **1440**. In one embodiment, each of corresponding upper wiper **1438** and lower wiper **1440** is linked via a rod (not shown), whereby upper wipers **1438** on adjacent collection plates **1434** may move concurrently with one another and lower wipers **1440** on adjacent collection plates **1434** may move concurrently with one another. In one embodiment, electrostatic precipitator **1400** is operatively connected to at least one actuator configured to actuate at least one upper wiper **1438** and at least one lower wiper **1440**.

[00100] In one embodiment, at least one upper wiper **1438** and/or at least one lower wiper **1440** may extend about opposing faces of collection plate **1434** at the same time. That is, a portion of at least one upper wiper **1438** and at least one lower wiper **1440** may extend through or around collection plate **1434** such that the leg of the wiper extending along a first face of collection plate **1434** is integrally connected with the leg of the wiper extending along a second face of collection plate **1434**. In another embodiment, at least one of upper wiper **1438** and lower wiper **1440** comprises a leg extending along a first face of a collection plate **1434** and a leg extending along a second face of a collection plate **1434**, wherein the two legs are not integrally connected.

[00101] In one embodiment, housing **1402** comprises a hopper **1442** oriented substantially below collection plate array **1420**. Char discharged from collection plate array **1420** may be allowed to fall via gravity into hopper **1442**. In one embodiment, hopper **1442** may be emptied of char manually. In another embodiment, hopper **1442** may be emptied of char automatically utilizing an auger, belt, or other material transport mechanism.

[00102] 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.” To the extent that the term “selectively” is used in the specification or the claims, it is intended to refer to a condition of a component wherein a user of the apparatus may activate or deactivate the feature or function of the component as is necessary or desired in use of the apparatus. To the extent that the term “operatively connected” is used in the specification or the claims, it is intended to mean that the identified components are connected in a way to perform a designated function. To the extent that the term “substantially” is used in the specification or the claims, it is intended to mean that the identified components have the relation or qualities indicated with degree of error as would be acceptable in the subject industry. As used in the specification and the claims, the singular forms “a,” “an,” and “the” include the plural. Finally, where the term “about” is used in conjunction with a number, it is intended to include $\pm 10\%$ of the number. In other words, “about 10” may mean from 9 to 11.

[00103] As stated above, while the present application 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, having the benefit of the present application.

Therefore, the application, in its broader aspects, is not limited to the specific details, illustrative examples shown, or any apparatus referred to. Departures may be made from such details, examples, and apparatuses without departing from the spirit or scope of the general inventive concept.

CLAIMS

1. An electrostatic precipitator, comprising:
 - a tube, wherein the tube comprises an interior surface and a polarity;
 - a gas flow inlet;
 - a gas flow outlet;
 - at least one corona wire extending within the tube from an isolator to a terminator, wherein the corona wire comprises a polarity;
 - at least one power supply and controller assembly; and
 - a liquid outlet;
 - wherein the polarity of the tube is opposite the polarity of the corona wire.
2. The electrostatic precipitator of claim 1, wherein the isolator orients the corona wire within the tube while maintaining the corona wire substantially radially centered within the tube.
3. The electrostatic precipitator of claim 1, wherein the isolator prevents the corona wire from contacting the tube.
4. The electrostatic precipitator of claim 1, wherein the isolator provides a tension to the corona wire.
5. The electrostatic precipitator of claim 1, wherein the isolator at least partially retains an end of the corona wire.
6. The electrostatic precipitator of claim 1, wherein the isolator comprises a corona wire magnet operatively connected to the corona wire.
7. The electrostatic precipitator of claim 1, wherein the isolator comprises a base magnet operatively connected to the tube.
8. The electrostatic precipitator of claim 1, wherein the isolator comprises:
 - a corona wire magnet operatively connected to the corona wire; and

a base magnet operatively connected to the tube;

wherein the corona wire magnet and the base magnet are attracted to one another via a magnetic force.

9. The electrostatic precipitator of claim 8, wherein the corona wire magnet and the base magnet are attracted to one another without actually making contact with one another.

10 An isolator, comprising:

at least one corona wire magnet operatively connected to a corona wire in an electrostatic precipitator, wherein the corona wire extends through at least a portion of a tube; and

at least one base magnet operatively connected to the tube;

wherein the corona wire magnet and the base magnet are attracted to one another via a magnetic force.

11. The isolator of claim 10, wherein the corona wire magnet and the base magnet do not actually make contact with one another.

12. The isolator of claim 10, wherein the isolator orients the corona wire within the tube while maintaining the corona wire substantially radially centered within the tube.

13. The isolator of claim 10, wherein the isolator prevents the corona wire from contacting the tube.

14. The isolator of claim 10, wherein the isolator provides tension to the corona wire.

15. The isolator of claim 10, wherein the isolator at least partially retains an end of the corona wire.

16. A method for removing droplets from a droplet-laden gas using an electrostatic precipitator, the method comprising:

introducing a droplet-laden gas into an electrostatic precipitator via a gas flow inlet;

applying a current to at least one corona wire;

directing the droplet-laden gas near the at least one corona wire to ionically charge droplets in the droplet-laden gas;

directing the ionically charged droplets and gas through a tube, wherein the ionically charged droplets are attracted to an interior surface of the tube;

directing a gas out of the electrostatic precipitator via a gas flow outlet; and

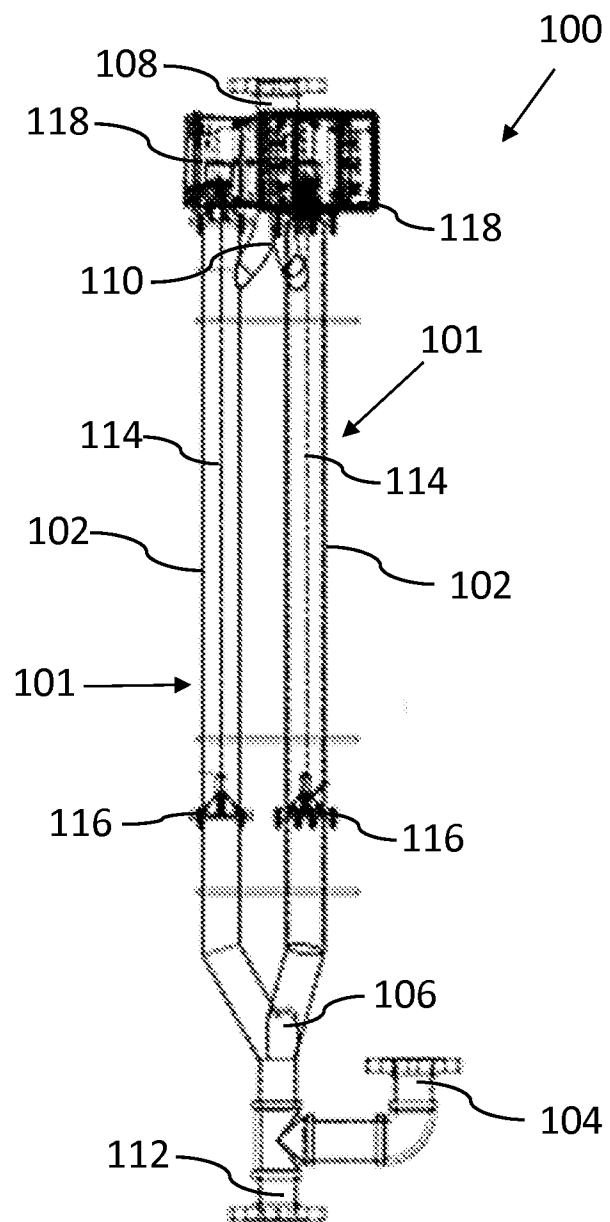
collecting droplets adhering to the interior surface of the tube after the droplets agglomerate and flow down the interior surface of the tube and out a liquid outlet.

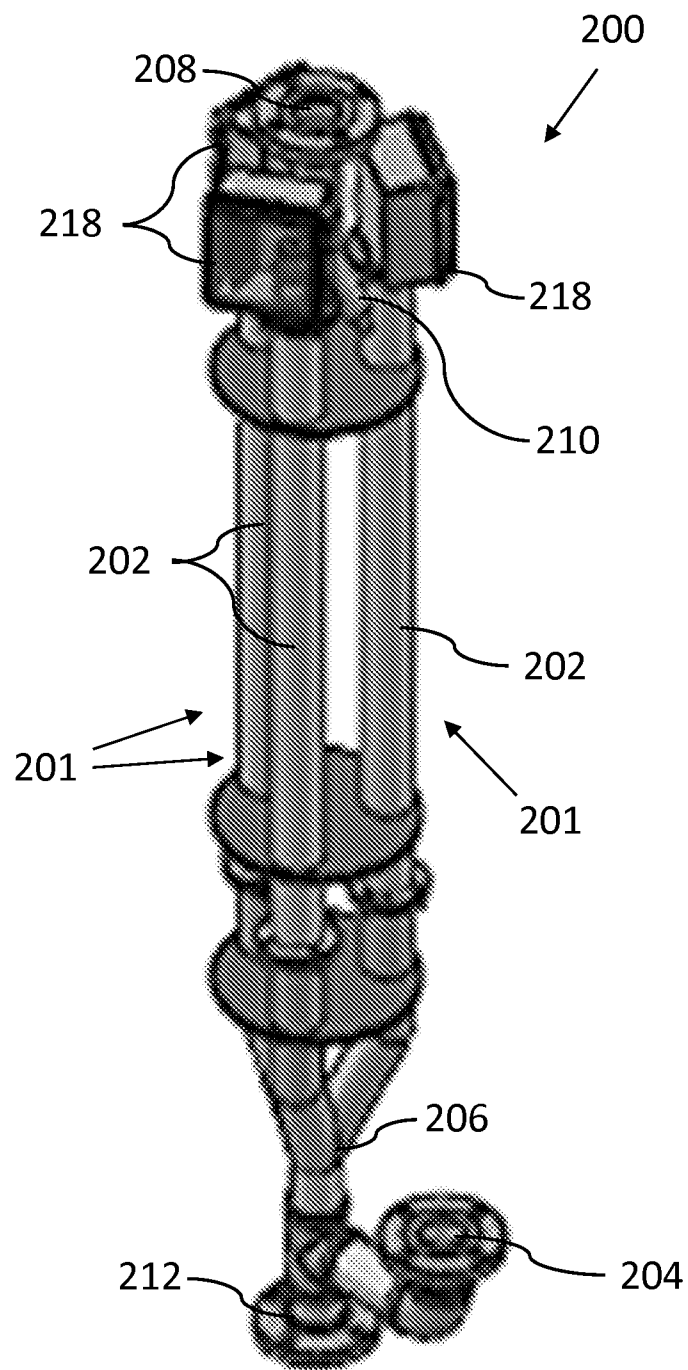
17. The method of claim 16, wherein the corona wire extends within the tube from an isolator to a terminator, wherein the corona wire comprises a polarity, wherein the tube comprises a polarity, and wherein the polarity of the tube is opposite the polarity of the corona wire.

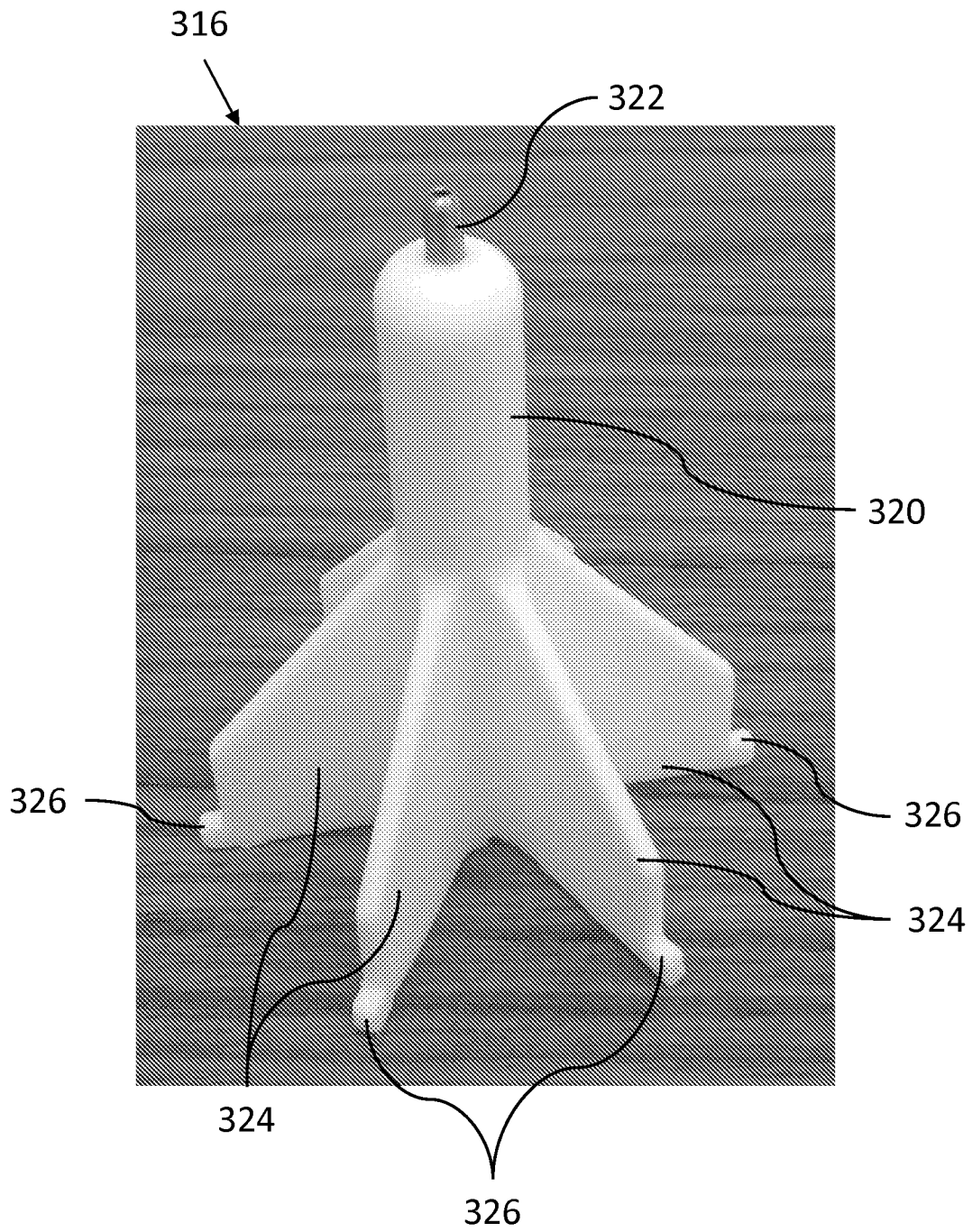
18. The method of claim 17, wherein the isolator comprises a corona wire magnet operatively connected to the corona wire and a base magnet operatively connected to the tube.

19. The method of claim 18, wherein the corona wire magnet and the base magnet are attracted to one another via a magnetic force.

20. The method of claim 18, wherein the corona wire magnet and the base magnet are attracted to one another via a magnetic force, without actually making contact with one another.

**FIG. 1**

**FIG. 2**

**FIG. 3**

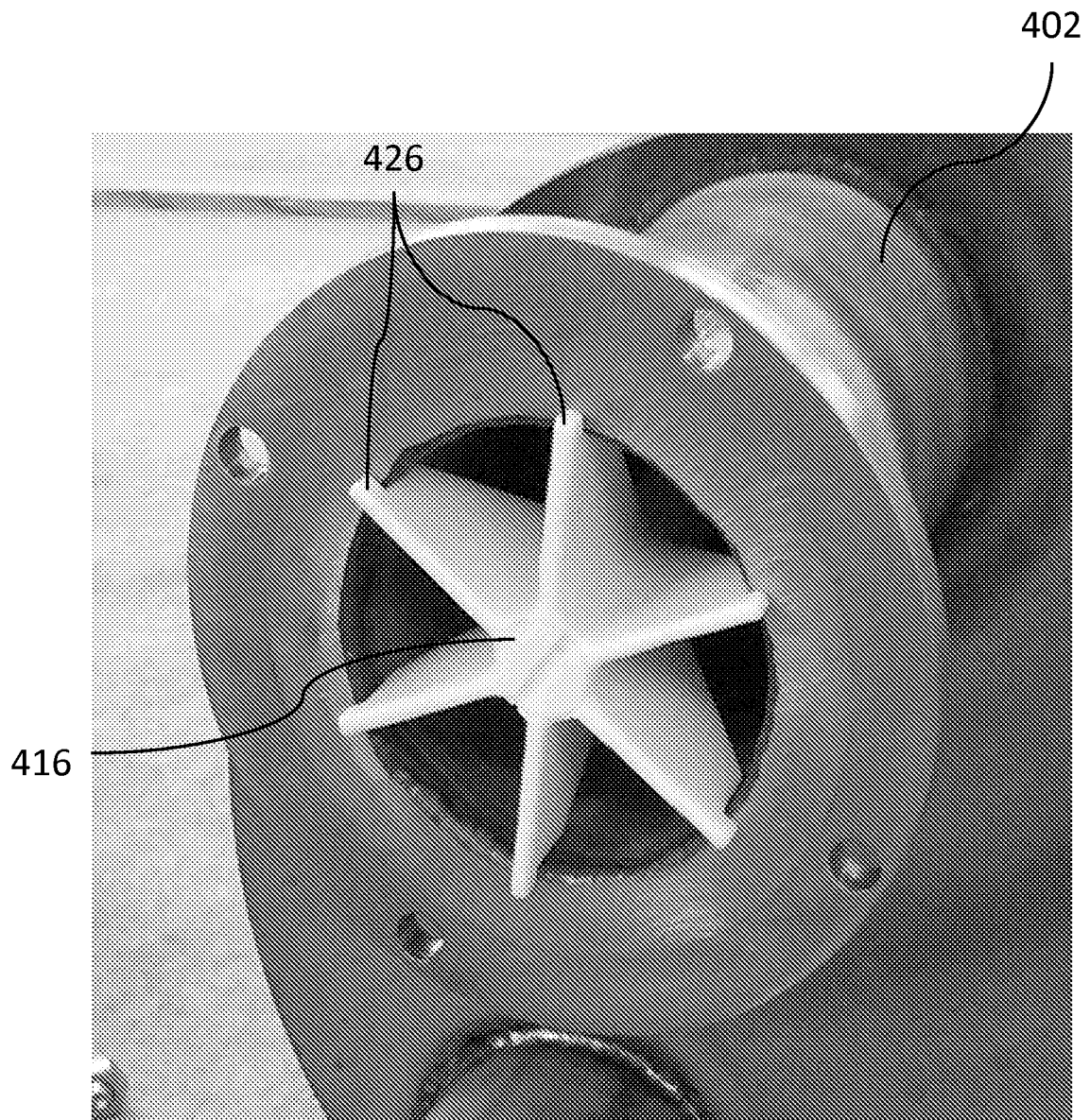


FIG. 4

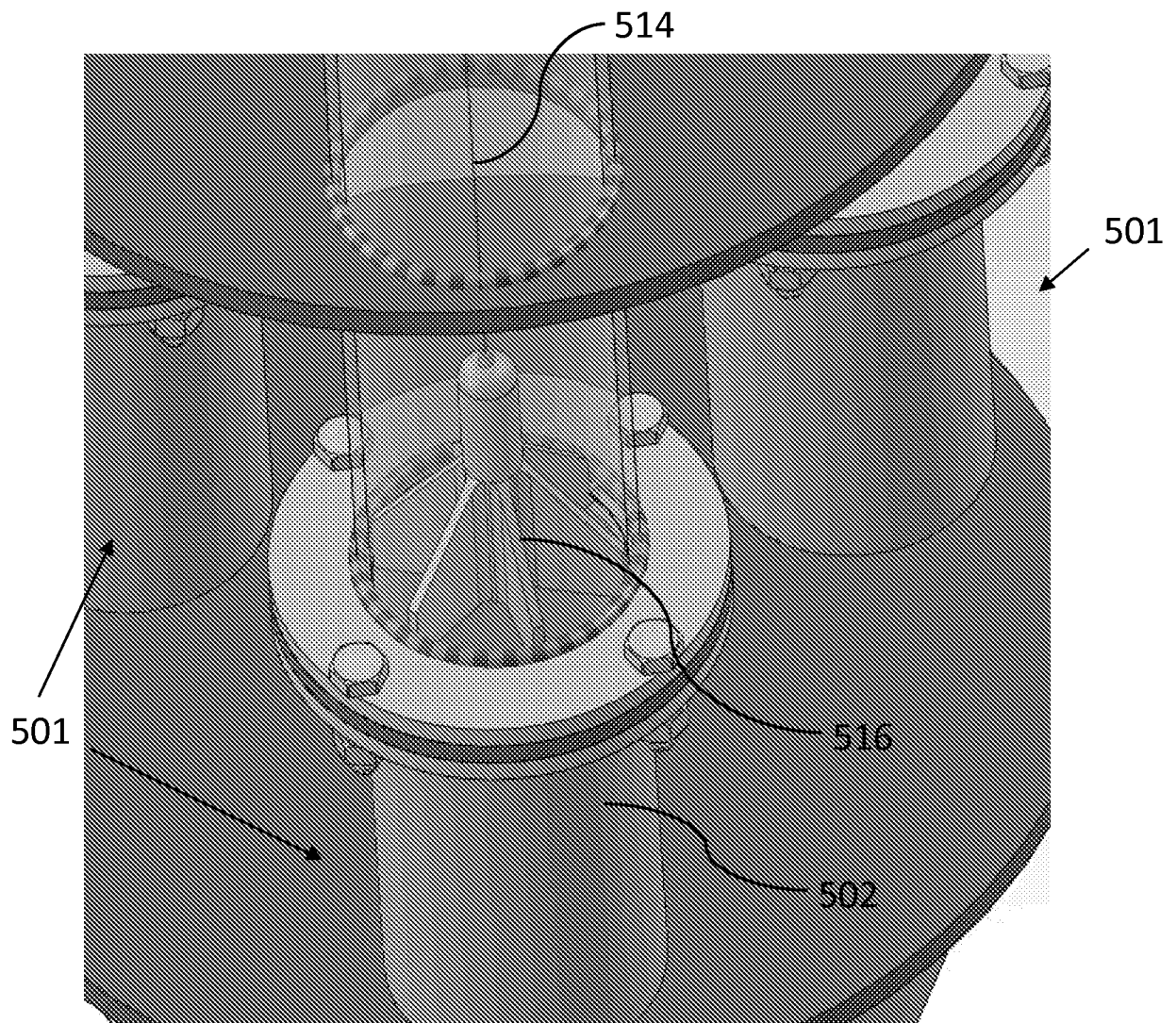
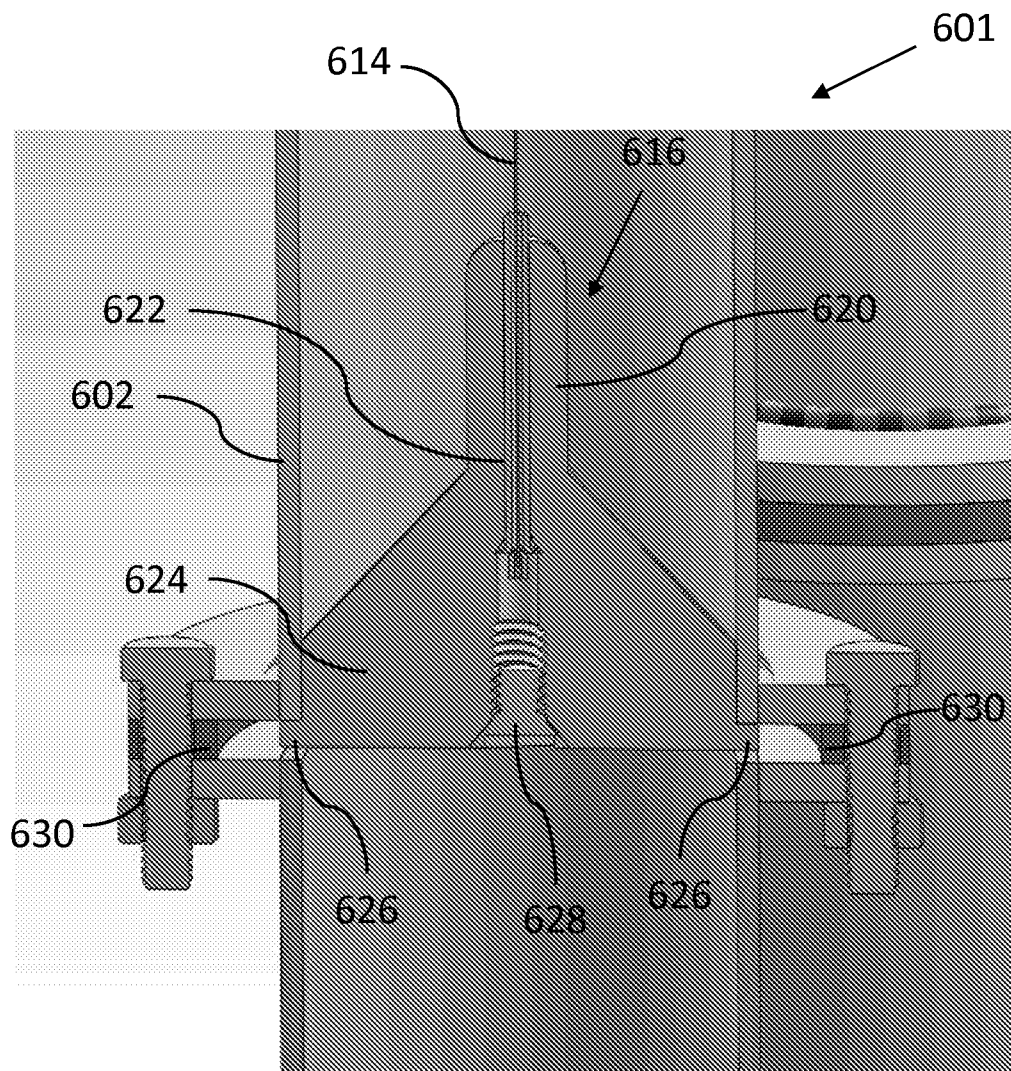


FIG. 5

**FIG. 6**

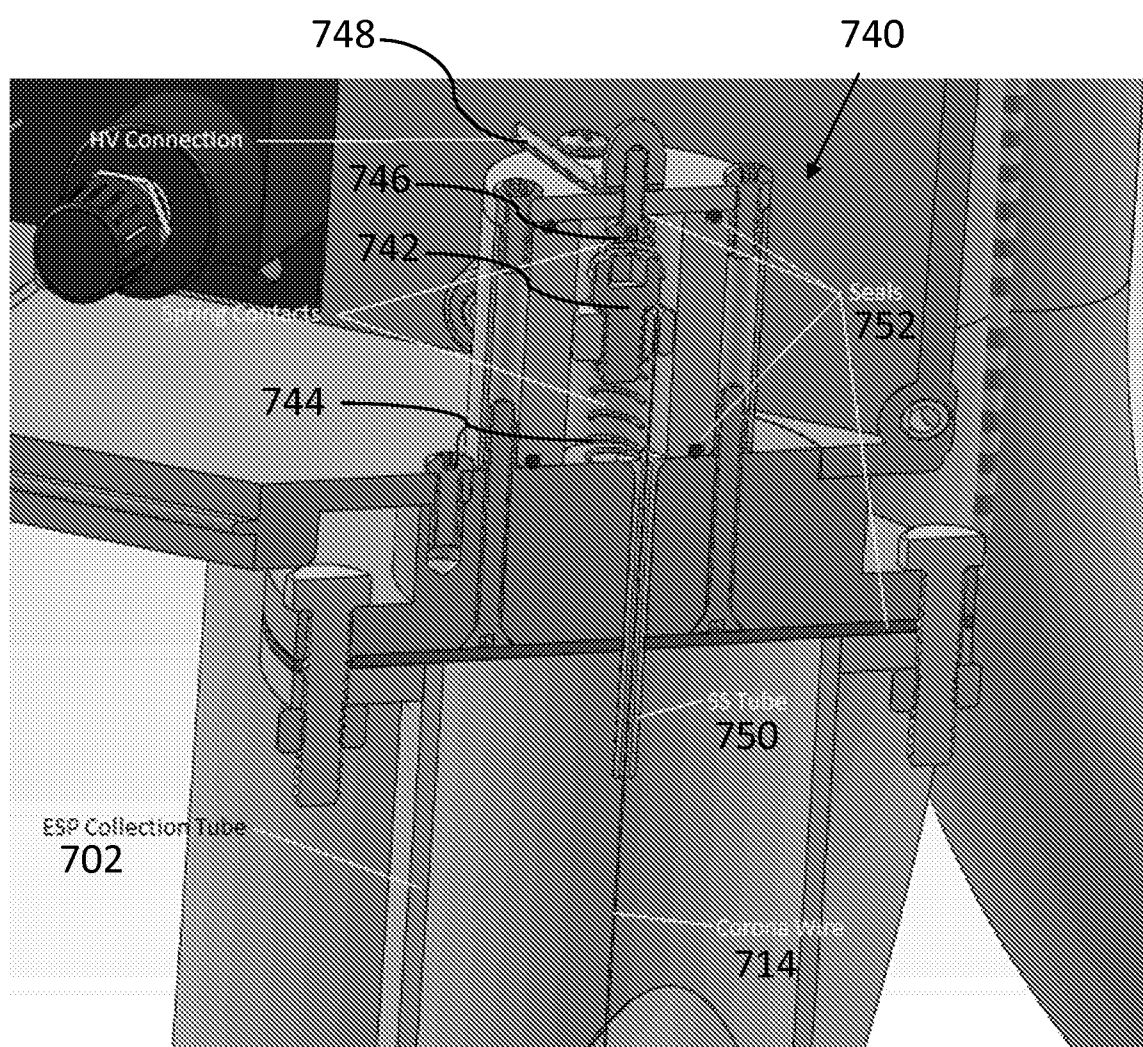


FIG. 7

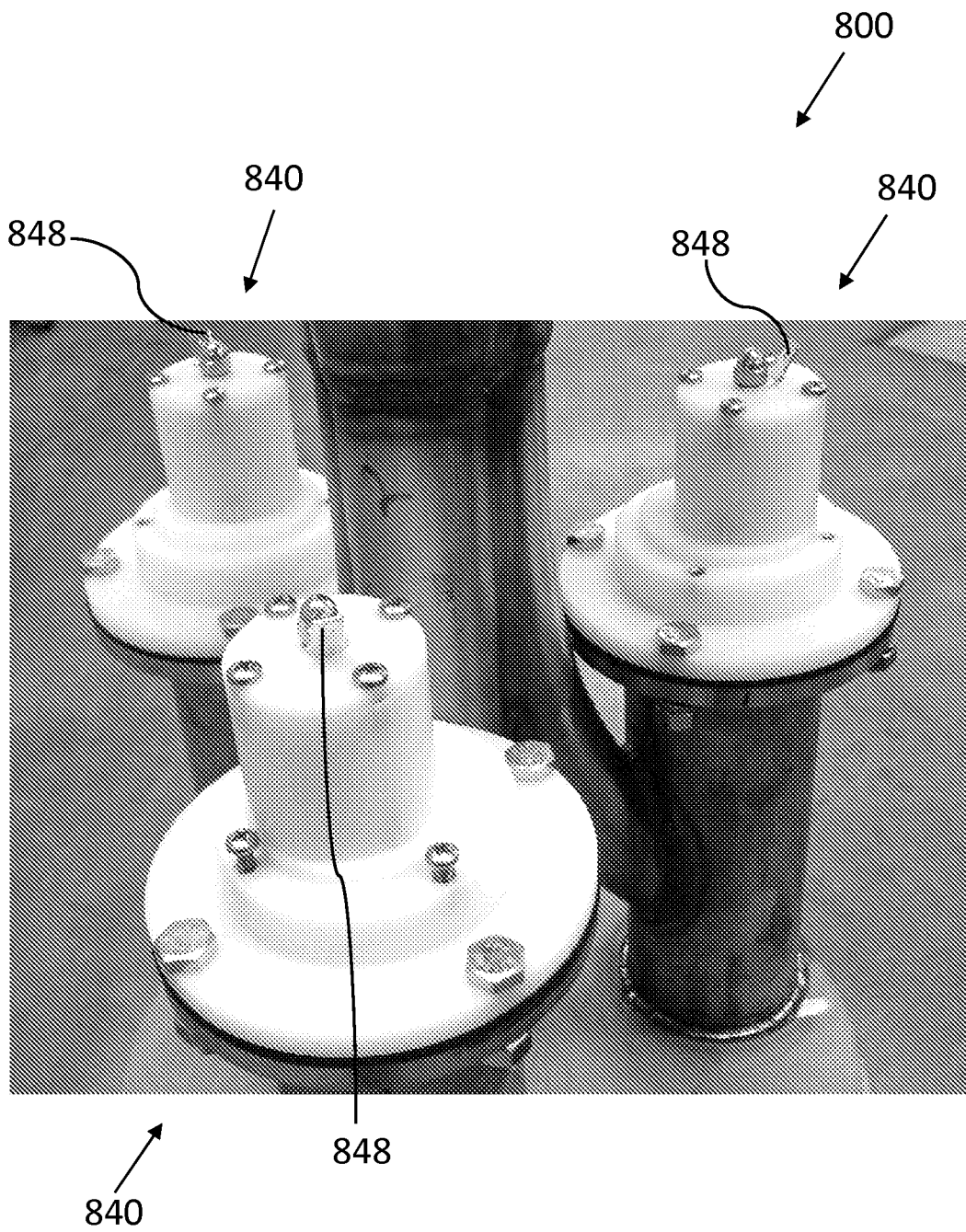
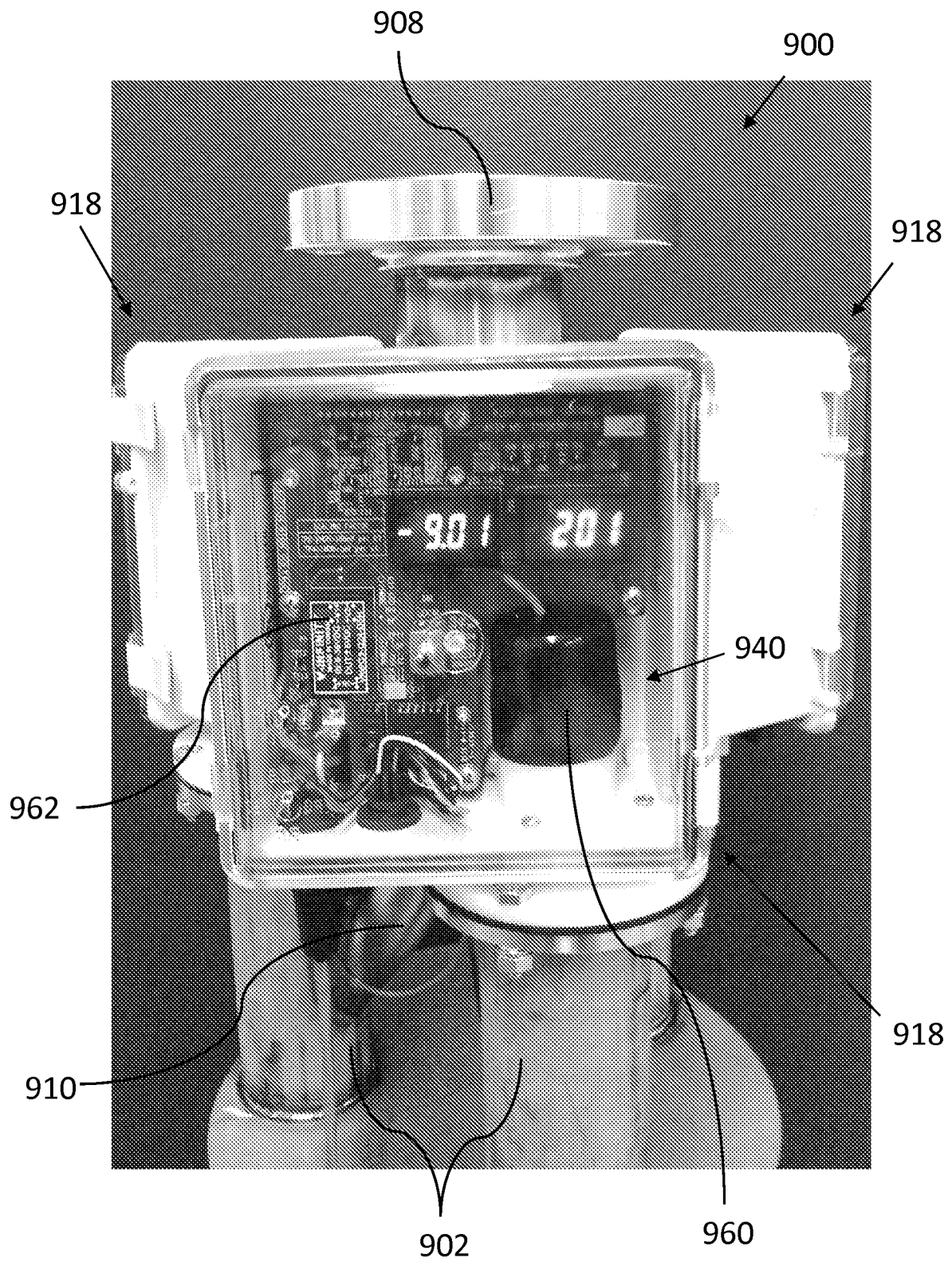
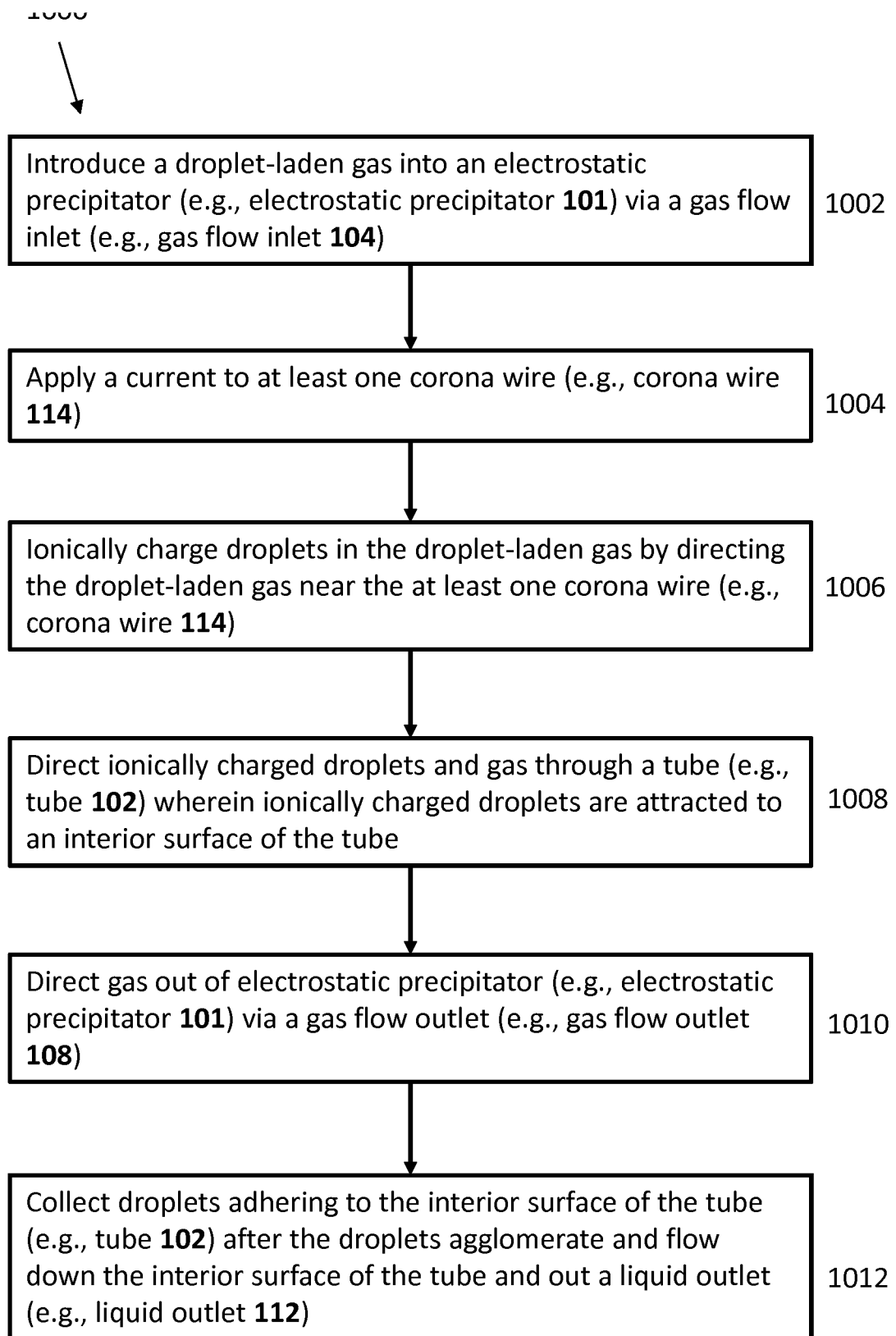
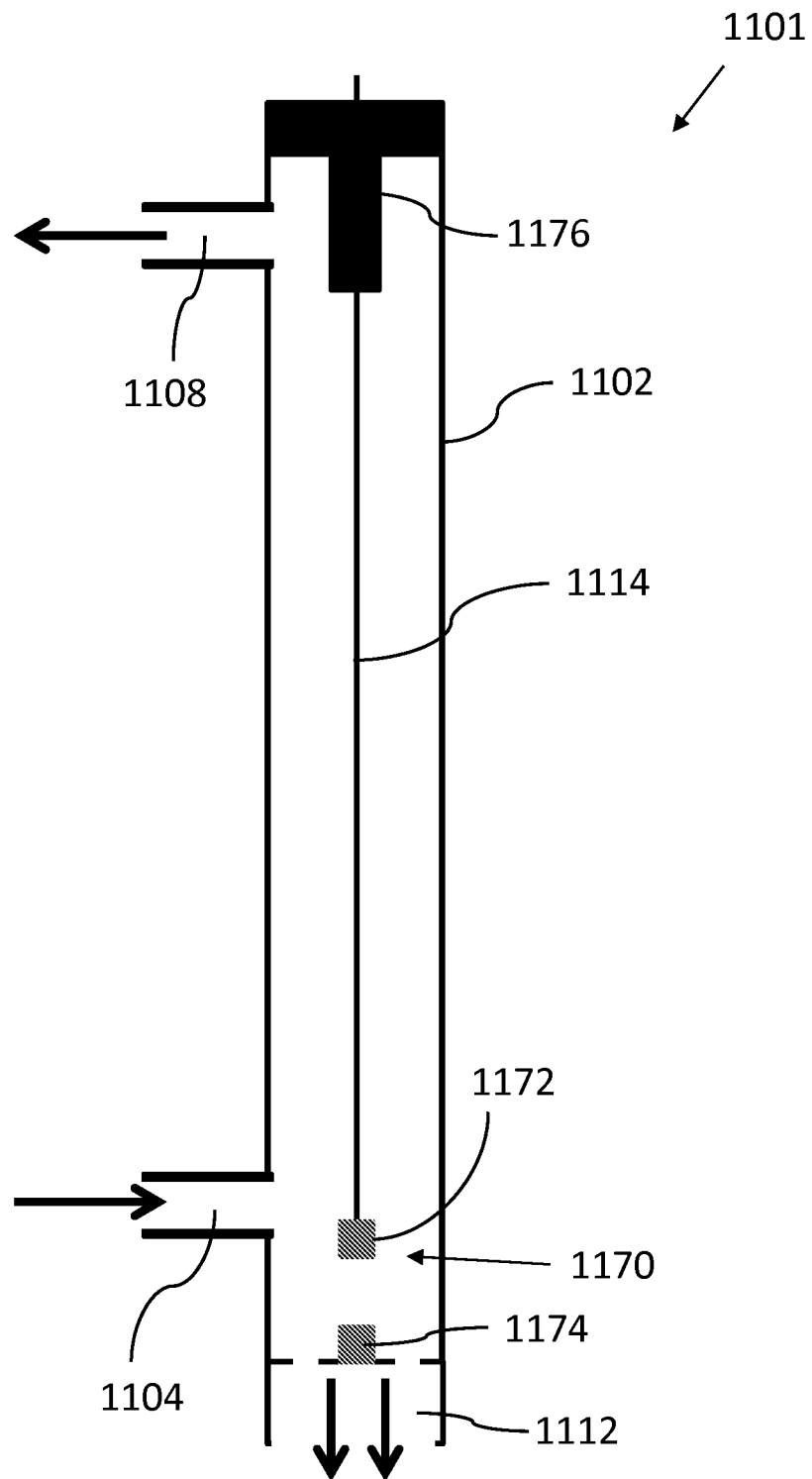
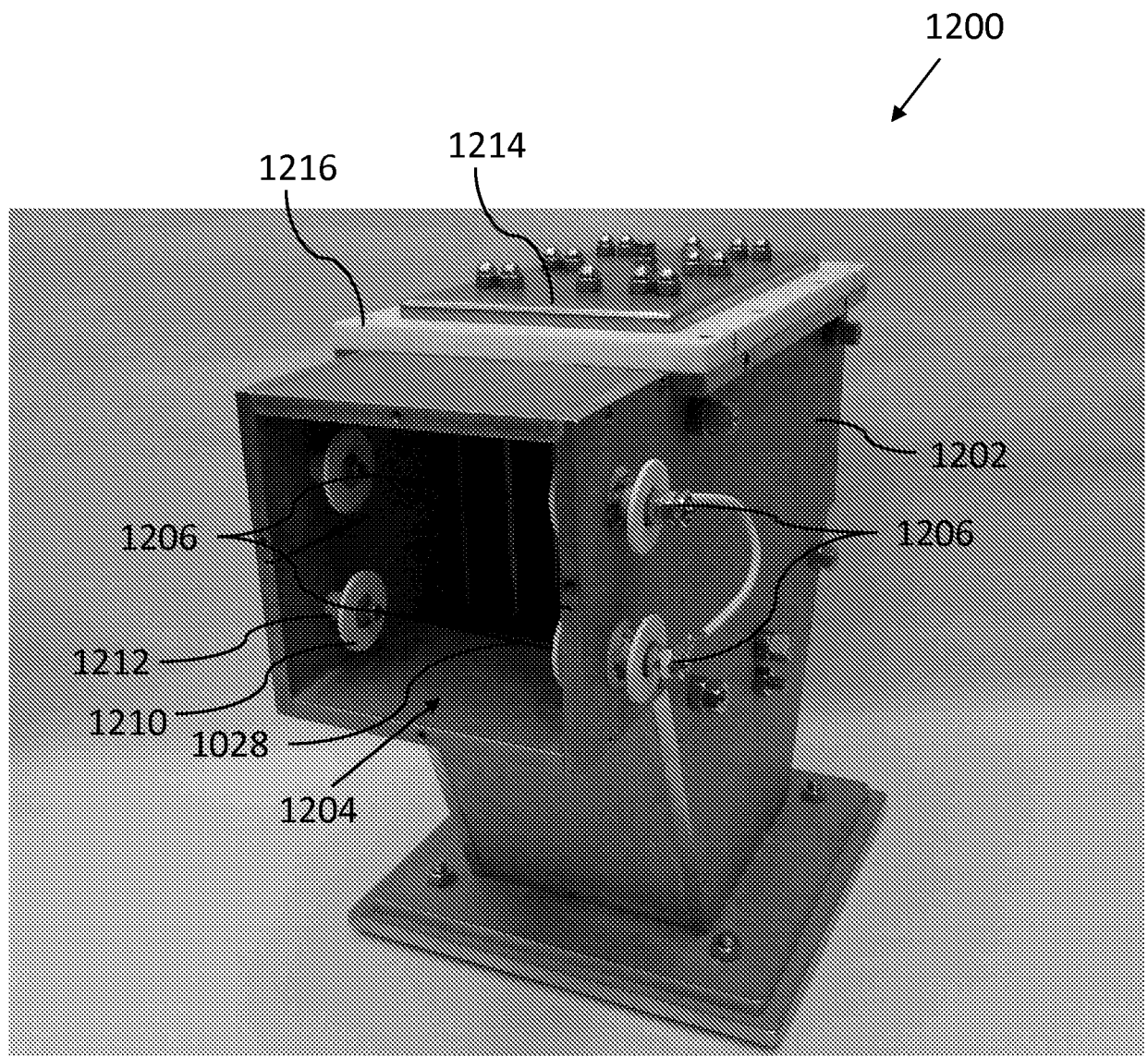


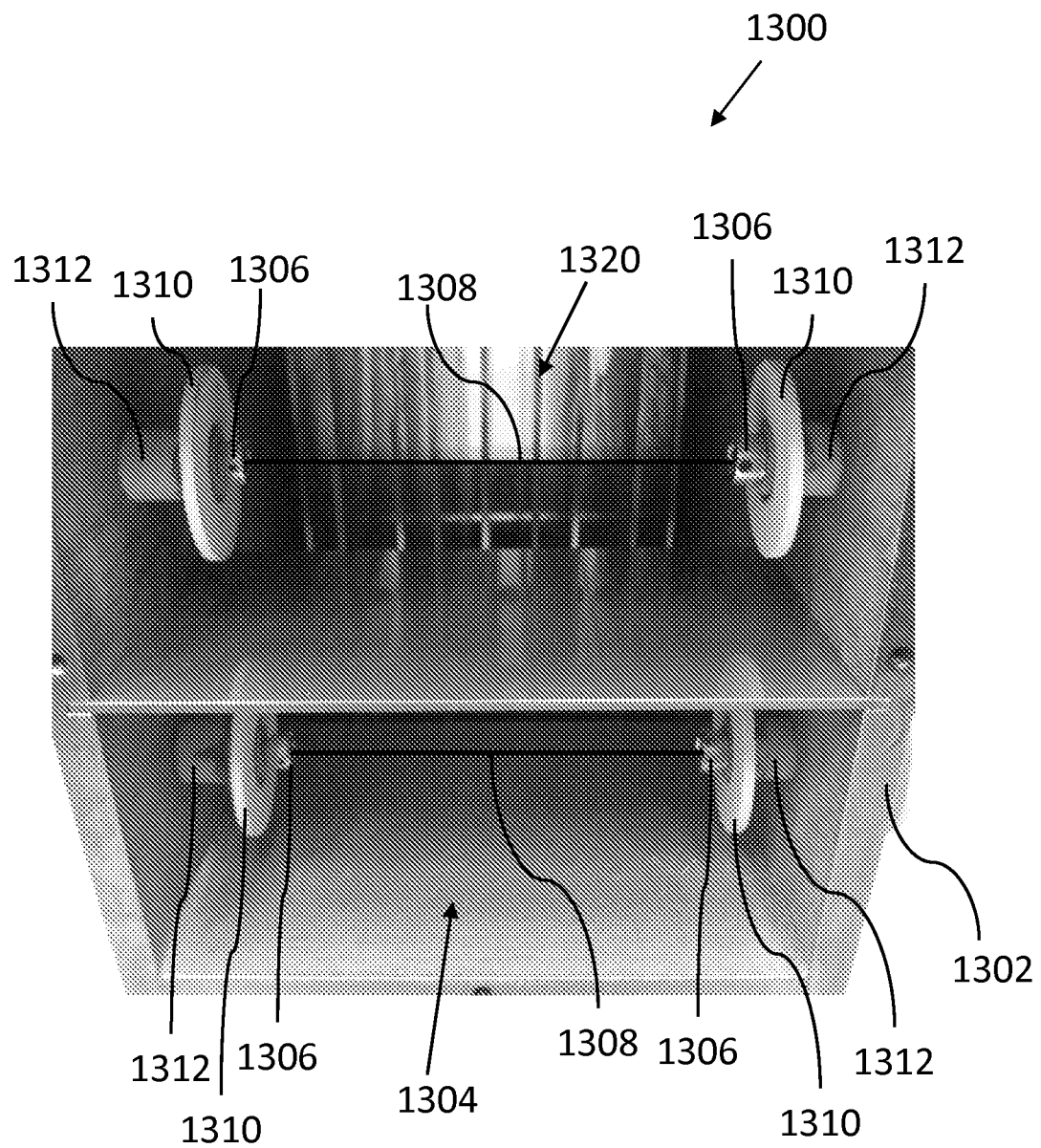
FIG. 8

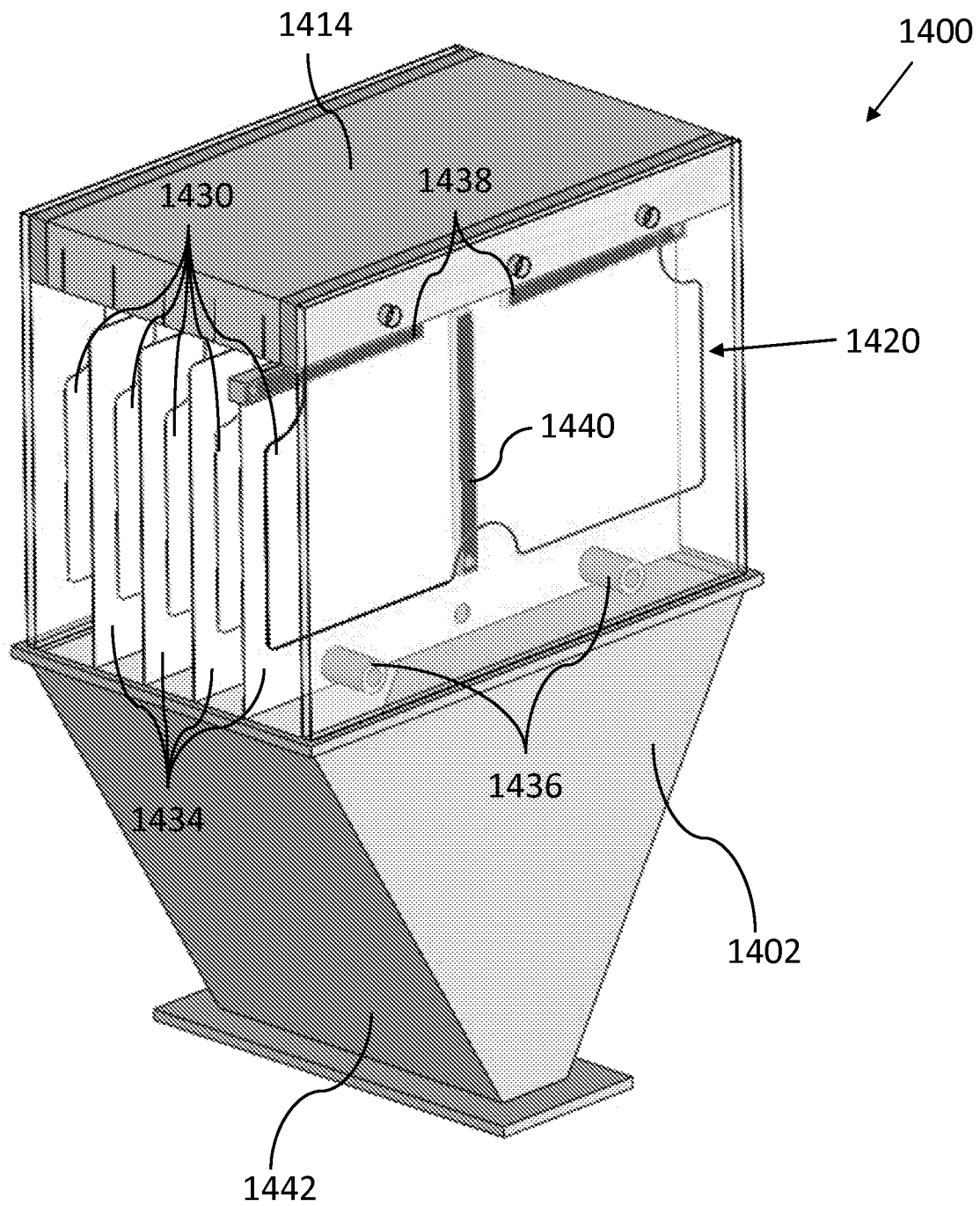
**FIG. 9**

**FIG. 10**

**FIG. 11**

**FIG. 12**

**FIG. 13**

**FIG. 14**

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/030006

A. CLASSIFICATION OF SUBJECT MATTER		
INV.	B03C3/41	B03C3/86
	B03C3/47	B03C3/49
ADD.	B03C3/06	B03C3/08
		B03C3/12
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) B03C		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 397 208 A2 (FRITZ EGGER GMBH [AT]) 14 November 1990 (1990-11-14) figure 1 column 3, line 48 - column 4, line 47 -----	1-20
X	FR 2 575 675 A1 (BACOT DOMINIQUE [FR]) 11 July 1986 (1986-07-11) figure (not numbered) page 2, line 1 - page 4, line 32 -----	1-20
X	DE 42 17 699 A1 (MICHEL KIM HERWIG [DE]) 2 December 1993 (1993-12-02) figure 1 column 2, line 55 - column 4, line 9 ----- -/--	1-20
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* 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 10 July 2014		Date of mailing of the international search report 17/07/2014
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Menck, Anja

INTERNATIONAL SEARCH REPORT

International application No

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

International application No

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