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(54) Title: ELECTROLYTIC CELL FOR HEATING ELECTROLYTE BY A GLOW PLASMA FIELD IN THE ELECTROLYTE

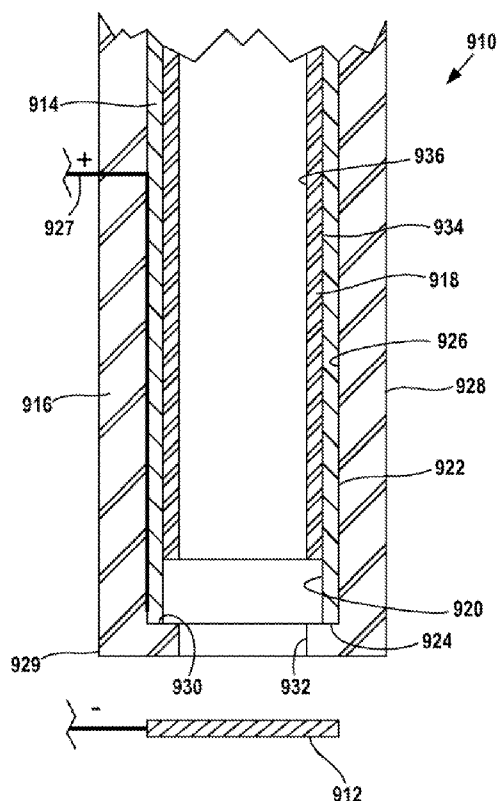


FIG. 16

(57) Abstract: An electrolytic cell for the generation of a plasma field in an electrolyte that heats the electrolyte forms part of a closed-loop heat transfer device, the electrolytic cell fluidly connected to a heat exchanger. A plasma electrode and a second electrode form part of the flow path of electrolyte from the tank to the heat exchanger. The electrolyte must flow through or along the electrodes when flowing from the tank to the heat exchanger.



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ELECTROLYTIC CELL FOR HEATING ELECTROLYTE BY A
GLOW PLASMA FIELD IN THE ELECTROLYTE

BACKGROUND OF THE DISCLOSURE

The present disclosure relates generally to electrolytic cells in which electrodes are in electrical contact with a liquid electrolyte. Specifically, the disclosure relates to an electrolytic cell for the generation of a plasma field in the electrolyte, and use of the electrolytic cell to generate heated electrolyte as a source of heat transfer.

DESCRIPTION OF THE PRIOR ART

Electrolytic cells that generate a plasma field in a liquid electrolyte are known. Such electrolytic cells are useful in different ways. First, they enable the study of the plasma field itself. Secondly, the electrolyte can be heated by the plasma field. The heated electrolyte can be circulated in a closed-loop or open-loop system as a heat source for space heating, industrial processes, or heat transfer.

A conventional electrolytic cell includes an aqueous electrolyte, such as a mixture of baking soda (sodium bicarbonate, NaHCO_3) and water held in a tank. Electrodes consisting of a bare metal anode and a bare metal cathode are partially immersed in the electrolyte and connected to the terminals of a suitable power supply.

When the power supply is energized, a plasma field is generated adjacent the cathode (referred to herein as the "plasma electrode"). The plasma field is visible to the naked eye and can be described as an intense white glow, whose appearance is similar to the intense light given off by the mantle of a gas-fired camping lantern (the color of the glow can be affected by the chemical composition of the electrolyte). The term "plasma field" refers to this bright plasma field in the electrolyte.

The plasma field may be extinguished if the partially immersed plasma electrode is immersed too deeply into the

electrolyte. It is theorized that as the surface area of the plasma electrode wetted by the electrolyte increases, the power density (the power transferred per unit area between the electrode surface to the electrolyte generating the plasma field) decreases. If the power density falls below a critical threshold, the plasma field is extinguished.

To maintain power density, the plasma electrode of a conventional electrolytic cell is partially immersed in the electrolyte and does not extend substantially beyond the electrolyte's upper surface. As a result, the generated plasma field is also near the surface. This reduces the ability of the plasma field to efficiently heat deeper electrolyte. And because the plasma field is below the plasma electrode, heat from the plasma field and heated electrolyte impinge against the electrode, deteriorating or eroding the electrode. The plasma field cannot be maintained for an extended period and the plasma electrode requires frequent replacement, typically after only five or ten minutes of use.

Furthermore, it is difficult to control the output of the plasma field in a conventional electrolytic cell. If the energy output of the power supply is reduced, the plasma field may be extinguished. It is theorized that a minimum power density from the plasma electrode to the electrolyte is required to support the plasma field. If the power density falls below the threshold, the plasma field is extinguished.

Hoffman et al. US Patent Application Publication 2012/0145540 discloses an improved electrolytic cell for generating a plasma field in an electrolyte. It is desired to further improve the electrolytic cell disclosed in the '540 publication to further extend the life of the plasma electrode.

BRIEF SUMMARY OF THE DISCLOSURE

Disclosed is an improved electrolytic cell to generate a plasma field in an electrolyte. The plasma electrode of the electrolytic cell of the present invention can be placed

essentially anywhere in the electrolyte without extinguishing the plasma field. The output of the plasma field is controllable without reducing the power density from the plasma electrode to the electrolyte. In some embodiments of the electrolytic cell, the plasma electrode can operate hundreds of hours generating a plasma field that efficiently heats the electrolyte heat to relatively high temperatures without need of replacement.

An electrolytic cell in possible embodiments includes a plasma electrode formed from at least one metal conductor immersed in an electrolyte held in a tank. Only a portion of the immersed conductor is wetted by the electrolyte. The wetted portion of the plasma electrode forms an active electrode area in direct electrical contact with the electrolyte. The plasma electrode can be placed essentially anywhere in the electrolyte without changing or affecting performance of the active electrode area.

The plasma electrode may in some embodiments be formed as an elongate member or rod held vertically in the electrolyte. The insulation covers all but the end of the rod immersed in the electrolyte. The uninsulated end surface is wetted by the electrolyte and forms the active electrode surface. The plasma field is generated on this active electrode surface.

In a possible embodiment, insulation is attached to and covers the entire portion of the plasma electrode immersed in the electrolyte except for the portion forming the active electrode area. The insulation forms a mechanical barrier separating the electrolyte from the plasma electrode.

The insulation attached to the plasma electrode must be mechanically capable of withstanding induced thermal stresses caused by thermal expansion of the plasma electrode. Insulation made of solid virgin polytetrafluoroethylene (PTFE) has been found to be a suitable insulation material, but other insulating materials could be used.

The plasma electrode is preferably formed having an enlarged disk portion located at the immersed end of the electrode. The surface of the disk portion forming the active electrode surface is flat. A number of spaced apart through-holes extend perpendicular through the thickness of the disk and open on the active electrode surface. The holes can be aligned with flow channels extending through the insulation to circulate heated electrolyte away from the active electrode surface through the flow channels.

The plasma electrode having the through-holes exhibits a long operating life before replacement is needed. For example, such a plasma electrode generated a plasma field continuously for over 107 hours of operation when used in an electrolytic cell generating sufficient heated electrolyte to heat an average-sized home. The electrolytic cell generated heated electrolyte that flows to a heat exchanger where heat is transferred from the electrolyte to heat the home. The electrolyte is returned back to the electrolytic cell for reheating by the plasma field, forming a closed-loop heating system. The long operating life of the plasma electrode enables practical and economical use of the electrolytic cell as part of a home heating system.

Inspection of the plasma electrode after the over 107 hours of continuous operation revealed no signs of mechanical erosion, corrosion, plating, or metal buildup on the electrode. Applicants believe that the plasma field is being generated at sites surrounding the holes in the active electrode surface. By distributing generation of the plasma field to multiple sites on the active electrode surface, erosion and degradation of the active electrode surface, and the electrode itself, is greatly reduced as compared to conventional plasma electrode constructions.

The plasma electrode preferably flows the heated electrolyte out of the tank, thus assuring the electrolyte leaving the tank has just passed through the plasma field.

In a second possible embodiment, the mechanical barrier is an air curtain that is not affected by thermal expansion.

In the second possible embodiment, the outside of the plasma electrode is not covered by solid insulating material. A tube surrounds the plasma electrode and extends the length of the electrode. In operation air bubbles flow in the annular space between the tube and rod forming an air curtain barrier. The electrolyte wets only the active electrode surface at the immersed end of the rod.

In yet other embodiments the output of the plasma field is increased or decreased by varying the active area of the plasma electrode, the effective area of the other electrode, or both, without affecting the power density between the plasma electrode and the electrolyte. Varying the active area of the plasma electrode varies the surface area generating a plasma field. Varying the effective area of the other electrode varies the intensity of the plasma field generated on the active electrode surface. The risk of extinguishing the plasma field is less because the power density does not change despite changes in plasma field output.

The active area of the plasma electrode may be varied by placing a plasma electrode made of a number of conductors in the electrolyte. The conductors are connected in parallel with the power supply, with each conductor connected through a switch. The switch can be selectively closed to connect the conductor with the power supply or opened to disconnect the conductor from the power supply.

Each conductor has an end surface wetted by the electrolyte. When the conductor is connected to the power supply the wetted surface becomes an active electrolyte surface. By opening and closing the switches, the active electrolyte surface is selectively increased or decreased without affecting the power density between the plasma electrode and the electrolyte.

In other possible embodiments the effective area of the other electrode is varied by varying the depth of immersion of the other electrode in the electrolyte. The tank of the electrolytic cell itself can be formed from an electrical conductor. Placing the other electrode in contact with the tank causes the tank to become part of the other terminal, maximizing the effective area of the terminal in contact with the electrolyte.

In alternative embodiments the other terminal includes a number of separate conductors immersed in the electrolyte and connected in parallel with the power supply. Switching the conductors into and out of the power supply circuit in the same manner as previously described for the plasma electrode selectively varies the effective area of the other terminal in contact with the electrolyte.

In yet an additional embodiment, the electrolytic cell is formed as a one-piece electrode module that includes both the anode and cathode, making installation and replacement of the anode and cathode easy and efficient. The anode and cathode are held in a fixed relationship facing one another and in the line of sight of one another by the insulating body. Electrolyte flowing out of the tank must flow through the plasma field shortly before leaving the tank, so the temperature of the electrolyte flowing to the heat exchanger is maximized. The anode defines an opening constriction for the flow of electrolyte. This constriction generates narrowed flow lines where the electrolyte flows past the cathode, reducing drag across the cathode.

The disclosed electrolytic cell has other advantages over conventional electrolytic cells. By locating the plasma field at the upper end (with respect to gravity) of the plasma electrode, heat generated by the plasma field is carried away from the entire plasma electrode, including the active electrode surface, by natural convection. Deterioration or erosion of the active electrode surface is reduced, extending

the operating life of the plasma electrode. Because the total surface area of the plasma electrode in the electrolyte may be greater than the area of the active electrode surface, the thermal capacity of the plasma electrode and its ability to transfer heat to the electrolyte is increased. The plasma electrode operates at a lower average temperature, further increasing operating life.

Other objects and features of the disclosure will become apparent as the description proceeds, especially when taken in conjunction with the accompanying drawing sheets illustrating multiple embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of a first embodiment electrolytic cell;

FIG. 2 is a vertical view of the plasma electrode of the electrolytic fuel cell shown in FIG. 1;

FIG. 3 is a partial vertical sectional view of the plasma electrode of a second embodiment fuel cell;

FIG. 4 is a schematic view of a third embodiment electrolytic cell;

FIG. 5 is a front view of a plasma electrode of a fourth embodiment electrolytic cell;

FIGS. 6 and 7 are opposite top and bottom views of the plasma electrode shown in Figure 5;

FIG. 8 is a schematic view of a home heating system incorporating the fourth embodiment electrolytic cell;

FIG. 9 is a front view of a plasma electrode of a fifth embodiment electrolytic cell;

FIGS. 10 and 11 are opposite top and bottom views of the plasma electrode shown in Figure 9;

FIG. 12 is a schematic view of a portion of a home heating system similar to that illustrated in Figure 8 but including the fifth embodiment electrolytic cell;

FIG. 13 is a front sectional view of a sixth embodiment electrolytic cell;

FIG. 14 is a schematic view of a closed-loop heating system that includes the electrolytic cell shown in Figure 13;

FIG. 15 is a front sectional view of a seventh embodiment electrolytic cell; and

FIG. 16 is a front sectional view of the lower portion of an eighth embodiment electrolytic cell.

DETAILED DESCRIPTION

Figures 1 and 2 illustrate an electrolytic cell 10. Electrolytic cell 10 generates a plasma field in an aqueous electrolyte 12 held in a vessel or tank 14. The tank 14 can be an insulated pressure vessel, similar to a domestic home hot water tank, if the heated electrolyte 12 circulates in a closed-loop or open-loop system.

The plasma electrode is a cathode 16 immersed in the electrolyte 12. The cathode 16 includes an active electrode surface 18 wetted by the electrolyte 12, that is, the active electrode surface 18 is the portion of the cathode 16 in direct physical contact with the electrolyte 12. The other electrode is an anode 20 formed from a stainless steel rod. The anode 20 is shown partially immersed in the electrolyte 12. Varying the immersion of the anode 20 in the electrolyte varies the intensity of the plasma field generated by the cell 10 as will be described in greater detail below.

A power supply 22 is connected to the cell electrodes 16, 20 and has a negative terminal 24 electrically connected to the cathode 16 and a positive terminal 26 connected to the anode 20.

Electrolyte 12 in the illustrated embodiment is an aqueous solution of water and baking soda (sodium bicarbonate, NaHCO_3) as is known in the art for forming a plasma field. Other electrolytes used in conventional electrolytic cells that generate a plasma field can also be used in other embodiments, including acidic or basic electrolytes.

Any suitable DC or AC power supply 22 can be used to provide the voltage necessary to create the plasma field. It

has been found that inverter power supplies or power supplies used in connection with welding machines and plasma cutters provide excellent results. Such power supplies provide a pulsed, high-frequency DC power output with preferably a 100% duty cycle. For example, the power supply 22 can be a Spectrum 3080 power source manufactured by Miller Electric Manufacturing of Appleton, Wisconsin. If desired, a custom power supply could be designed to meet the specific current, voltage, and power factor requirements of a specific electrolytic cell design.

The cathode 16 includes six spaced-apart stainless steel rods 28 attached to a stainless steel mounting plate 30. The rods 28 each extend upwardly from the plate 30 to an upper free end having an end surface 32. The relative size of the cathode 16 and the anode 20 with respect to the tank 14 is exaggerated in the drawings for clarity.

Solid virgin polytetrafluoroethylene (PTFE) insulation 34 covers the entire outer surface of the cathode 16 with the exception of the rod upper end surfaces 32. The PTFE insulation is sold commercially under the TEFLON trademark by E.I. Du Pont de Nemours and Company Corporation, Wilmington, Delaware and is available from other suppliers. The PTFE insulation 34 prevents contact of the electrolyte 12 with the insulated portions of the cathode 16. The end surfaces 32, however, are wetted by the electrolyte 12 and each forms a portion of the active electrode surface 18.

The number of active electrode surface portions 32, and the shape and area of each active anode portion, can vary in other embodiments to meet design requirements. The active electrode surface portions can be located at other points along the rods or multiple active electrode surface portions can be defined on an individual rod. Differently-shaped conductive members or different conductor materials can be used for forming the anode in other embodiments.

In operation, the power supply 22 is energized to generate a plasma field 36 at each active electrode surface portion 32. The plasma fields 36 heat the rod surfaces 32 and the nearby electrolyte 12. The plasma fields 36 are located above the rods 28 so that the heat generated by the plasma fields 36 is carried away from the rods by natural convection to the remainder of the electrolyte. This heat transfer cools the rod surfaces 32. Heat transfer from the cathode 16 to the electrolyte 12 also takes place across the entire surface area of the anode, further cooling the anode. Deterioration and erosion of the cathode 16, and particularly the active electrode surface 18, is substantially reduced. The plasma field can be maintained for a relatively long period without replacing the anode.

The cathode 16 can be located as desired in the electrolyte 12 without affecting the active electrode surface 18. This enables the cathode 16 to be located away from the surface of the electrolyte without affecting the power density between the active electrode surface 18 and the electrolyte 12. The area of active electrode surface 18 remains constant regardless of the depth 38 of the cathode 16 in the tank 12. For example, the cathode 16 may be located near the bottom of the tank to enable easier access of test equipment to the plasma field for study.

For heating electrolyte, the cathode 16 is preferably placed near the bottom of the tank 14 so that natural convection more efficiently transfers heat to the entire mass of electrolyte. If desired, a pump or stirrer can generate mechanically forced convection in the tank 14.

Increasing or decreasing the surface area of the anode 20 in contact with the electrolyte 12 varies the intensity of the plasma field 36. Figure 1 illustrates the anode 20 in a first operating position. Lowering the anode 20 to a second operating position 40 (shown in phantom in Figure 1) increases the effective area of the anode 20 in the electrolyte 12 and

increases the intensity of the plasma field 36. Similarly, raising the anode 20 decreases the effective area of the anode 20 in the electrolyte 12 and reduces the intensity of the plasma field.

In the illustrated embodiment the tank 14 is a stainless steel tank with the steel in direct contact with the electrolyte. Placing the anode 20 in a third operating position 42 against the tank 14 (shown in phantom in Figure 1) adds the wetted surface of the tank to the effective area of the anode 20, maximizing the intensity of the plasma field 36. An anode automatic control system 44 operatively connected to the anode 20 can automatically position the anode 20 as needed to regulate the temperature of the electrolyte or in response to some other input variable.

Thermal expansion and contraction of the rods 28 generates stress in the insulation 34. The insulation must accommodate the expansion and contraction of the rods without through-cracking or separating from the rods to function effectively as a mechanical barrier between the rods and the electrolyte. Figure 3 illustrates a second embodiment electrolytic cell 110 with a cathode 112 similar to the cathode 16, but having no insulation along the rods. Instead, the electrolyte is kept from the rods by an air barrier rather than a solid barrier as with the cathode 16. Only the differences between the cathode 112 and cathode 16 will be discussed below.

Each stainless steel rod 116 (only one rod is shown in Figure 3) extends from a mounting plate 114 to an upper rod surface 118 forming a portion of the active electrode surface of the cathode 112. A tube 120 attached to the plate 114 surrounds the rod 116 and extends the length of the rod 116. The inner tube wall 122 is spaced from the rod 116 and defines an annular space or chamber 124 between the rod and tube. Through bores 126 extend through the thickness of the plate 114 and open into the volume 124.

An air hose 128 attached to the bottom of the plate flows air from an air pump (not shown) through the bores 126. Air bubbles 130 flowing between the rod 116 and the tube 120 generate an air curtain or fluid barrier that prevents the electrolyte from contacting the sides of the rod 116. The electrolyte can, however, wet the upper surface 118 to support a plasma field 132 generated on the active electrode surface portion 118.

Thermal expansion and contraction of the rod 116 does not stress the surrounding tube, and does not affect the air curtain surrounding the rod 116. The length of the tube 120 is preferably sized to accommodate the length of the rod at its maximum operating temperature.

Figure 4 illustrates a third embodiment electrolytic cell 210. Electrolytic cell 210 is similar to electrolytic cell 10 so only the differences will be discussed in detail.

A cathode 212 forming the plasma electrode is immersed in the electrolyte 214 and connected to a power supply 216. The cathode 212 includes a number of separate conductor rods 218. Each rod 218 is insulated from the electrolyte except for the upper end 220 of the rod. An anode 222 is provided.

The rods 218 are connected in parallel to the power supply 216 through respective electrical connections 224. Each connection 224 includes a switch 226 that breaks or makes the circuit between the power supply 216 and the rod 218 connected to the switch. The switches 226 are opened and closed by a controller (not shown) that is responsive to a signal representing temperature, flow, or other control parameter.

Each rod end 220 contributes to the active electrode surface of the cathode 212 and supports a local plasma field 228 when the corresponding switch 222 is closed. When all the switches 226 are closed, the active electrode surface of the cathode 212 is at its maximum. The area of the active electrode surface can vary between the maximum and zero by

selectively opening and closing the switches 226 to vary the number of rods 218 energized by the power supply.

As illustrated in Figure 4, one switch 226 is open and the other switches 226 are closed. The area of the active electrode surface of the cathode 212 is seventy-five percent of maximum, and can be varied in twenty-five percent increments. The number of rods can vary from the illustrated embodiment, or the size and wetted surface area of each rod can vary among the rods, to enable finer control of active cathode area.

The power supply 216 has sufficient capacity to generate a plasma field 228 on each rod 218 when all the switches 226 are closed. The voltage drop across each active rod 218 is independent of the active or inactive state of the other rods 218 because the rods are connected in parallel with the power supply 216.

In yet other embodiments the anode 222 can be formed from separate conductors wired in parallel with the power supply and controlled by switches in the same manner as the cathode 212. If desired, the anode conductors can include the tank itself.

Figures 5-7 illustrate a plasma electrode 310 used as a cathode in a fourth embodiment electrolytic fuel cell. The electrolytic fuel cell is otherwise identical to the fuel cell 10 previously discussed above and so only the differences will be discussed.

The plasma electrode 310 includes an elongate metal conductor 312 surrounded by solid virgin PTFE insulation 314. The insulation 314 has a threaded portion 316 that threads into a threaded opening preferably located along the bottom of the electrolyte tank (not shown) and an annular flange 318 that abuts against the bottom of the tank to axially locate the electrode 310 in the tank. The electrode 310 forms the cathode, and may be coaxially aligned with an elongate metal conductor forming the anode.

The conductor 312 includes an elongate metal rod 320 that screws into one side of a metal annular disk 322 to form the conductor. The disk 322 has a larger diameter cylindrical collar portion or flange 324 on the one side of the disk 322 that receives the rod 320 and a reduced diameter cylindrical portion 326 on the other side of the flange 324 that includes the other side or upper surface 328 of the disk. A number of circumferentially spaced, parallel through-holes 330 extend through the axial thickness of the disk 322 from the upper surface 328 of the disk.

In the illustrated embodiment the rod 320 is one-quarter inch in diameter. The disk flange portion 324 has a diameter of about one and one-half inches, and the disk reduced-diameter cylindrical portion 326 has a diameter of about one and one-quarter inches. The thickness of the disk 322 is three-eighths of an inch. Each hole 330 is three-tenths of an inch in diameter.

The insulation 314 includes a tubular sleeve 332 and an enlarged diameter collar 334 that threads onto the upper end of sleeve 332. The sleeve 332 includes the threaded portion 318 and the flange 318, and closely receives the rod 320. The collar 334 is spaced away from the sleeve flange 318 and includes an undercut top opening 336 that closely receives the disk flange portion 324, with the upper disk surface 328 slightly proud of the collar 334. The collar 334 covers the annular surface of the disk flange portion 324 not covered by disk portion 326 as can be seen in Figure 7.

A number of flow channels 338 extend axially between the sleeve 332 and the collar 334 and are aligned with respective disk holes 330. In the illustrated embodiment the flow channels 338 are each formed by a groove or indentation formed on the outside of the sleeve 332. The holes 330 and the flow channels 338 fluidly communicate the surface 328 with the back side 340 of the collar 334.

The operation of the plasma electrode 310 is similar to that of a single conductor 28 of the plasma electrode 16. The upper disk surface 328 is the active electrode surface. The disk surface 328 is predominately a generally flat, planar surface having a circular perimeter.

When the power supply 22 is energized, a plasma field at the active electrode surface 328 is generated that heats the electrolyte in the vicinity of the plasma field. The heated electrolyte can circulate by natural convection away from the active electrode surface 328. Cooler electrolyte can circulate from the bottom side 340 of the collar 334, through the flow channels 338 and be discharged through the disk openings 330 to replace the heated electrolyte and more efficiently transfer heat from the plasma field to the electrolyte. This "chimney-type" induced circulation or draft also assists in cooling the active electrode surface 328. The axial length of the collar 334 assures that the electrolyte adjacent the collar bottom side 340 is away from the plasma field and is cooler than the heated electrolyte at the plasma field. If desired, additional axial through-holes could extend through the outer radial portion of the collar 334 to assist this circulation.

Thermal expansion of the metal disk 322 compresses the metal disk 322 against the collar 334. The axial component of the expansion urges the disk flange 324 against the overlying upper end of the collar 334, forming a tight joint between them that resists leakage of electrolyte into the collar top opening 336.

The perforated plasma electrode 310 exhibited a long operating life as compared to a conventional non-perforated or solid plasma electrode. For example, the plasma electrode 310 generated a plasma field that transferred about 160,000 BTUs per hour to the electrolyte, enough to heat an average-sized home. The electrolytic cell generated heated electrolyte that flowed to a heat exchanger where heat is transferred from the

electrolyte. The electrolyte was returned back to the electrolytic cell for reheating by the plasma field, forming a closed-loop heating system.

The long operating life of the plasma electrode enables practical and economical use of the electrolytic cell as part of a home heating system or other process system utilizing heated liquid as a source of heat transfer.

Inspection of the plasma electrode 310 after the over 107 hours of continuous operation revealed no signs of mechanical erosion, corrosion, plating, or metal buildup on the active electrode surface 330. Applicants believe that the plasma field is being generated on the active electrode surface 328 at sites surrounding the holes 330. By distributing generation of the plasma field to multiple sites on the active electrode surface 328, erosion, degradation, and plating of the active electrode surface is greatly reduced as compared to conventional plasma electrode constructions.

Figure 8 illustrates a closed-loop home heating system 410 incorporating an electrolytic cell 412 that includes the plasma electrode 310 as described above connected to the power supply 22. The long operating life of the plasma electrode 310 renders use of a plasma field to provide a continuous source of heated working fluid a practicality. Steam and hot electrolyte generated during operation of the cell 412 flows to a heat exchanger 414 that transfers heat from the flow for use in heating the home in a conventional manner. The flow continues from the heat exchanger 414 to a reservoir tank 416 located vertically above the electrolytic cell 412. Electrolyte flows by gravity feed out of the reservoir tank 416 and back into the electrolytic cell 412. A filter (not shown) can filter the electrolyte returning to the electrolytic cell 412.

It is believed that the high temperature of the plasma field efficiently transfers heat to the electrolyte, and that the improved circulation of the electrolyte in the vicinity of

the active electrode surface 328 further increases the efficiency of heat transfer from the plasma to the electrolyte as compared to conventional electrolytic cells.

The electrolytic cell 412 includes one plasma electrode 310. In other possible embodiments the electrolytic cell 412 can have multiple plasma electrodes 310. The number of plasma electrodes 310 active at any instant can be regulated by a control system as previously described above to meet the thermal demand.

Figures 9-11 illustrate a plasma electrode 510 used as a cathode in a fifth embodiment electrolytic fuel cell.

The plasma electrode 510 includes an elongate metal conductor 512 surrounded by solid virgin PTFE insulation 514. The insulation 514 is formed as a uniform-diameter cylinder and includes a radially-enlarged flange 516 similar to the flange 318 and abuts against the bottom of the tank to divide the insulation into an internal portion 514a in the tank and an external portion 514b outside the tank. The free end portion 518 of the insulation portion 514b outside of the tank is externally threaded for connection to a fluid conduit as will be described later below.

The conductor 512 is an elongate metal rod 520 that is similar to the conductor rod 320. Unlike the rod 320, the conductor rod 520 is located in a radially-outer portion of the insulation 514 and mechanically and electrically connects to a metal annular disk 522. The disk 522 is positioned within a centered undercut opening in the insulation 514 as previously described above. The disk 522 is identical to the disk 322 except that the rod 520 connects to the radially outer portion of the disk 522. The rod 520 extends from the disk 522 sufficiently past the flange 318 and into insulation portion 514b. This enables a metal rod 524 outside of the tank to extend into the outer insulation 514b and electrically connect the rod 520 with the remainder of the circuit to the power supply.

A number of flow channels 526, similar to the flow channels 328, extend axially through the entire length of the insulation 514. The flow channels 526 are aligned with and coaxial with respective holes in the disk 522.

Figure 12 illustrates a portion of the fifth embodiment fuel cell 610 forming part of a closed-loop home heating system otherwise similar to the home heating system 410. The fuel cell 610 includes the plasma electrode 510 as a cathode and an electrode 612 as an anode. The electrodes 510, 612 are electrically connected to the power supply as previously described. The electrode 612 is similar to the electrode 510 but does not include flow channels in the insulation or openings extending through the metal disk.

The plasma electrode 510 extends through an upper wall (with respect to gravity) of the tank 614, and the anode electrode 612 extends through a lower wall of the tank 614. The tank 614 holds about two liters of electrolyte. The electrodes 510, 612 are coaxial with one another, with the metal disks of the electrodes facing each other and spaced vertically about one-and-one half inches apart. The upper or outer insulation portion 518 of the electrode 510 threads into a pipe 616 that extends to the heat exchanger 618, the heat exchanger 618 identical to the heat exchanger 414.

During operation of the fuel cell 610, a plasma field 620 is generated on the active plasma surface of the cathode disk 522 as already described. The plasma field 620 is located between the electrodes 510, 612. The plasma field 620 heats the electrolyte and generates steam between the electrodes 510, 612. The steam, in cooperation with the flow resistance through the closed-loop system, raises the operating pressure within the tank 614 to about 1.35 pounds per square inch above atmospheric pressure. The steam and natural convection (indicated by the arrows in Figure 12) also urges heated electrolyte, as well as the steam itself, located between the electrodes 510, 612 to enter through the openings the

electrode disk 522 and flow through the flow openings 526 to the heat exchanger 618 without the use of a pump.

The electrode 510 itself structurally forms the part of the closed flow loop flowing heated electrolyte and steam out of the tank 614. This maximizes the temperature of the fluid discharged from the tank 614 since the discharge is not of electrolyte remote from the plasma field. An additional advantage of this construction is that steam and electrolyte entering the holes in the disk 522 pass through the plasma field 620.

Tests conducted by the applicants disclosed essentially no free hydrogen gas being generated by the fuel cell 610. It is theorized that by having the flow discharge pass through the plasma field 620, any free hydrogen that might be generated by electrolysis is in effect "burned off" by the plasma field 620. At current energy prices, operation of the fuel cell 610 to heat the electrolyte was economically competitive with comparably sized propane-fired or oil-fired heating systems.

Figure 13 illustrates an electrolytic cell 710 that can be used in the closed-loop heating system described above. The electrolytic cell 710 forms part of the flow path of the closed-loop heating system so that the flow of electrolyte moves through the plasma field before reaching the heat exchanger, thereby further increasing the efficiency of the heating system.

The cell 710 includes a plasma electrode 712 formed as a cathode and connected to a negative terminal of a DC power supply (similar to the power supply 22 described earlier) by a negative lead wire 714. The illustrated DC power supply 22 is a THERMAL DYNAMICS CUTMASTER 8200 Power Supply manufactured by Thermodyne Industries, Inc., St. Louis, Missouri, but equivalent or other DC power supplies can be used. The other electrode 716 is formed as an anode and is connected to a

positive terminal of the DC power supply by a positive lead wire 718.

The cathode 712 and the anode 716 are mechanically supported by a tubular insulating body 720 formed preferably from virgin PTFE insulation (brand name TEFLON). The insulating body 720 is an elongate member having an interior bore 722 that extends the length of the body. The illustrated bore 722 is one-and-one-half ($1\frac{1}{2}$) inches in diameter. The upper end portion 723 of the body 722 has external threads 724 for mounting through the wall of a tank that holds the electrolyte as will be explained in further detail below.

The cathode 712 is carried within the body 720 and is spaced two (2) inches from the lower end 726 of the body 720. The cathode 712 is formed as a circular copper disk that has an outer radius of one-and-eleven-sixteenths ($1\frac{11}{16}$) inches and an inner radius of one-and-three-sixteenths ($1\frac{3}{16}$) inches and an axial length of about one-eighth ($\frac{1}{8}$) inch. The cathode 712 is centered in the bore 722 and extends radially one-thirtyseconds ($\frac{1}{32}$) inches into the bore 722.

The anode 716 is located on the lower end 726 of the body 720 and is also formed as a circular disk. The anode 716 has an outer diameter equal to the outer diameter of the body 720 and an inner diameter of three-quarters ($\frac{3}{4}$) of an inch. The anode 716 is centered along the axis of the body 720.

The lead wires 714, 718 extend into the body 720 a short distance below the threaded upper body portion 723 and extend through the body 720 to form electrical connections with the cathode 712 and the anode 716 respectively as shown in Figure 13.

As shown in Figure 14, the electrolytic cell 710 is located within a tank 728 that is essentially filled with the electrolyte 730. The threaded body portion 723 extends through an upper wall of the tank 728 and engages corresponding threads formed in the wall to form a watertight seal between the electrolytic cell 710 and the tank wall. The

electrolytic cell 710 forms part of a flow path that extends from the tank 728 to a pump 732, and from the pump 732 to a heat exchanger 734, and back to the tank 728.

In operation, the DC power supply generates a plasma field on the active, wetted surface of the cathode 712. The pump 730 flows electrolyte out of the tank 728 through the cell bore 722, the electrolyte leaving the tank being forced to flow through the plasma field at the cathode 712. The electrolyte flowing through the cell bore 722 is heated by the plasma field shortly before being discharged from the tank 728. The heated electrolyte flows from the pump 730 to the heat exchanger 372 where heat is extracted from the electrolyte (for space heating, process heating, or the like). The cooled electrolyte then flows back into the bottom of the tank 728 to complete the closed loop flow path.

The electrolytic cell 710 has a number of advantages. The electrolyte cell forms a one-piece electrode module that includes both the anode and cathode, making installation and replacement of the anode and cathode easy and efficient. The anode and cathode are held in a fixed relationship facing one another and in the line of sight of one another by the insulating body. Electrolyte flowing out of the tank must flow through the plasma field shortly before leaving the tank, so the temperature of the electrolyte flowing to the heat exchanger is maximized. The anode defines an opening constriction for the flow of electrolyte into the bore 722. This constriction generates narrowed flow lines where the electrolyte flows past the cathode, reducing drag across the cathode.

The dimensions given for the illustrated electrolytic cell 710 are for illustration only, and not intended to be limiting. Generally, the faster the flow velocity of the electrolyte through the cathode, the nearer the cathode should be located from the anode.

Figure 15 illustrates an electrolytic cell 810 similar to the electrolytic cell 710, the corresponding elements numbered using the same reference numerals as used in describing the cell 710. Only differences between the cell 710 and the cell 810 will be discussed. In the cell 810, the cathode 712 and its lead wire 714 are located outside of and spaced away from the insulating body 720. The cathode 712 faces the anode 716 but is spaced away from the body 720 by a support member (not shown). The body 720 and the anode 716 form part of the flow path as previously described and so heated water must still flow through the anode 716 before being discharged from the tank 728. If desired, the cathode 712 can be formed as an annular body to permit flow through the cathode 712.

Figure 16 illustrates the lower end portion of an electrolytic cell 910 that is partially immersed in the electrolyte. The electrolytic cell 910 can be used instead of the electrolytic cell 710 in the system shown in Figure 14. The electrolytic cell 910 has a cathode 912 similar to the cathode 712 of the cell 810, an anode 914, an outer insulating or dielectric body 916, and an inner insulating or dielectric body 918. The upper end portions of the anode 914 and/or the bodies 916, 918 can be threaded for mounting the electrolytic cell 910 in the electrolyte.

The anode 914 is formed as an electrically conductive tube having an inner wall 920, an exterior wall 922, and an end surface 924 facing the cathode 912.

The outer insulating body 916 is a tubular body having an inner wall 926 and an outer wall 928. The inner wall 926 is in contact with substantially the entire outer cathode wall 922 (the exception being where a lead wire 927 that functions similarly as the lead wire 718 extends from the anode 914 and through the body 916. The lead wire 927 can be out of the electrolyte where it emerges from the outer insulating body 916). The insulating body 916 extends beyond the end surface 924 and has a reduced diameter, circularly cylindrical free

end portion 929 defining an annular surface 930 abutting and covering the end surface 924 of the cathode 912. The end portion 929 has an inner wall 932 defining a reduced diameter portion of the insulating body 916.

The inner insulating body 918 is a tubular body disposed inside the anode 914. The inner insulating body 918 has an outer wall 934 and an inner wall 936. The outer wall 934 is in contact with all but the lower end portion 938 of the cathode 914 that includes the end surface 924. The inner wall 936 has, in the illustrated embodiment, about the same diameter as the wall 932 of the outer insulating body 916.

The end portion 929 of the outer insulating body 916 is disposed between the cathode 912 and the anode end surface 924 facing the cathode 912. The inner wall 932 of the outer insulating body portion 929, the inner wall of the lower end portion 938 of the anode 914, and the inner wall of the inner insulating body 918 are in contact with the electrolyte and form part of the flow path as previously described, and so electrolyte must still flow through the anode 914 before being discharged from the tank 728.

The electrolytic cell 910 can be disposed in a housing that has an inlet immersed in the electrolyte that assists in defining a flow path forcing electrolyte to flow from the inlet, between the cathode 912 and the anode 914, and through the flow path defined in parts by the outer insulating member 916, the anode 914, and the inner insulating member 918 as described above.

If desired, the cathode 912 can be formed as an annular body to permit flow through the cathode 912.

Although insulation or dielectric covers the end surface 924 as shown in Figure 16, it was found that covering the end surface 924 with insulation or dielectric still resulted in a plasma field being generated in the electrolyte. Shrouding the anode from the cathode with insulation or dielectric reduced the rate of wear of the anode as compared to an

unshrouded anode. The mechanism or underlying cause for the improved wear is not yet understood.

The illustrated embodiments of a closed loop heating system utilize a pump to mechanically generate hydraulic head urging fluid flow. In other embodiments other known methods of generating hydraulic head, including gravity-induced flow or flow induced by temperature or pressure gradients in the system, can be adapted for use with heating systems utilizing electrolytic cells of the type disclosed herein.

While we have illustrated and described one or more embodiments, it is understood that these are capable of modification, and we therefore do not wish to be limited to the precise details set forth, but desire to avail ourselves of such changes and alterations as fall within the purview of the following claims.

CLAIMS:

1. An electrolytic cell for the generation of a plasma field on an active surface of a plasma electrode in an electrolyte, the electrolytic cell comprising:

a vessel containing a liquid electrolyte, a first tubular body immersed in the electrolyte, a plasma electrode immersed in the electrolyte, a second electrode immersed in the electrolyte spaced from the plasma electrode, a power supply, and a circuit extending from the plasma electrode and the second electrode to the power supply and electrically connecting the plasma electrode, the second electrode, and the power supply;

the plasma electrode being a tubular body comprising an inner wall defining an opening extending through the body and comprising a first end, the first end having a surface facing the second electrode, at least a portion of the inner wall being disposed in contact with the electrolyte;

the first tubular body being an electrical insulator and comprising an inner wall defining an opening through the first tubular body, at least a portion of the inner wall of the first tubular body being disposed in contact with the electrolyte;

the plasma electrode being in contact with the first tubular body;

the said at least a portion of the inner wall of the first tubular body being adjacent to the said at least a portion of the inner wall of the plasma electrode wherein the said wall portions cooperatively define a flow path extending therethrough that is surrounded by said wall portions.

2. The electrolytic cell of claim 1 wherein the first tubular body is disposed inside of the plasma electrode.

3. The electrolytic cell of claim 2 wherein the first tubular body includes a first end disposed inside of the plasma electrode and spaced from the first end of the plasma electrode, the said at least a portion of the wall of the plasma wall extending from the first end of the first tubular body to the first end of the plasma electrode

4. The electrolytic cell of claim 3 comprising a second tubular body immersed in the electrolyte, the second tubular body being an electrical insulator, the plasma electrode being disposed inside of the second tubular body.

5. The electrolytic cell of claim 4 wherein the second tubular body extends from the first end of the plasma electrode beyond the plasma electrode and covers the surface of the first end of the plasma electrode.

6. The electrolytic cell of claim 1 wherein the plasma electrode is disposed inside of the first tubular member.

7. The electrolytic cell of claim 6 wherein the first tubular member comprises an end portion extending from the first end of the plasma electrode beyond the plasma electrode to an end of the first tubular member, the said at least a portion of the wall of the first tubular member extending from the end of the first tubular member to the first end of the plasma electrode.

8. The electrolytic cell of claim 6 wherein the end portion of the first tubular member defines a reduced diameter portion of the first tubular member.

9. The electrolytic cell of claim 1 wherein the first tubular member extends to a first end, the plasma electrode being outside of the first tubular member next to the first end of the first tubular member.

10. The electrolytic cell of claim 1 wherein the second electrode is an annular body surrounding a through-opening, the second electrode being disposed in the first tubular body spaced from the plasma electrode, the opening of the second electrode in the first tubular body.

11. The electrolytic cell of claim 1 wherein the circuit comprises a circuit portion that extends from the plasma electrode, the circuit portion located in the first tubular body and not wetted by the electrolyte.

12. The electrolytic cell of claim 1 wherein the opening of the plasma electrode has a first cross-sectional area and the opening of the first tubular body has a second cross-sectional area different from the first cross-sectional area.

13. The electrolytic cell of claim 1 wherein the first tubular member shrouds the plasma electrode from the second electrode.

14. A closed-loop heat transfer device comprising:
a heat exchanger, an electrolytic cell, the electrolytic cell including a tank containing a liquid electrolyte, a first flow path extending from the electrolyte in the tank to the heat exchanger, and a second flow path extending from the heat exchanger to the electrolyte;

the electrolytic cell further comprising a plasma electrode and a second electrode spaced from the plasma electrode, each electrode immersed in the electrolyte, a power supply, and a circuit electrically connecting the power supply with the plasma electrode, the second electrode, and the electrolyte, the power supply capable when energized of generating a plasma field on the plasma electrode; and

the plasma electrode surrounding a portion of the first flow path wherein electrolyte flowing from the tank to the heat exchanger must flow through the plasma electrode.

15. The heat transfer device of claim 14 further comprising an insulated first tubular member in contact with the plasma electrode, the first tubular member being an electrical insulator, the first tubular member forming a portion of the first flow path.

16. The heat transfer device of claim 15 wherein the plasma electrode is disposed inside of the first tubular member.

17. The heat transfer device of claim 16 comprising a second tubular member inside of the plasma electrode, the second tubular member being an electrical insulator.

18. The heat transfer device of claim 15 wherein the plasma electrode is outside of the first tubular member next to an end of the first tubular member.

19. The heat transfer device of claim 18 wherein the second electrode is inside of the first tubular member and is disposed along the first flow path.

20. The heat transfer device of claim 15 wherein the first tubular member shrouds the plasma electrode from the second electrode.

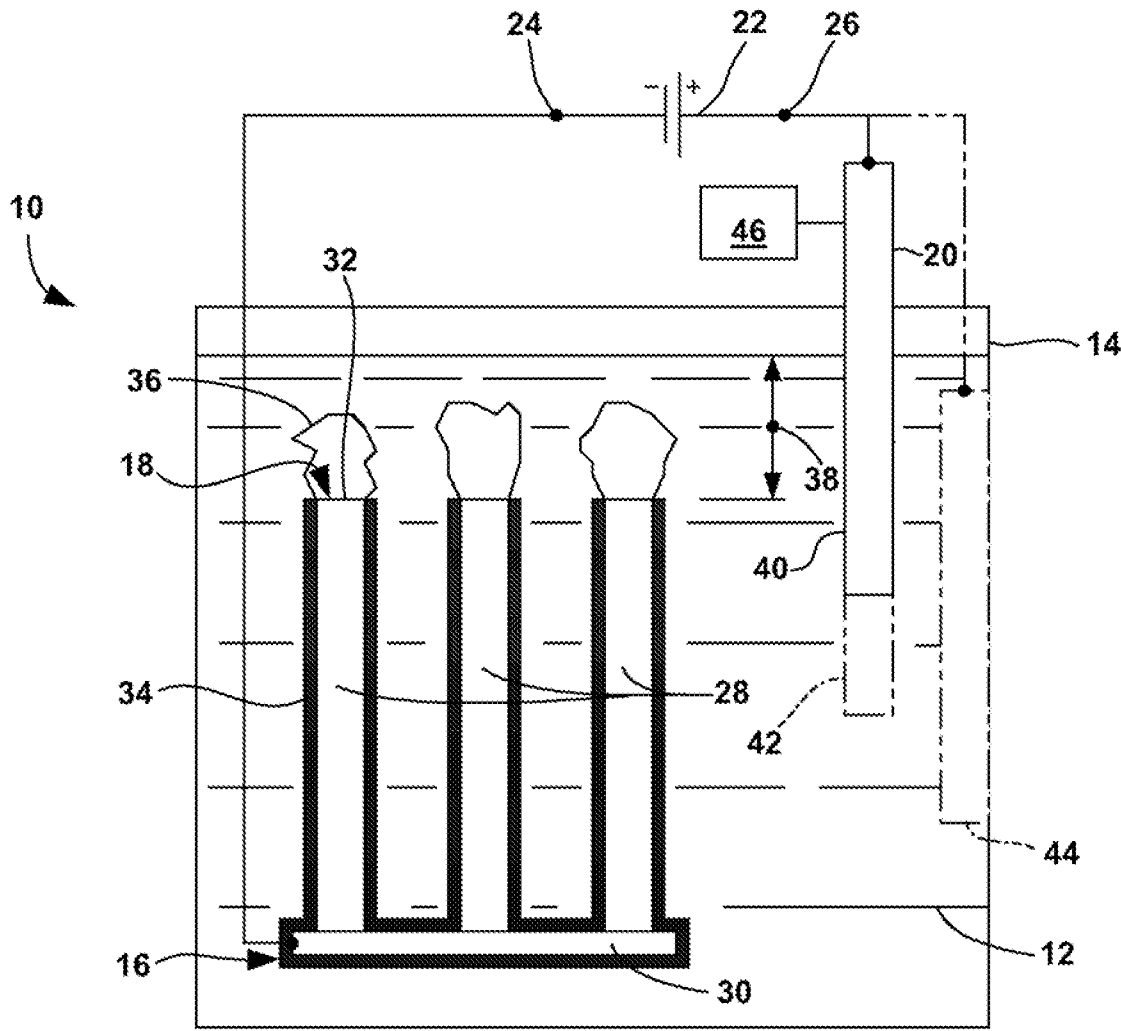
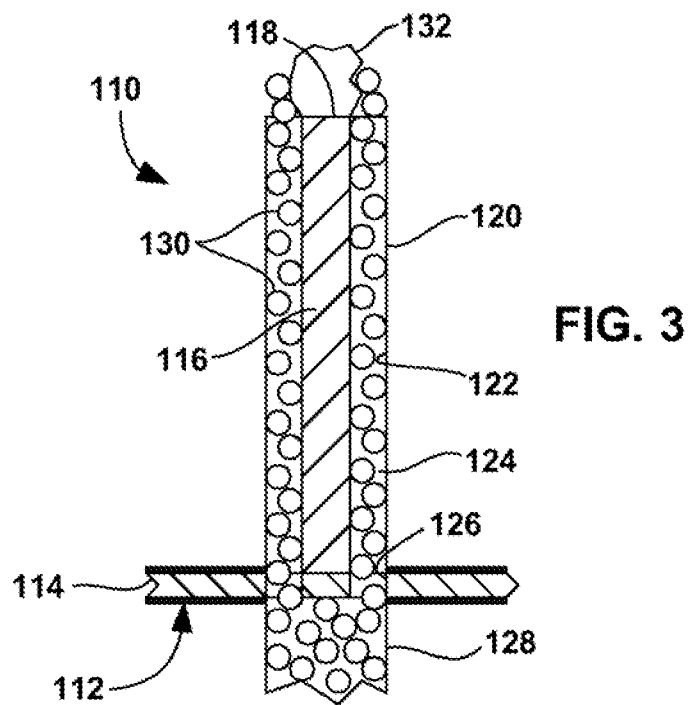
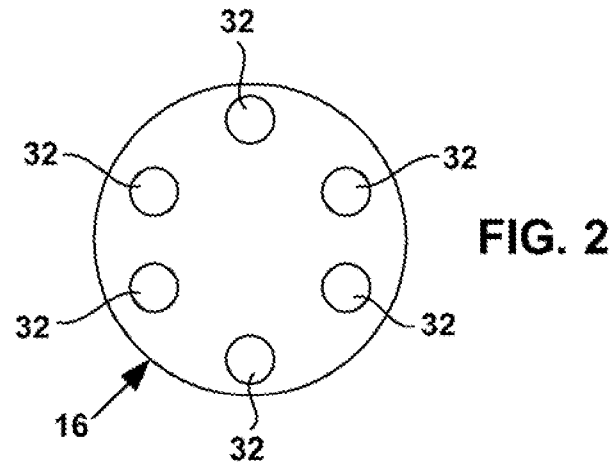


FIG. 1

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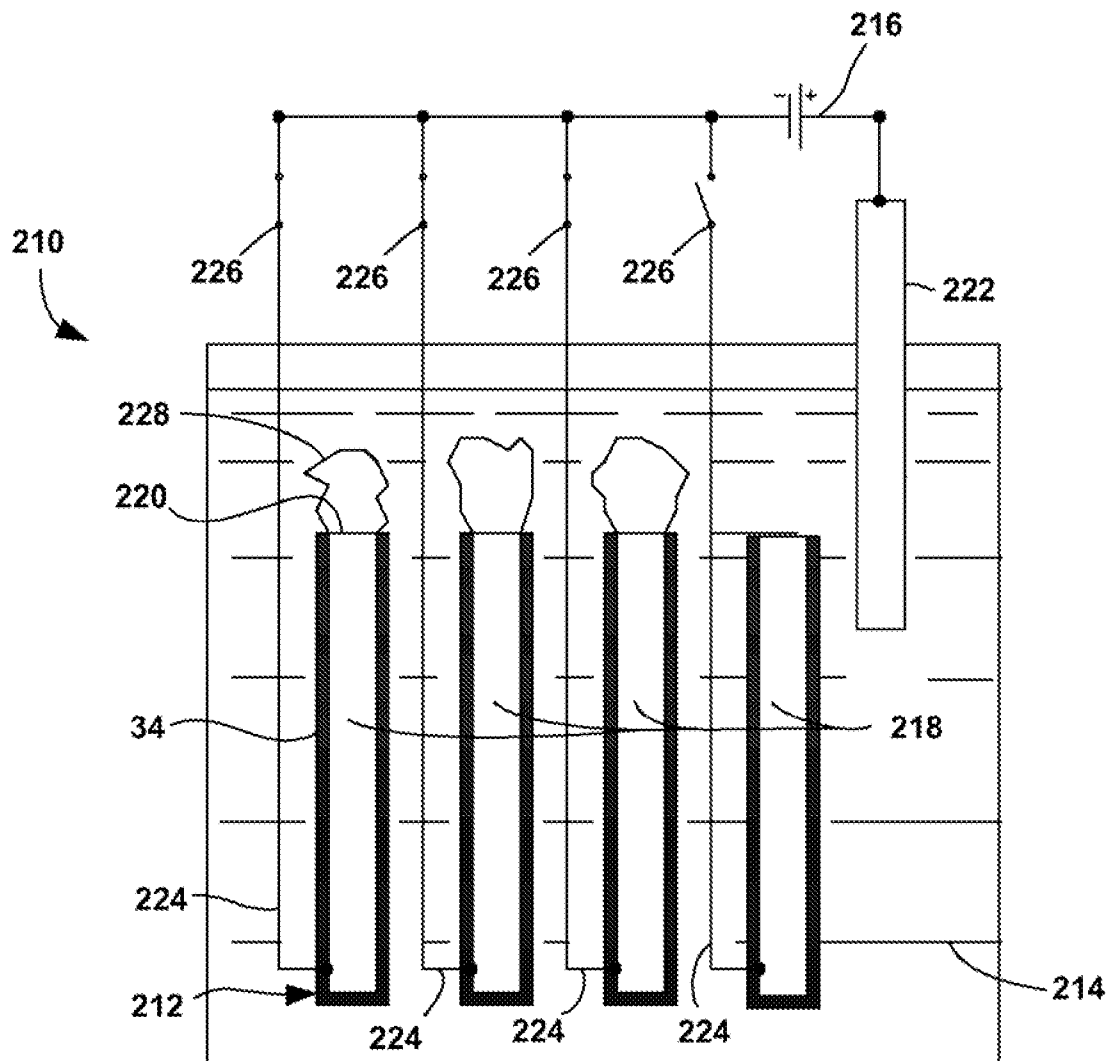


FIG. 4

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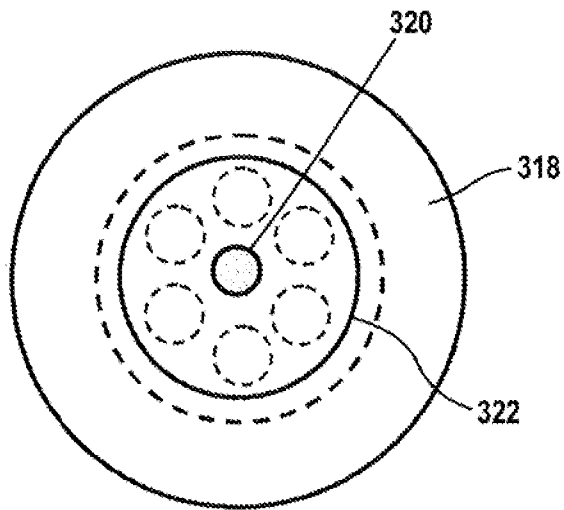


FIG. 6

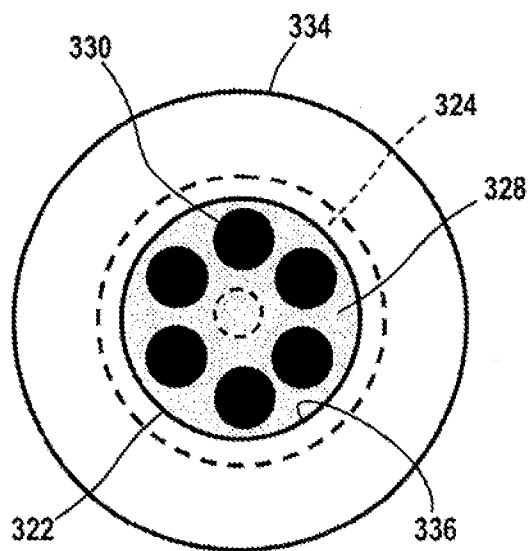


FIG. 7

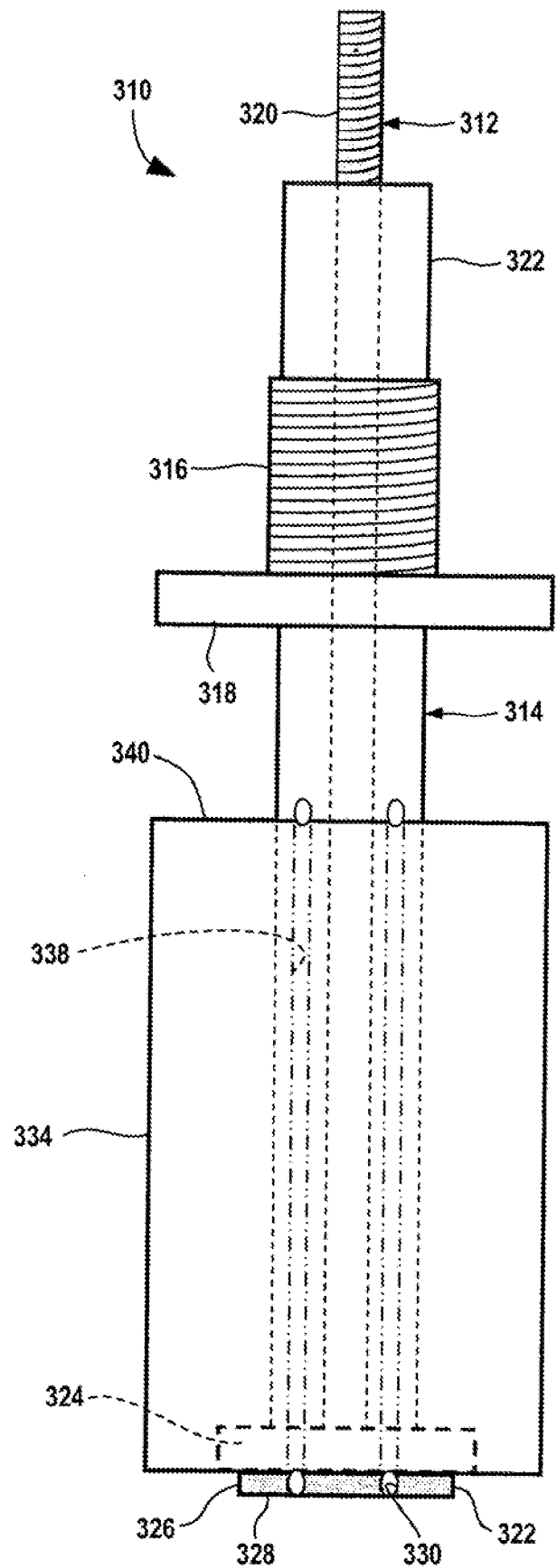


FIG. 5

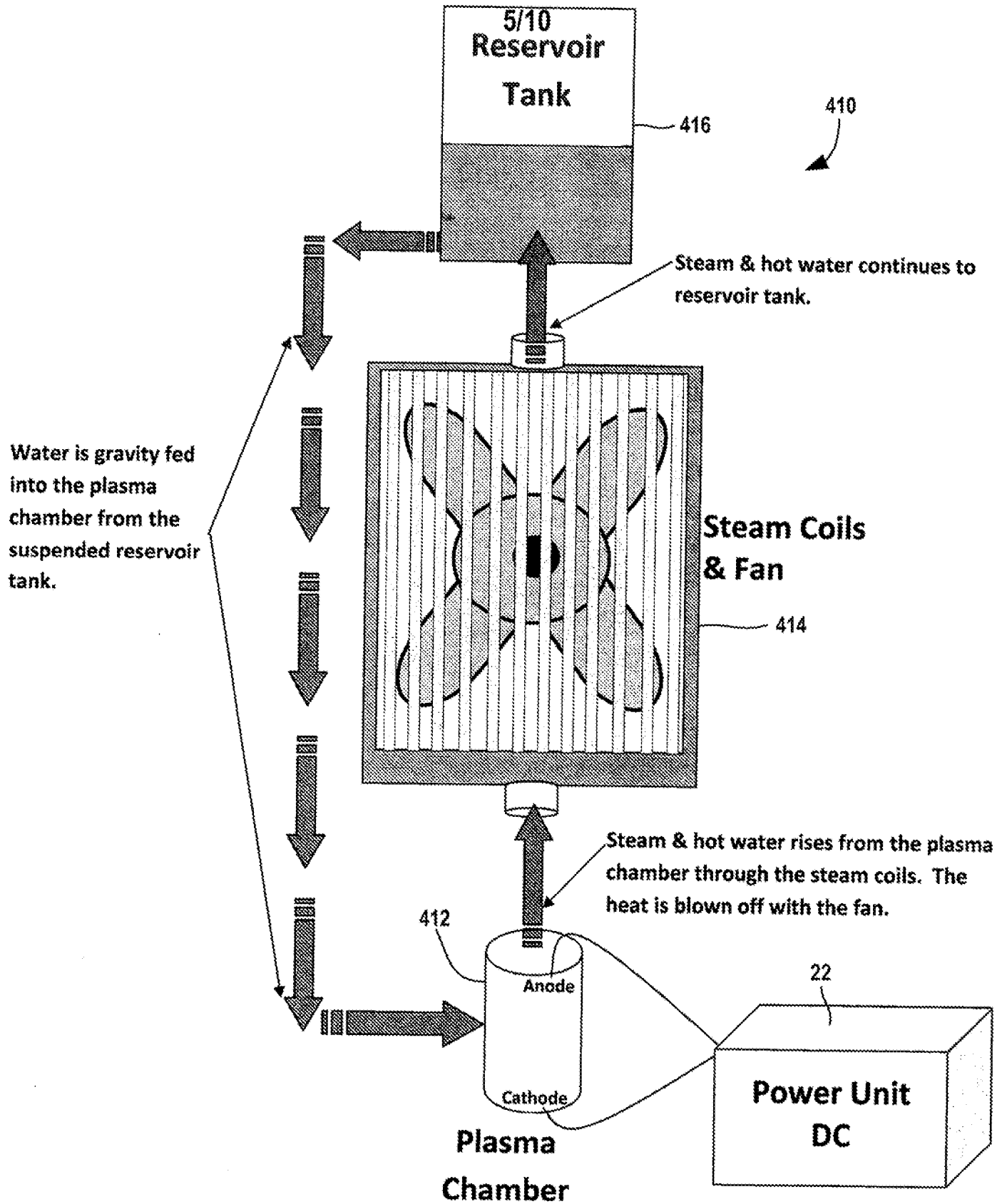


FIG. 8

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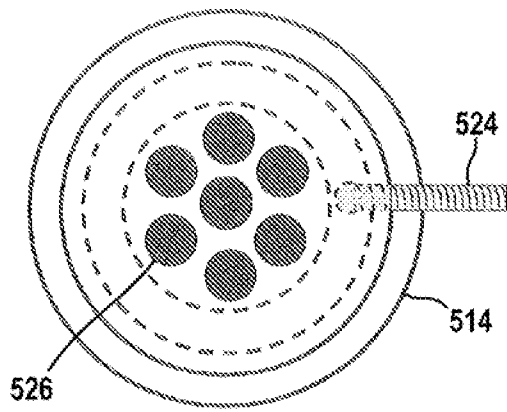


FIG. 10

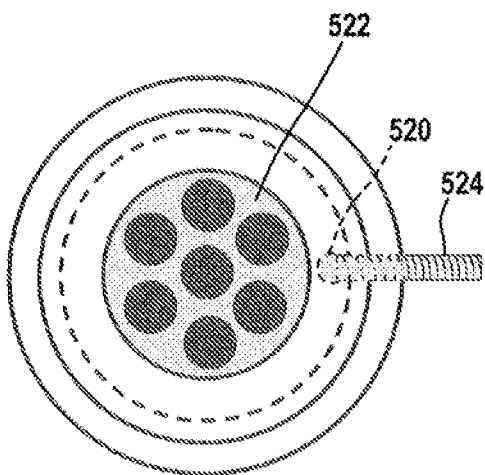


FIG. 11

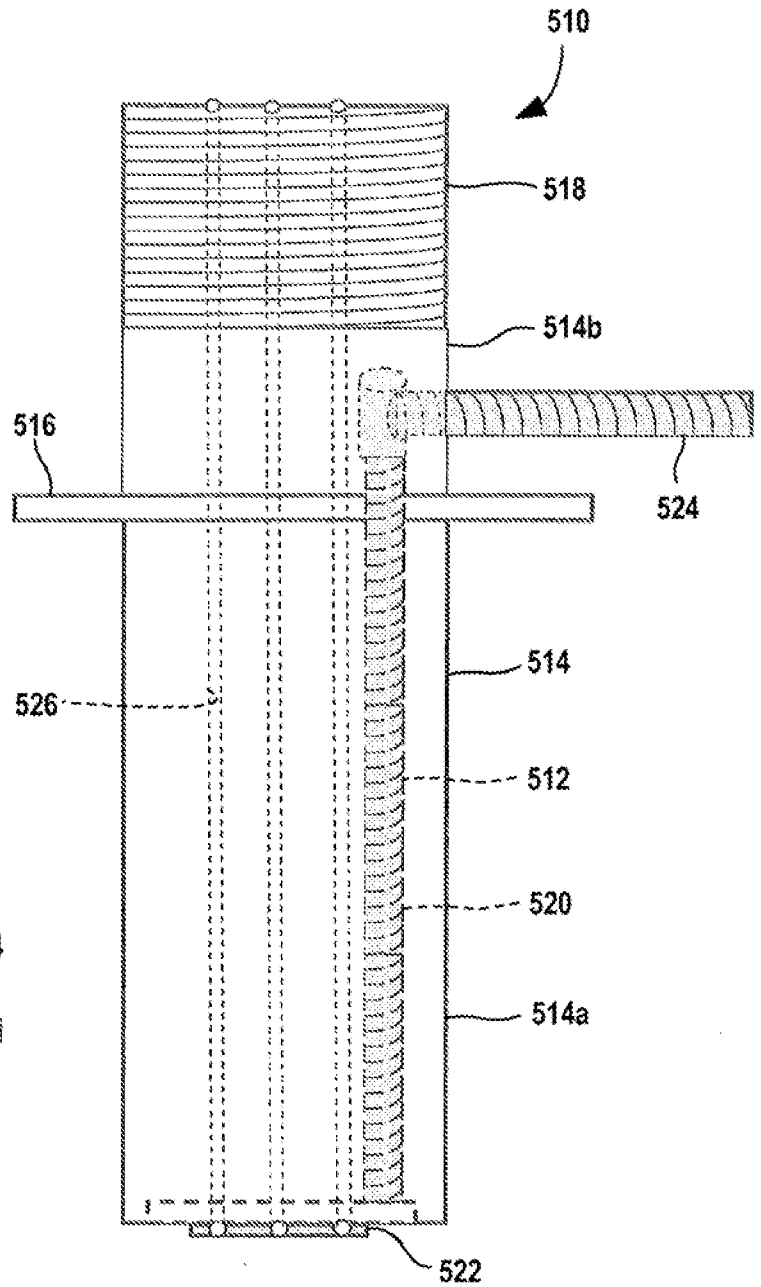


FIG. 9

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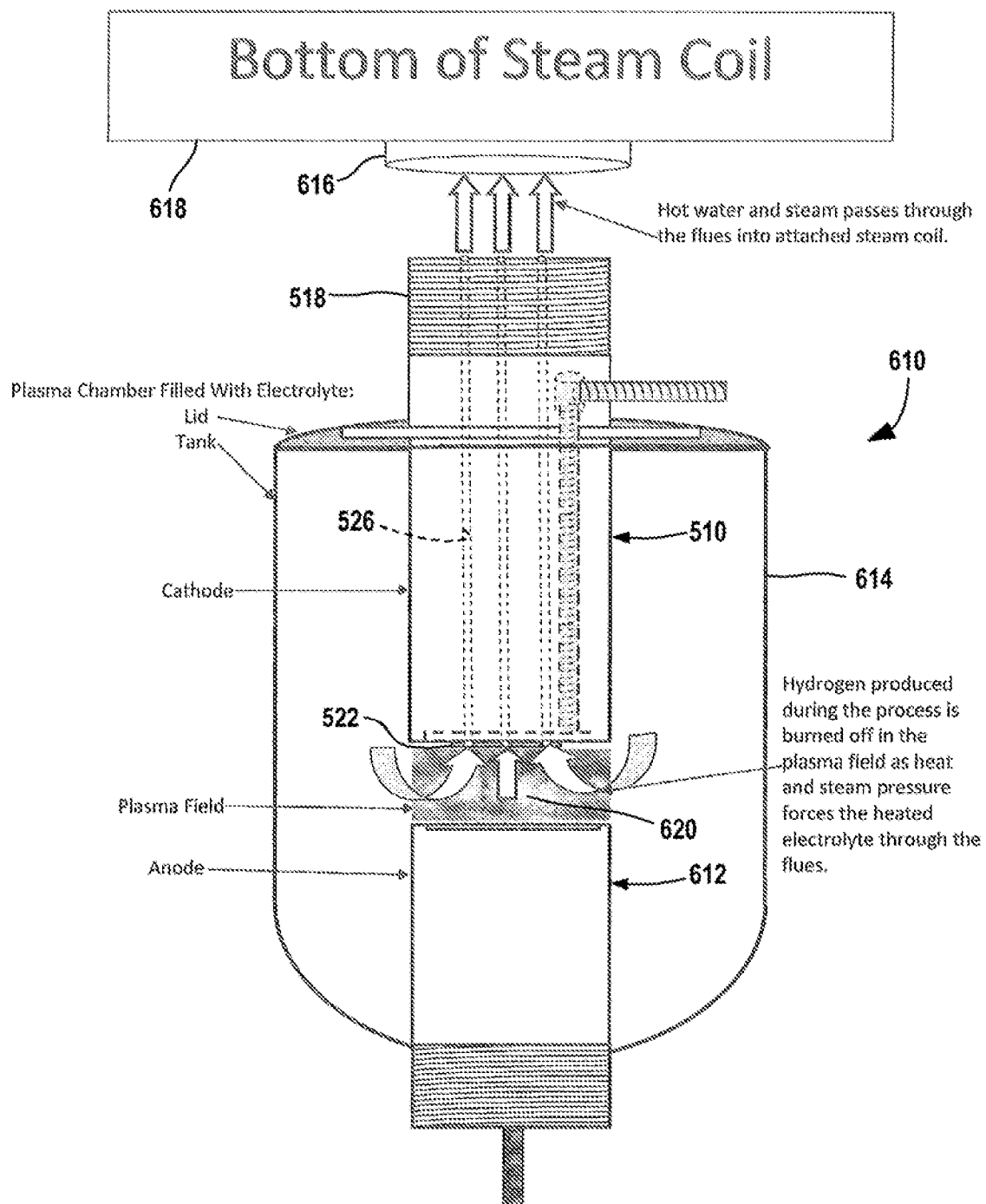


FIG. 12

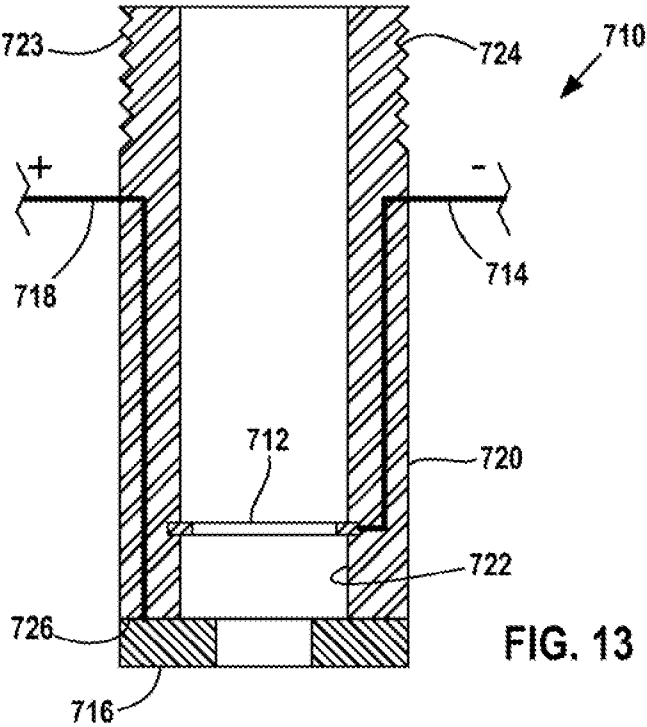


FIG. 13

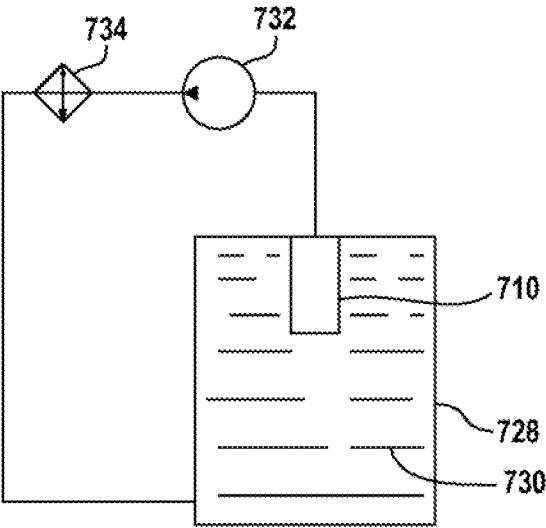
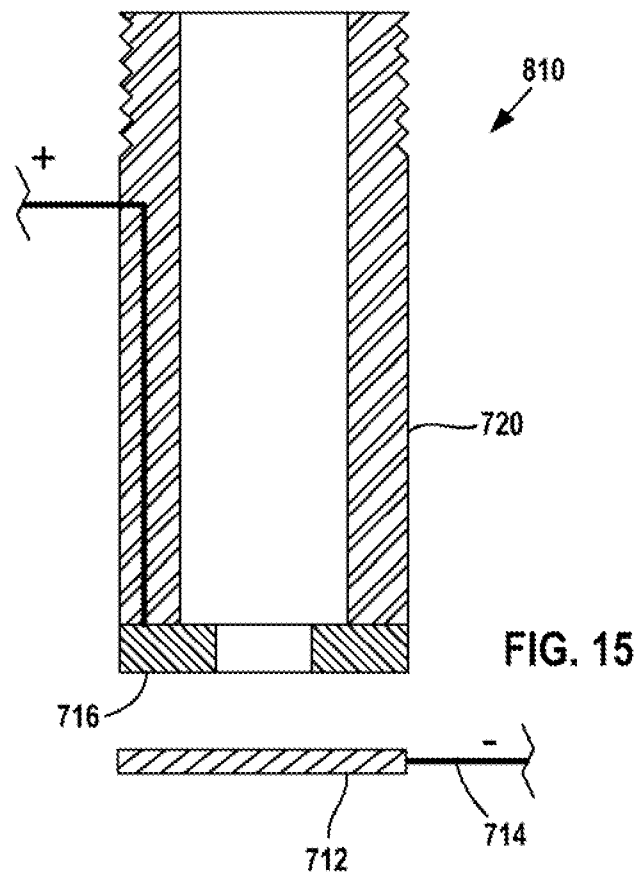


FIG. 14



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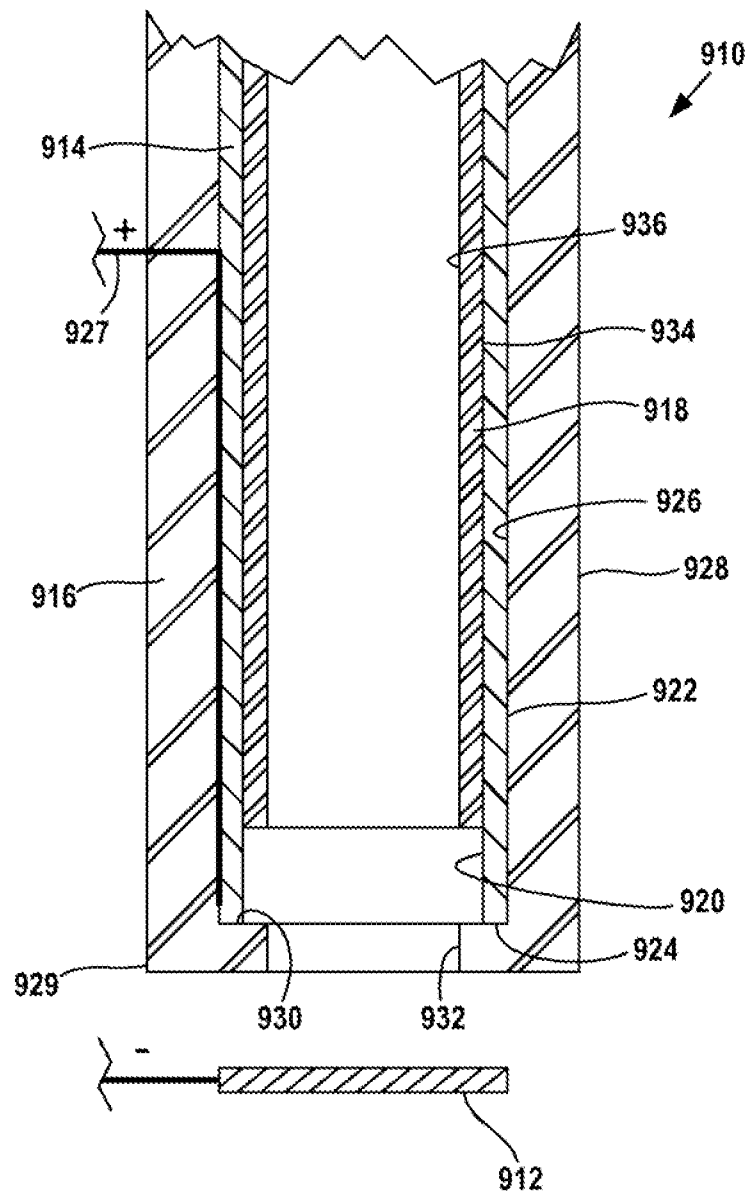


FIG. 16