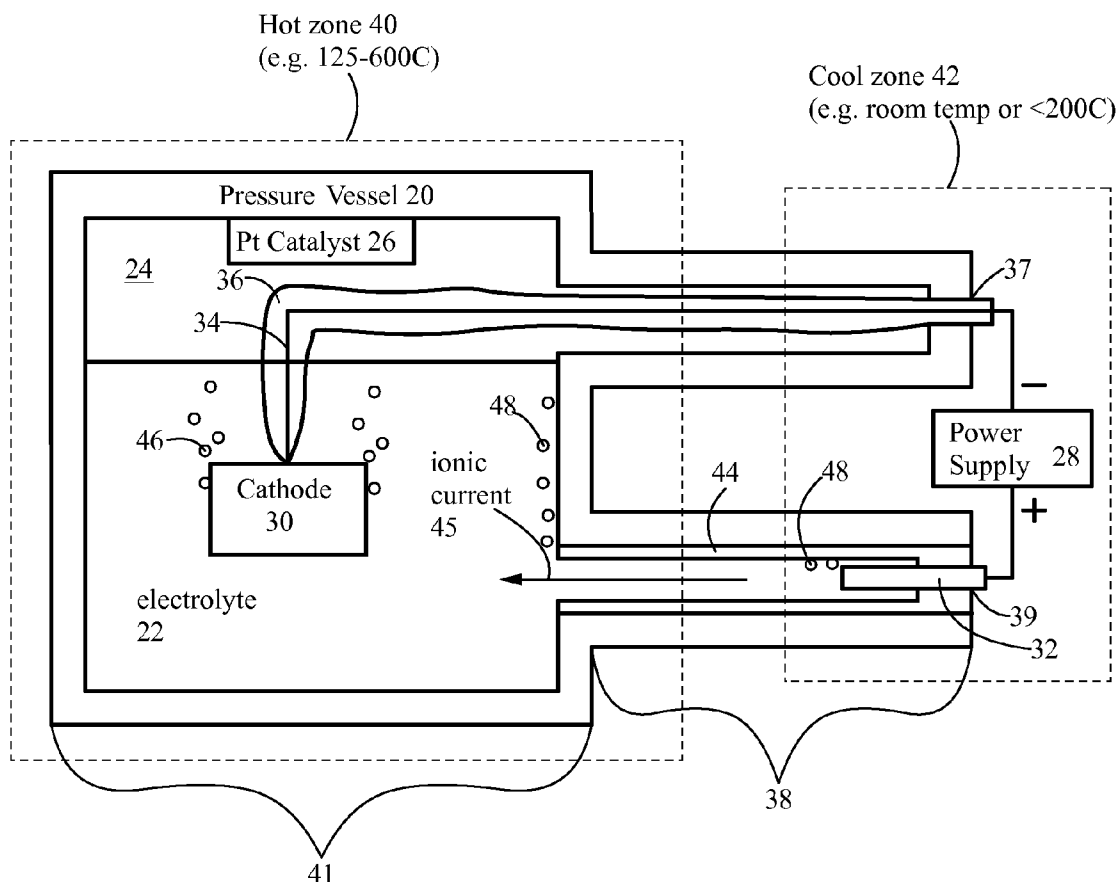




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(19) **United States**(12) **Patent Application Publication**
Steinberg(10) **Pub. No.: US 2015/0136588 A1**(43) **Pub. Date: May 21, 2015**(54) **APPARATUS WITH COLD ANODE FOR
HIGH-TEMPERATURE ELECTROLYTIC
HYDROGEN LOADING AND HYDROGEN
GENERATION**(71) Applicant: **Dan Steinberg**, Blacksburg, VA (US)(72) Inventor: **Dan Steinberg**, Blacksburg, VA (US)(21) Appl. No.: **14/082,184**(22) Filed: **Nov. 17, 2013****Publication Classification**(51) **Int. Cl.**
C25B 13/00 (2006.01)
C25B 1/04 (2006.01)(52) **U.S. Cl.**
CPC .. **C25B 13/00** (2013.01); **C25B 1/04** (2013.01)(57) **ABSTRACT**

An apparatus comprising a vessel containing an electrically conductive electrolyte. The electrolyte contains hydrogen. A cathode and anode are disposed in the electrolyte and are connected to a source of electrical power. A portion of the vessel interior is in a hot zone, and a portion is in a cool zone. The cathode is disposed in the hot zone and the anode is disposed in the cool zone. The electrolyte is in contact with both the cathode and anode and is continuous between the cathode and anode such that it conducts an electrical current between the cathode and anode. Because the anode is at a temperature lower than the cathode, anodic corrosion is greatly reduced and the apparatus can be operated continuously for long periods.



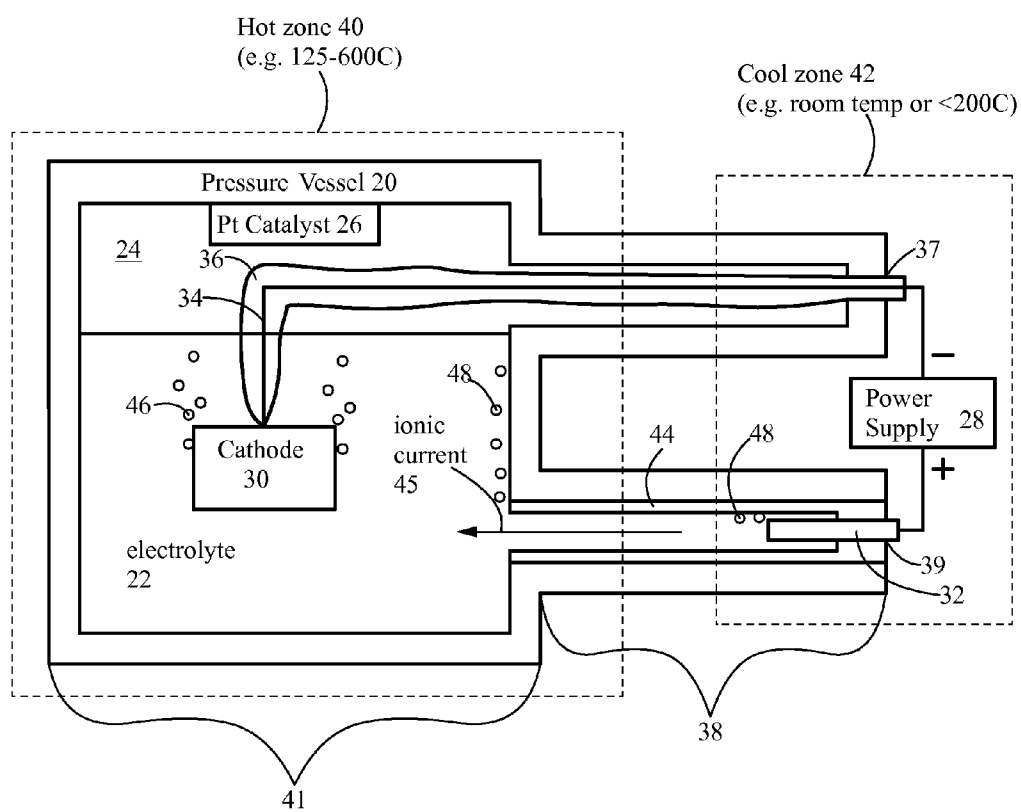


Fig. 1A

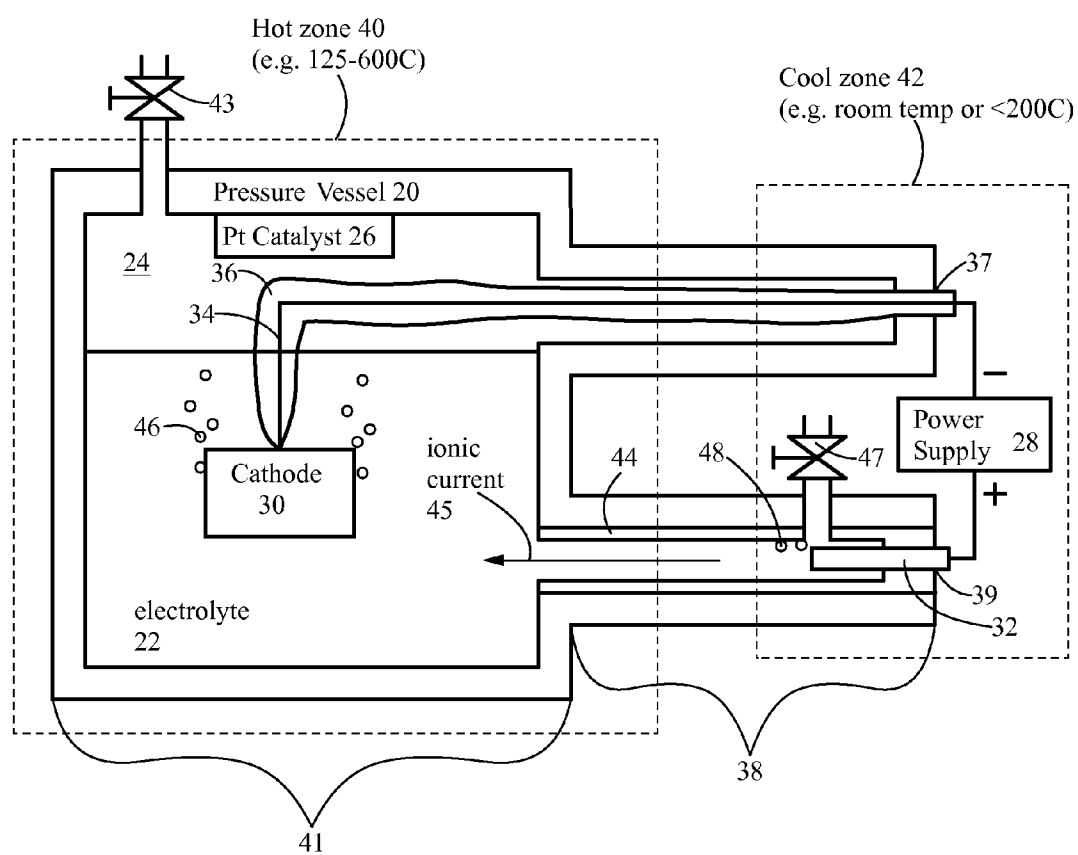


Fig. 1B

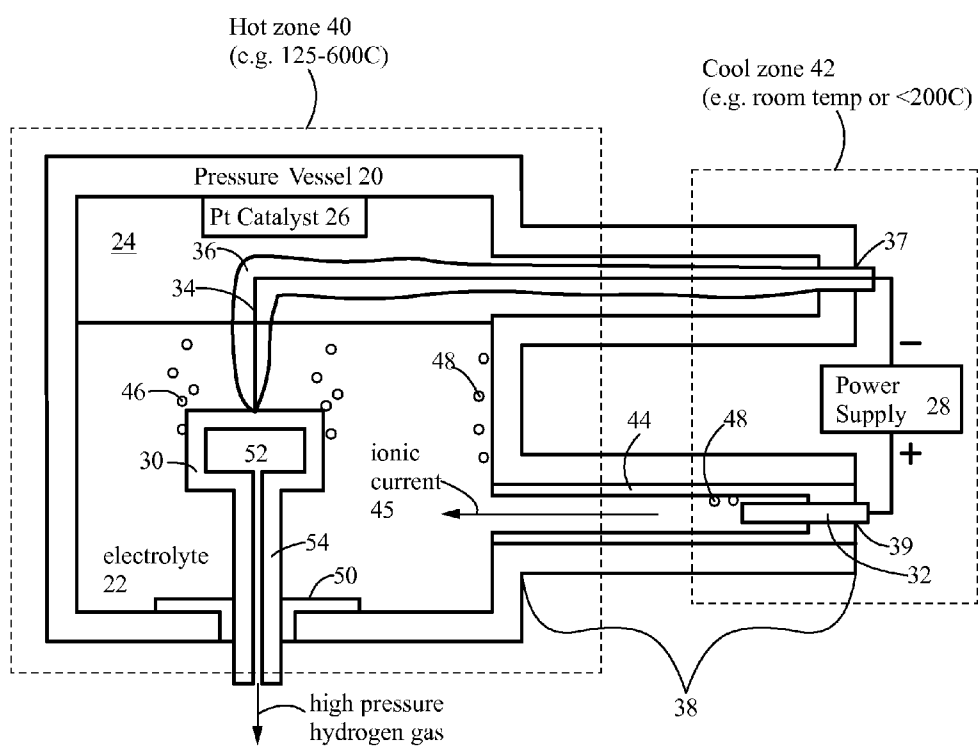


Fig. 2

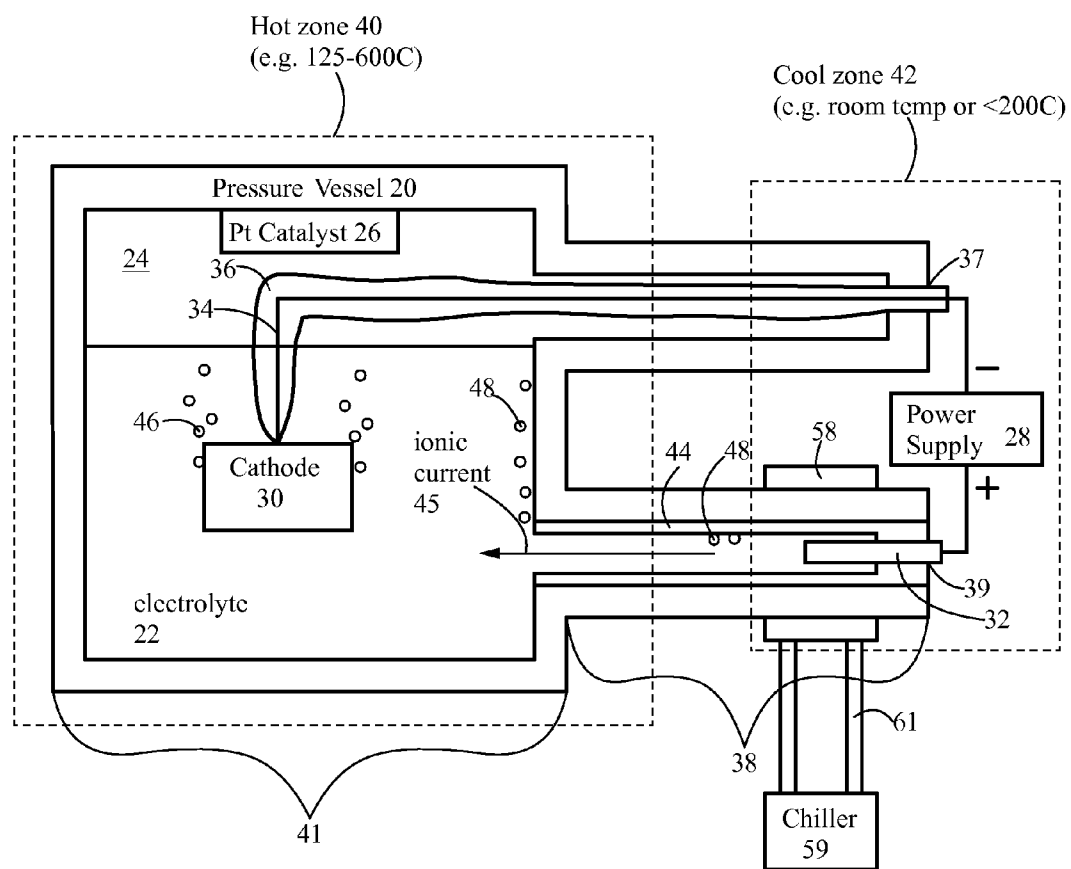


Fig. 3

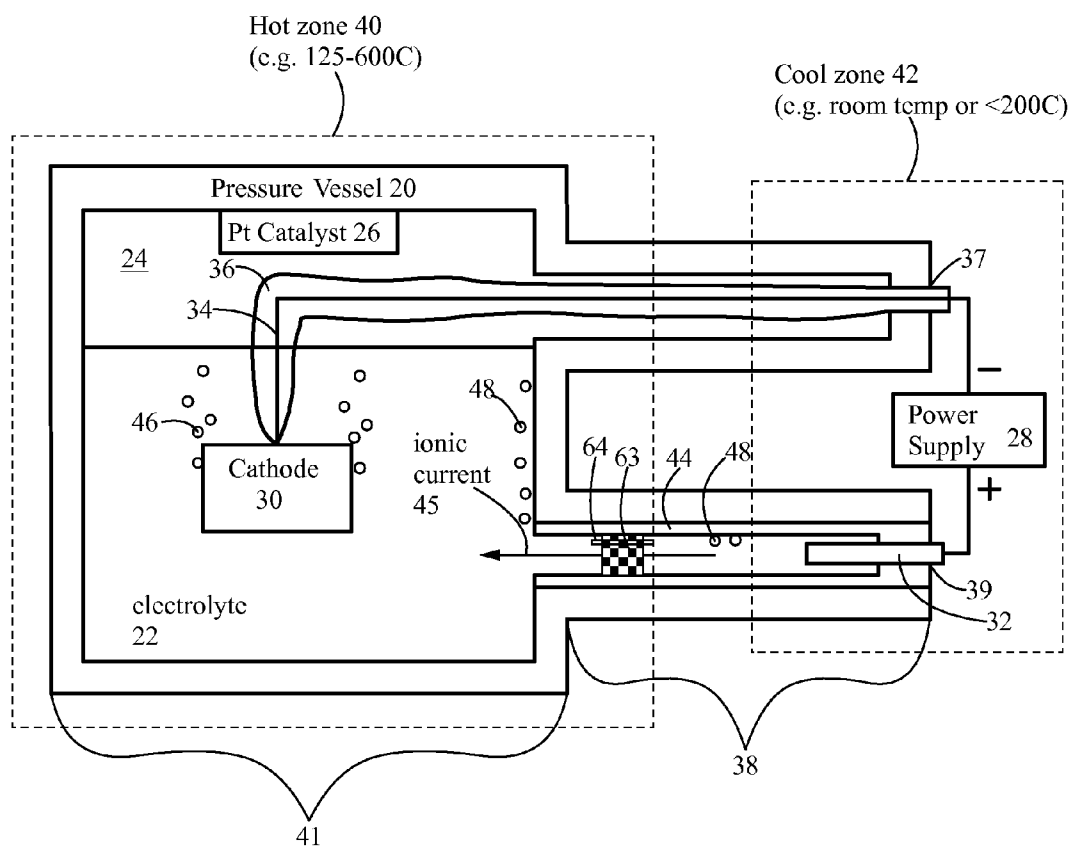
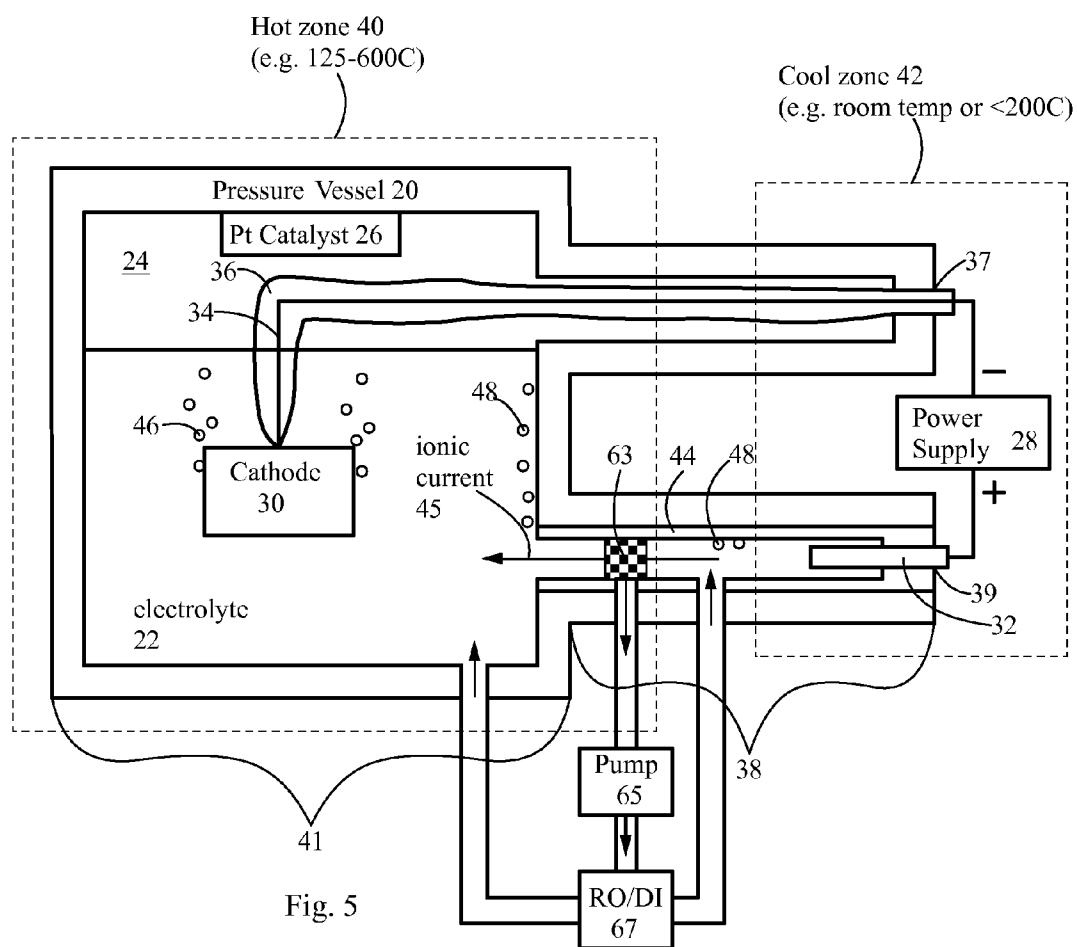


Fig. 4



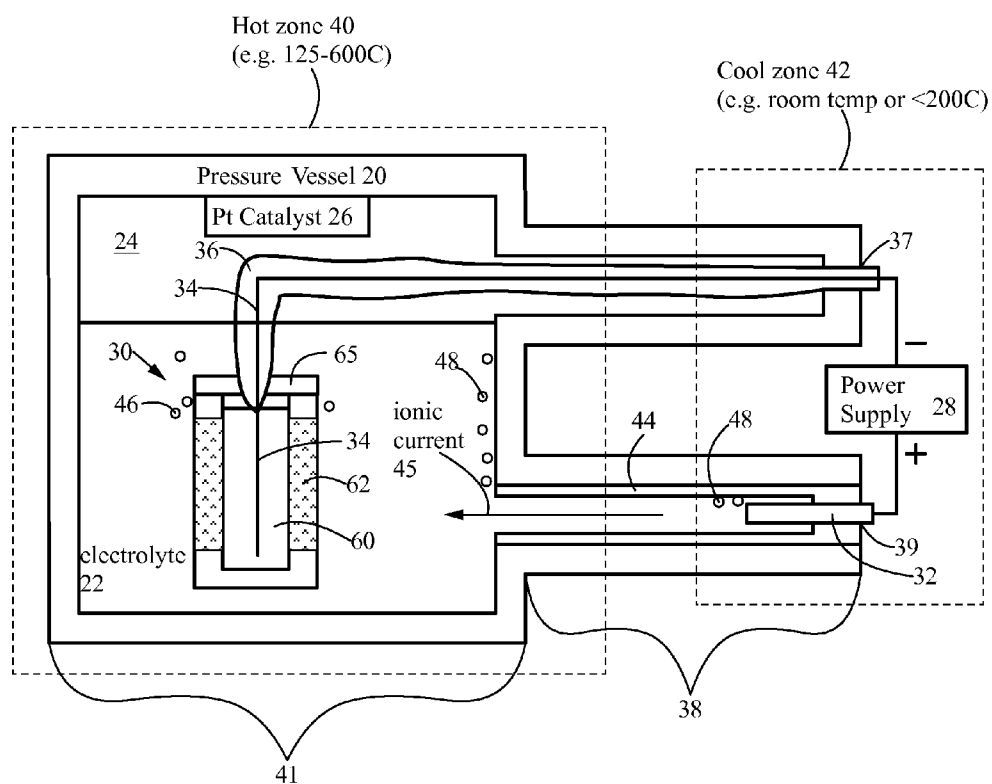


Fig. 6

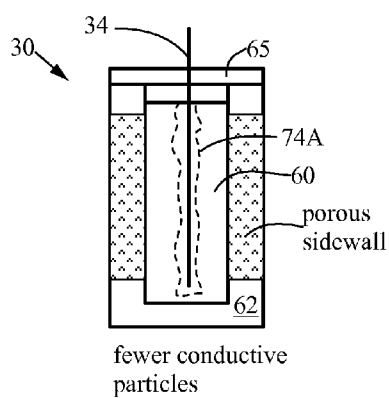


Fig. 7A

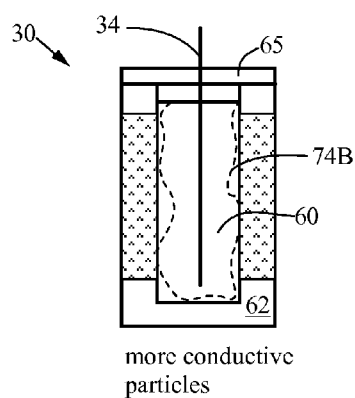


Fig. 7B

Fig. 8

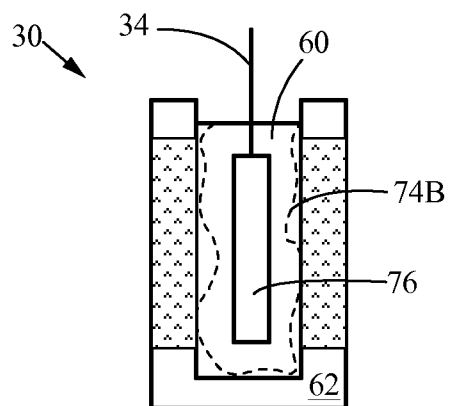


Fig. 9

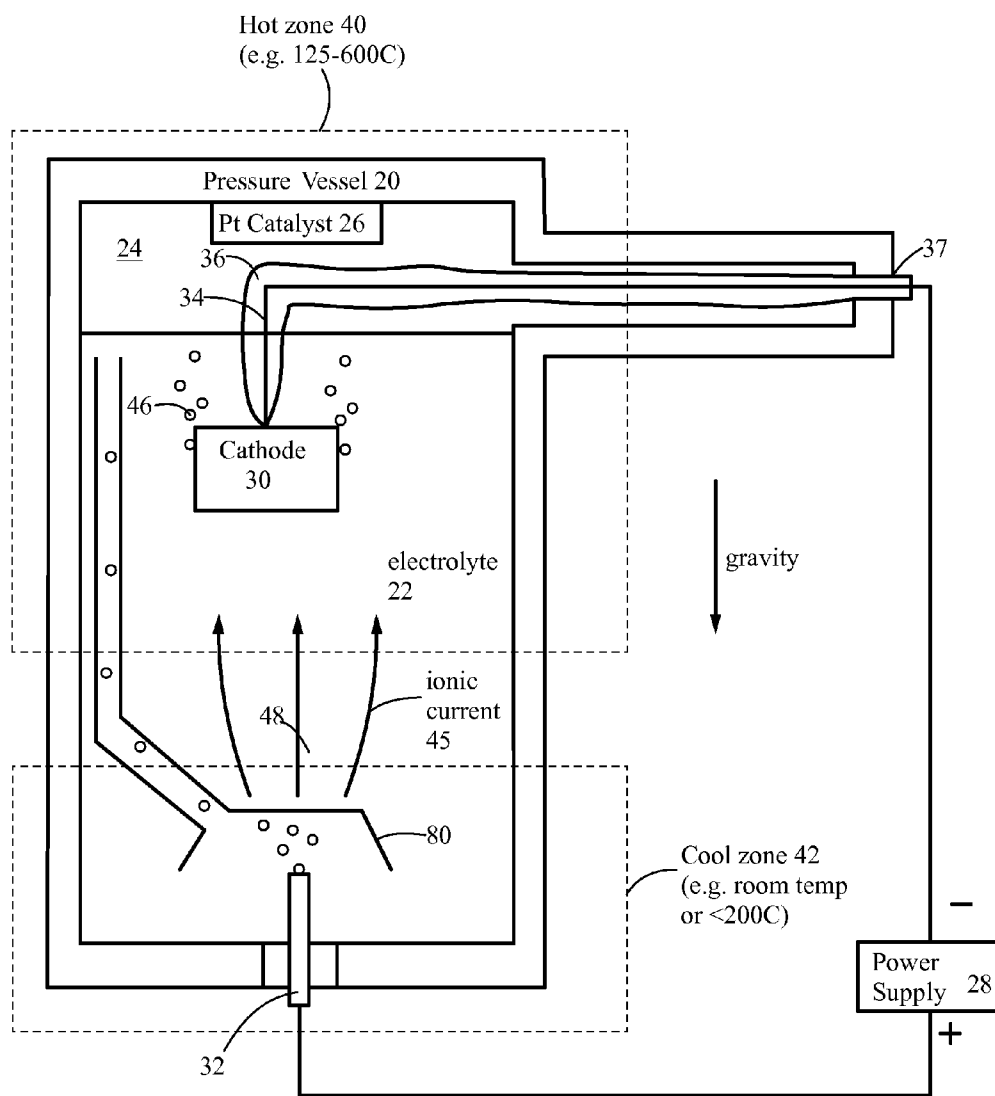


Fig. 10

APPARATUS WITH COLD ANODE FOR HIGH-TEMPERATURE ELECTROLYTIC HYDROGEN LOADING AND HYDROGEN GENERATION

RELATED APPLICATIONS

[0001] The present application claims the benefit of priority from provisional patent application 61/796,649 filed on Nov. 16, 2012 and provisional patent application 61/848,474 filed on Jan. 4, 2013, which are hereby incorporated by reference. The present application is also a continuation-in-part of copending patent application Ser. No. 13/545,983, filed on Jul. 11, 2012.

FIELD OF THE INVENTION

[0002] The present invention relates generally to hydrogen storage materials, high temperature electrolysis, and hydrogen generation.

BACKGROUND OF THE INVENTION

[0003] Hydrogen storage materials will be necessary for transporting hydrogen fuels. Such hydrogen storage materials may require loading with high pressure hydrogen gas. Accordingly, it will be necessary to investigate the properties of hydrogen storage materials under high pressure conditions, and to provide an inexpensive source of high pressure hydrogen.

[0004] Hydrogen can be produced by electrolysis of water. Electrolysis of water can be more energy efficient if it is performed at elevated temperature (e.g. above 100 C or above 250C). However, when electrolysis is performed at high temperature, the anode is corroded and oxidized rapidly. This adds considerable expense and downtime delays because corroded anodes must be replaced frequently. Also, anodic corrosion results in chemical contamination of a water electrolyte, which may contaminate and adversely affect the cathode surface, resulting in reduced efficiency at the cathode.

[0005] Accordingly, there is a need for an apparatus for electrolysis of water at high temperature, testing of hydrogen-storage materials, and hydrogen gas generation that experiences a greatly reduced rate of anodic corrosion. Such a device may also find uses in low energy nuclear reaction (LENR) research and applications.

SUMMARY

[0006] The present invention provides an apparatus for electrolysis, hydrogen loading of materials, hydrogen generation and study of low energy nuclear reaction phenomena. The apparatus comprises a hollow vessel with an interior volume. A portion of the interior volume is in a hot zone, and a portion is in a cool zone. An electrically conductive, hydrogen-containing electrolyte is disposed in the vessel. A cathode is disposed in the hot zone, and in contact with the electrolyte. An anode is disposed in the cool zone, and in the contact with the electrolyte. The electrolyte provides a path for an electrical current between the cathode and anode. The hot zone is at a temperature of at least 125 C and the cool zone is at a temperature of less than 200 C. The cool zone is at a lower temperature than the hot zone.

[0007] The vessel can comprise an anode containing electrolyte tube that extends between the hot zone and cool zone. The anode can be disposed in a distal, closed end of the anode tube.

[0008] A porous barrier can be disposed in the electrolyte and in the path of the electrical current. The porous barrier is permeable to the electrolyte and electrical current. The porous barrier tends to prevent hot electrolyte from contacting the anode.

[0009] The cathode can comprise a crucible filled with powder comprising conductive particles. The powder can comprise a mixture of metallic and ceramic particles. The power can comprise boron enriched in boron-10 or lithium.

[0010] The electrolyte may comprise water and may contain a solute to increase electrical conductivity.

DESCRIPTION OF THE FIGURES

[0011] FIG. 1A shows a reactor according to the present invention. The apparatus has an extension containing liquid electrolyte and anode at a cool, distal end.

[0012] FIG. 1B shows a reactor with valves for venting hydrogen and oxygen streams.

[0013] FIG. 2 shows an embodiment of the present invention for generating high pressure hydrogen gas.

[0014] FIG. 3 shows an embodiment having a cooling jacket around the anode tube.

[0015] FIG. 4 shows an embodiment having a porous barrier disposed in the anode tube, in the electrical current path between the anode and cathode.

[0016] FIG. 5 shows an embodiment having an active system for maintaining a solute concentration differential across the porous barrier.

[0017] FIG. 6 shows an embodiment in which the cathode comprises a porous crucible filled with electrically conductive powder.

[0018] FIGS. 7A and 7B show closeups of the porous crucible cathode in which the powder has different amounts of conductive particulates.

[0019] FIG. 8 shows an embodiment in which the porous crucible cathode is rotated during operation.

[0020] FIG. 9 shows a closeup of a cathode with a paddle-shaped cathode wire.

[0021] FIG. 10 shows an embodiment in which the cathode is above the anode, and the pressure vessel does not have an anode tube.

DETAILED DESCRIPTION

[0022] The present invention provides an apparatus for electrolysis of water at high temperature, testing of hydrogen-storage materials, and high pressure hydrogen gas generation that experiences reduced anodic corrosion. The present apparatus is also useful for advancing understanding of highly hydrogen-loaded materials at high temperature. The present apparatus may also be useful for understanding hydrogen storage materials, physical properties of metal hydrides, and low energy nuclear reaction (LENR) phenomena. The present apparatus may also be useful for practical applications of LENR phenomena, such as isotope production, transmutation of elements, or energy generation.

[0023] The present invention comprises a pressure vessel containing a fluid electrolyte and having a hot zone and a cool zone. The electrolyte continuously extends between the hot zone and cool zone, thereby providing an electrical connection (e.g. an ionic electrical connection) between the hot and cool zones. A cathode is disposed in the hot zone and an anode is disposed in the cool zone. An optional porous barrier can be disposed between the hot and cool zones to provide thermal

insulation between hot and cool electrolyte volumes. The present invention facilitates hydrogen-loading of the cathode and hydrogen production at high temperatures, while preventing high temperature electrolyte from contacting the anode. Because the anode is kept cool, corrosion and oxidation of the anode is greatly reduced. Consequently, the device can be continuously operated for long periods without requiring anode replacement. Also, contamination of the cathode surface by substances from the anode tends to be reduced.

[0024] Definitions

[0025] Hydrogen: Can refer to hydrogen atoms with no neutrons, a single neutron (deuterium) or two neutrons (tritium).

[0026] Electrolytically-loaded: Describes loading of hydrogen into a cathode from a liquid electrolyte, or an electrolyte operating above its critical point. The electrolyte is a source, or contains a source of hydrogen atoms or ions. The electrolyte can be water. If water is used above its critical point, the water preferably has a density of at least about 10% or 30% of the density of liquid water at room temperature.

[0027] High temperature: Above 100 C or 200 C, or above the boiling temperature of the electrolyte at atmospheric pressure.

[0028] Anode: Electrode connected to a source of current that is principally positive.

[0029] Cathode: Electrode connected to a source of current that is principally negative.

[0030] FIG. 1A shows an apparatus according to the present invention. The apparatus comprises a pressure vessel 20 containing water electrolyte (e.g. heavy water/deuterium oxide or ordinary light water) 22 at high temperature and pressure (e.g. about 300 C and 1200 PSI).

[0031] The vessel includes a headspace 24 containing water vapor, released hydrogen and oxygen, and optionally inert gases such as argon. An optional hydrogen oxidation catalyst 26 (e.g. containing platinum) is disposed in the headspace 24 and in contact with gases in the headspace 24: An electrical power supply 28 external to the vessel 20 is electrically connected to a cathode 30 and anode 32 inside the vessel. Both the cathode 30 and anode 32 must be in electrical contact with the electrolyte 22. Electrical power is provided to cathode 30 and anode 32 via cathode electrical feedthrough 37 and anode electrical feedthrough 39. It is preferable for the electrical feedthroughs 37 39 to be located in the cool zone because the feedthroughs may contain elastomeric sealing materials (e.g. Viton™ fluoroelastomer or silicone rubber) that are not tolerant of the high temperatures in the hot zone 40.

[0032] Feedthroughs 37 39 can be any conventional electrical feedthroughs for pressurized vessels.

[0033] A cathode wire 34 provides an electrical connection between the cathode 30 and the power supply 28. The cathode wire 34 may have an optional electrically insulating coating or covering 36 made of glass tubing, ceramic, metal oxide or vitreous enamel for example. The coating or covering 36 tends to prevent hydrogen loading of the wire, and therefore prevents undesirable hydrogen embrittlement of the cathode wire 34. The cathode wire is preferably electrically insulated from the pressure vessel 20 up to the point of connection with the cathode. The cathode wire 34 may comprise metal, graphite, carbon fiber or other electrically conductive material.

[0034] The pressure vessel 20 comprises an anode tube 38 and a main body 41. The anode tube 38 and main body 41 are fluidically connected. The anode tube 38 is at least partially

filled with electrolyte 22 such that the anode 32 and cathode 30 are electrically connected via the electrolyte 22. The main body 41 and cathode 30 are disposed in a hot zone 40; a distal end of the anode tube 38 is disposed in a cool zone 42. Accordingly, the cathode 30 is at a higher temperature than the anode 32. Because the anode is relatively cool, the rate of corrosion of the anode 32 tends to be lower than the corrosion rate that would occur if the anode 32 was in the hot zone 40. The low corrosion rate of the anode 32 is a substantial advantage and goal of the present invention.

[0035] Preferably, both the anode and cathode are electrically isolated from (i.e. not in electrical contact with) the pressure vessel 20.

[0036] An inner surface of the anode tube may have an optional electrically insulating coating 44. The coating may comprise glass, enamel, vitreous enamel, polymers or ceramic for example. The coating protects the inner surface of the anode tube 38 from corrosion in the vicinity of the anode 32. The coating 44 may extend to cover the entire interior surface of the vessel 20.

[0037] The pressure vessel 20 may be made of steel, stainless steel, or nickel superalloys for example. The pressure vessel should be resistant to water corrosion and oxygen at high temperature. Optionally, the entire inner surface of the pressure vessel can be coated with a protective material such as glass, enamel, ceramic, vitreous enamel or the like.

[0038] The cathode 30 can be made of any material under investigation for its hydrogen loading, cathodic hydrogen generation or hydrogen permeability properties. The present invention is not limited to any particular structure or composition of the cathode material. Exemplary materials that can be used in the cathode include palladium, nickel, titanium, carbon nanotubes, niobium, or metallic glasses (e.g. zirconium-based metallic glasses) and alloys and compounds thereof. Materials of particular interest include materials with a high hydrogen loading capability, or efficient hydrogen production capability or high hydrogen permeability, or that are known to produce low energy nuclear reactions (LENRs).

[0039] The anode 32 may comprise an electrically conductive material resistant to anodic corrosion such as platinum, graphite, Pt-coated titanium, palladium, carbon nanotubes, stainless steel or conductive oxide ceramics (e.g. lanthanum niobate).

[0040] However, in some embodiments, it may be desired to use anode materials that do corrode somewhat, such that anode material is dissolved in the electrolyte and is later electrodeposited on the cathode. In this case, the lower temperature in the cool zone may provide a desired reduced rate of anodic corrosion.

[0041] Power supply 28 may provide DC power, pulsed DC power, or intermittent reversed power, as known in the electroplating arts.

[0042] The pressure vessel can operate over a wide range of temperatures and pressures, for example, up to 600 C and 5000 PSI. The electrolyte can be in a subcritical or supercritical state. The electrolyte can be water and may contain a solute such as lithium hydroxide to increase electrical conductivity. Alternatively, the electrolyte can be high purity water that does not contain a solute. Preferably, if the electrolyte is water and a solute is present, the solute is selected such that oxygen is produced at the anode 32.

[0043] The hot zone and cathode can be at a temperature higher than 125 C 150C or 200 C, and the cool zone and anode

can be at a temperature lower than 200 C 150 C or 100 C. In all embodiments, the anode must be at a temperature lower than the cathode.

[0044] If the present apparatus is operated in the subcritical state (i.e. below 374 C for water), it is preferably for both the cathode and anode to be fully submerged in the liquid phase. If the present apparatus is operated in the supercritical state (i.e. above 374 C for water), it is preferable for the density of the water fluid to have a density of at least 30% or 60% the density of liquid water at room temperature.

[0045] It is noted that supercritical pure water has a relatively high electrical resistivity (e.g. 115 mega-ohm-cm at 374 C versus 0.413 mega-ohm-cm at 300 C). Consequently, it may be necessary to dissolve salts in the supercritical water to increase electrical conductivity, or use a power supply with a higher operating voltage.

[0046] Other electrolyte materials can also be used such as molten salts or ionic liquids. However, the electrolyte must contain hydrogen (as a constituent of the electrolyte molecule or dissolved in the electrolyte) that is evolved from and/or loaded into the cathode during operation.

[0047] The hot zone 40 is generally at a temperature suitable for increasing the rate of hydrogen loading of the cathode (e.g. by removing a surface oxide layer), increasing the energy efficiency of hydrogen generation, or increasing the rate of LENR phenomena, or chemically reducing metal oxides on the cathode surface. The cool zone 42 is generally at a temperature suitable for reducing the rate of anode corrosion to a tolerable or desirable level. Also, the cool zone 42 can be at a temperature low enough to avoid thermal damage to cathode and anode feedthroughs 37 39.

[0048] In operation, power supply 28 drives an electrical current between cathode 30 and anode 32, creating an ionic current 45 that flows through the anode tube 38. In the case of a water electrolyte, hydrogen 46 is generated at the cathode 30 and oxygen 48 is generated at the anode 32. Hydrogen gas 46 and oxygen gas 48 rise into the headspace 24. The oxygen gas 48 flows through the anode tube 38 into the hot zone 40 to reach the headspace 24. The hydrogen 46 and oxygen 48 are combined into water vapor at the Pt catalyst 26. A portion of the generated hydrogen enters the cathode 30, resulting in substantial, measurable changes to the cathode material properties, and possibly LENR phenomena, as known in the art.

[0049] FIG. 1B shows an alternative embodiment in which hydrogen and oxygen are separated. In this embodiment, only hydrogen 46 collects in the headspace 24 and can be released through valve 43. Oxygen is separately collected and can be released through valve 47. In this embodiment, the catalyst 26 functions to remove residual oxygen from the hydrogen stream, by reacting it with hydrogen to convert it into water vapor.

[0050] The cathode 30 can be studied with known techniques, such as electrical resistance measurements, optical probes or calorimetry for example. Many different types of sensors or electrical probes (not shown) can be connected to the cathode 30 or disposed in the hot zone, as known in the art.

[0051] A substantial advantage of the present invention is that the apparatus can be operated without exposing the anode 32 to the high temperature present in the hot zone. This tends to greatly reduce the rate of anodic corrosion of the anode. Consequently, the present apparatus can be continuously operated for long durations. Also consequently, little of the anode material is electrodeposited on the cathode surface. The present apparatus therefore enables prolonged study and

usage of the hydrogen-loaded cathode, and long-duration continuous hydrogen production.

[0052] FIG. 2 shows a specific embodiment of the present invention useful for generating a stream of ultrapure hydrogen gas at extremely high pressure and high flow rate. In the embodiment of FIG. 2, the cathode 30 is made of a hydrogen-permeable material (e.g. palladium), and has an interior hollow cavity 52. The cavity 52 is fluidically connected to a tube 54 that extends out of the pressure vessel 20. In a preferred embodiment, the cathode 30 is electrically isolated from the pressure vessel 20. In the specific embodiment of FIG. 2, the tube 54 is electrically connected to the cathode 30, and an electrical insulator 56 is disposed between the pressure vessel 20 and the tube 54. In some embodiments, the tube 54 can be coated with an electrically insulating material.

[0053] In operation, hydrogen 46 is produced at the cathode 30. Some hydrogen enters the cathode 30 and diffuses through the cathode material into the cavity 52. Because the cathode 30 is at high temperature, the hydrogen diffusion rate is increased and the cavity rapidly fills with hydrogen. Extremely high pressures can be obtained inside the cavity 52, such as 5,000 atmospheres or more. High pressure hydrogen is provided from the tube 54, external to the pressure vessel 20. The present apparatus of FIG. 2 operates in a manner similar to the apparatus described in U.S. Pat. No. 5,647,970 to Arata, which is hereby incorporated by reference.

[0054] Because the anode 32 is not exposed to the high temperature in the hot zone, anode corrosion is greatly reduced. Consequently, the anode 32 can operate for longer periods before requiring replacement, and less anode material is dissolved into the electrolyte, resulting in less contamination on the surface of the cathode 30. Also, energy efficiency will be improved.

[0055] FIG. 3 shows another embodiment of the present invention in which a cooling jacket 58 is disposed around the anode tube 38. A chiller 59 can flow cold water through tubes 61 to the jacket. In another embodiment (not shown) liquid coolant can flow through the anode 32 to keep it cool.

[0056] FIG. 4 shows an embodiment in which a porous barrier 63 is disposed in the path of the ionic current 45. In the embodiment of FIG. 4, the most convenient place for the porous barrier 63 is in the anode tube 38. The porous barrier has an open-pore structure that is conductive to ionic current and liquids. The porous barrier tends to reduce convective flow of electrolyte between the hot zone 41 and cool zone 42. Consequently, the porous barrier prevents hot electrolyte from flowing into the anode tube and contacting the anode. The porous barrier 63 can be made of open-cell ceramic foam, porous ceramics, metallic foams, wire cloth, high temperature polymeric membrane, or glass or silica frit for example. Suitable materials for the porous barrier include alumina, zirconia, silica, cordierite, silicon carbide, metals with a passivating surface oxide or high-temperature polymers and the like. Preferably, the porous barrier 63 is made of a nonmetallic, non-electrically conductive material. Also, the porous barrier 63 should be made of a material that does not chemically react with or dissolve in the electrolyte at high temperature.

[0057] It is noted that the porous barrier 63 may have a small tube 64 for allowing the escape of oxygen bubbles or other gases created at the anode 32.

[0058] Alternatively, the porous barrier 63 may block the flow of oxygen bubbles, and thereby direct oxygen towards the valve 47 in the embodiment of FIG. 1B.

[0059] In some applications of the present invention, it may be desirable to use pure water or deionized water (i.e. lacking a solute) as the electrolyte. Pure water has a relatively high electrical conductivity at high (but subcritical) temperatures present in the hot zone 41. However, pure water in the cool zone 42 may have a much lower electrical conductivity that is too low for efficient operation. Consequently, it may be desirable for the electrolyte on the hot/cathode side of the barrier 63 to have a lower solute concentration than the electrolyte on the cool/anode side of the barrier 63. However, this creates a new problem of maintaining the solute concentration gradient across the porous barrier 63. Without an active system for maintaining the concentration gradient, eventually the solute concentration will become equal on both sides of the barrier 63.

[0060] FIG. 5 shows an embodiment with an active system for maintaining a concentration gradient across the porous barrier 63. The active system comprises a pump 65 that obtains electrolyte from an area in proximity to the porous barrier 63. The electrolyte can be obtained from within the porous barrier 63 for example. The electrolyte passes through a reverse osmosis filter and/or deionizer 67. Concentrated fluid is sent into the anode tube 38, and purified/deionized water is sent to the hot zone. In this way, a concentration gradient can be maintained across the porous barrier. Consequently, a continuous, low-resistance electrical path is maintained between the anode 32 and cathode 30 without contacting solute to the cathode 30.

[0061] Alternatively, the reverse osmosis system can be replaced with a distillation device for separating pure water and concentrated solute solution.

[0062] In the embodiment of FIG. 5 having an active concentration gradient-maintaining system, the porous barrier 63 is preferably disposed in the hot zone 41 or close to the hot zone because such a location will ensure that no cool, purified electrolyte (i.e. lacking solute) is in the electrical path. If cool, purified electrolyte is in the electrical path, then it can undesirably increase the electrical resistance between anode and cathode.

[0063] FIG. 6 shows another embodiment in which the cathode 30 comprises electrically conductive powder 60. (e.g. including metal powder) disposed in a porous crucible 62. The conductive powder 60 is in electrical contact with the cathode wire 34. The porous crucible 62 is preferably non-conductive and can be made of ceramics such as alumina, zirconia, silica or the like. The porous crucible functions to contain the powder 60 while still allowing the electrolyte 22 to contact and wet the powder. The porous crucible 62 has at least one porous sidewall with open pores that allow the electrolyte and ionic current to pass through. The pore sizes in the crucible sidewall can be about 1-50 microns for example. A crucible lid 65 (porous or nonporous) can be provided to prevent the escape of powder particles (e.g. by convection currents). The lid can be fixedly attached to the crucible 62. The crucible 62 can be completely closed, except for porous sidewall sections

[0064] In operation, hydrogen is generated inside the powder 60, for example optionally near the boundary of the crucible 62 and powder 60. During operation, particles within the powder can become loaded with hydrogen. Hydrogen

bubbles can rise through the powder 60 or can escape through the porous walls of the crucible 62.

[0065] An advantage of the embodiment of FIG. 6 is that it avoids problems caused by embrittlement of cathode materials. For example, many metals typically become brittle when loaded with hydrogen. A brittle cathode in the shape of a wire or foil can break or crack during operation. This can block electrical current flow, cause leakage of hydrogen from the loaded materials, and adversely effect hydrogen generation efficiency. This problem is avoided or lessened by the powder-in-crucible cathode of FIG. 6.

[0066] The powder 60 in the crucible 62 can comprise a mixture of conductive and nonconductive powders, such as a mixture of metallic and ceramic particles. Ceramic particles can comprise alumina, zirconia, zeolites, niobates, titanates or silica powder for example. Conductive powders can comprise metals (e.g. palladium, nickel, niobium, vanadium, titanium), metallic glasses, carbon nanotubes, graphene, electroceramics or intermetallics for example. The conductive powder can also comprise other materials possibly suitable for hydrogen storage or suitable as a cathode material for water electrolysis or suitable for accelerating LENR reactions (e.g. boron-10, boron-containing ceramics or lithium-containing ceramics such as lithium niobate or lithium titanate). The powder particles can have many shapes, such as flakes, fibers, dendrites, nanowires, nanoribbons or the like. The powder particles can have a wide range of sizes, such as 1 nm-100 microns, for example.

[0067] Preferably, the content of conductive particles is high enough such that the powder 60 has some bulk electrical conductivity. In some embodiments, the conductivity will not extend to the inner surface of the crucible 62, but instead conductive paths from the wire 34 through the conductive particles will almost all terminate in the bulk of the powder 60.

[0068] FIG. 7A shows a closeup view of the powder-in-crucible cathode 30 illustrating a cathodic surface 74A. The cathodic surface is approximately where conductive paths from the cathode wire 34 terminate. The cathodic surface is also approximately where much of the cathode half-reaction occurs (i.e., $H^+ + e^- = 1/2 H_2$). For a powder 60 with fewer conductive particles, the cathodic surface 74A will tend to be closer to the cathode wire 34. FIG. 7B shows a cathode 30 with more conductive particles. The cathodic surface 74B is further from the cathode wire 34 and closer to the interior wall of the crucible 62. The exact shape of the cathodic surface depends on the spatial distribution of the conductive particles within the powder 60 and will tend to be random, and may change over time.

[0069] Percolation theory holds that the probability of a continuous conductive path (i.e. through randomly distributed conductive particles) decreases exponentially with distance. Accordingly, the "cathodic surface" where the cathodic half reaction occurs will not necessarily be a 2-D surface, but rather will be a 3-dimensional volume in the vicinity of the illustrated cathodic surface. The location and distribution of the cathodic surface will depend on the morphology, size, and proportion of the conductive particles.

[0070] A possible shortcoming of the embodiment of FIG. 6 is that only a fraction of the conductive particles in the powder 60 will be located at the cathodic surface and therefore be available for involvement in the cathodic half reaction. Consequently, the active particles at the cathodic surface may become degraded or consumed, shortening the useable life-

time of the cathode. Cathode life and functionality can be increased by circulating all conductive particles through the cathodic surface. Accordingly, the powder 60 can be actively mixed or stirred (e.g. by vibration, hydrogen bubble injection or mechanical impellers) during operation, such that all or most of the conductive particles have an opportunity to spend some time involved with the cathodic half reaction.

[0071] FIG. 8 shows an embodiment having a motor 66 for rotating the crucible 62 and thereby actively stirring the powder 60 during operation. The motor 66 is physically connected to the crucible 62 by a rotating axle 68. The axle extends through a rotary feedthrough 70. The rotary feedthrough is preferably located outside the hot zone 40 and is maintained at a temperature low enough to avoid damage to the rotary feedthrough 70. The axle 68 and crucible 62 may rotate at a slow speed such as 0.1-60 RPM for example, or may rotate intermittently. A stationary (non-rotating) mixing blade 72 may be disposed in the powder 60 to cause mixing and particle movement of the powder 60 when the crucible is rotating. The blade 72 may be fixedly attached to an inner surface of the vessel 20 as shown, or attached to the cathode wire 34, such that it remains stationary as the crucible 62 rotates around it.

[0072] FIG. 9 shows a cathode 30 according to an alternative embodiment in which the cathode wire 34 has a paddle-shaped end 76. The paddle end is stationary while the porous crucible rotates. The relative motion of the paddle and crucible causes mixing of the powder 60.

[0073] Mixing of the powder 60 during operation will continuously expose new conductive particles to the cathodic surface where, electrochemical reactions are occurring. In this way, the lifetime of the cathode is extended, and all conductive particles in the powder 60 have an opportunity to spend some time at the cathodic surface involved in the cathodic reactions.

[0074] FIG. 10 shows another embodiment in which gravity helps to maintain a temperature gradient between the cathode 30 and anode 32. In this embodiment, the cathode 30 is disposed above the anode 30, assuming that hot electrolyte is less dense than cool electrolyte. In operation, cool electrolyte will tend to stay at the bottom of the pressure vessel 20. It is noted that gases released at the anode 32 may cause undesirable mixing of hot and cool electrolyte. To avoid this, a funnel 80 may be disposed above the anode 32 to channel bubbles into the headspace 24. Also, a porous barrier (not shown) can be disposed between the anode 32 and cathode 30 in the embodiment of FIG. 10.

[0075] It is noted that in some embodiments the pressure vessel may also be loaded with pressurized hydrogen gas. This hydrogen gas can be dissolved in the electrolyte.

[0076] Preferably in the present invention the electrolyte is a fluid or liquid.

[0077] Preferably, the cathode is at least 50 C, 100 C, or 150 C hotter than the anode.

Utility

[0078] As noted above, the present invention is useful for generating high pressure hydrogen gas, for efficiently electrolyzing water, and for investigating hydrogen storage materials.

[0079] The present invention is also useful for basic research of highly hydrogen-loaded metals and materials at

high temperature. Such investigations are particularly useful for exploring materials for hydrogen energy storage, for example.

[0080] Also, the present invention may be useful for research into low energy nuclear reaction (LENR) and cold fusion phenomena and applications thereof. Such applications may include transmutation of elements, new element production, new isotope production, and energy production.

[0081] The above embodiments may be altered in many ways without departing from the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.

What is claimed is:

1. An apparatus for electrolysis and hydrogen loading, comprising:

- a) a hollow vessel with an interior volume, wherein a portion of the interior volume is in a hot zone and a portion of the interior volume is in a cool zone;
- b) an electrically conductive electrolyte disposed in the vessel;
- c) a cathode disposed inside the vessel in the hot zone, and in contact with the conductive electrolyte;
- d) an anode disposed inside the vessel in the cool zone, and in contact with the conductive electrolyte

wherein the hot zone is at a temperature of at least 125 C, and the cool zone is at a temperature of at most 200 C, and the cathode is at least 25 C hotter than the anode; and wherein the electrolyte is fluidically continuous between the hot zone and the cool zone such that the electrolyte conducts an electrical current between the anode and cathode.

2. The apparatus of claim 1 further comprising an anode tube that extends between the hot zone and cool zone, wherein the anode tube contains the electrolyte that conducts an electrical current between the anode and cathode.

3. The apparatus of claim 1 further comprising an anode electrical feedthrough disposed in the cool zone, and a cathode electrical feedthrough disposed in the cool zone.

4. The apparatus of claim 1 further comprising a porous barrier disposed in the path of the electrical current, wherein the porous barrier is conductive to an ionic current flowing through the electrolyte.

5. The apparatus of claim 4 wherein electrolyte on a cool anode side of the porous barrier contains an ionic solute for increasing electrical conductivity, and electrolyte on a hot cathode side of the porous barrier contains a lower concentration of the ionic solute.

6. The apparatus of claim 1 wherein the cathode comprises a crucible comprising electrically insulating material with at least one porous sidewall, and a powder comprising electrically conductive particles disposed in the crucible.

7. The apparatus of claim 6 wherein the powder contains boron enriched in boron-10 or lithium.

8. The apparatus of claim 1 wherein the hot zone is at a temperature of at least 200 C, and the cool zone is at a temperature of at most 150 C.

9. An apparatus for electrolysis and hydrogen loading, comprising:

- a) a hollow vessel with an interior volume, wherein a portion of the interior volume is in a hot zone and a portion of the interior volume is in a cool zone;
- b) an electrically conductive electrolyte disposed in the vessel;

c) a cathode disposed inside the vessel in the hot zone, and in contact with the conductive electrolyte, wherein the cathode comprises a crucible with at least one porous wall permeable to the electrolyte and conductive to electrical current in the electrolyte, and a powder comprising electrically conductive particles disposed in the crucible;

d) an anode disposed inside the vessel in the cool zone, and in contact with the conductive electrolyte

wherein the hot zone is at a temperature of at least 125 C, and the cool zone is at a temperature of at most 200 C, and the cathode is at least 50 C hotter than the anode; and wherein the electrolyte is fluidically continuous between the hot zone and the cool zone such that the electrolyte conducts an electrical current between the anode and cathode.

10. The apparatus of claim **1** further comprising an anode tube that extends between the hot zone and cool zone, wherein the anode tube contains the electrolyte that conducts an electrical current between the anode and cathode.

11. The apparatus of claim **9** further comprising a porous barrier disposed in the path of the electrical current, wherein the porous barrier is conductive to an ionic current flowing through the electrolyte.

12. The apparatus of claim **11** wherein electrolyte on a cool anode side of the porous barrier contains an ionic solute for increasing electrical conductivity, and electrolyte on a hot cathode side of the porous barrier contains a lower concentration of the ionic solute.

13. The apparatus of claim **9** wherein the powder comprises a mixture of conductive particles and nonconductive particles.

14. The apparatus of claim **9** wherein the powder contains boron enriched in boron-10 or lithium.

15. The apparatus of claim **9** wherein the hot zone is at a temperature of at least 200 C, and the cool zone is at a temperature of at most 150 C.

16. An apparatus for electrolysis and hydrogen loading, comprising:

a) a hollow vessel with an interior volume, wherein a portion of the interior volume is in a hot zone and a portion of the interior volume is in a cool zone;

b) a hydrogen-containing, conductive electrolyte disposed in the vessel;

c) a cathode disposed inside the vessel in the hot zone, and in contact with the conductive electrolyte,

d) an anode disposed inside the vessel in the cool zone, and in contact with the conductive electrolyte

wherein the hot zone is at a temperature of at least 125 C, and the cool zone is at a temperature of at most 200 C, and the cathode is at least 25 C hotter than the anode; and

wherein the electrolyte is fluidically continuous between the hot zone and the cool zone such that the electrolyte conducts an electrical current between the anode and cathode;

5) an electrical power supply electrically connected to the cathode and anode.

17. The apparatus of claim **16** further comprising an anode tube that extends between the hot zone and cool zone, wherein the anode tube contains the electrolyte that conducts an electrical current between the anode and cathode.

18. The apparatus of claim **16** further comprising a porous barrier disposed in the path of the electrical current, wherein the porous barrier is conductive to an ionic current flowing through the electrolyte.

19. The apparatus of claim **16** wherein the cathode comprises a crucible comprising electrically insulating material with at least one porous sidewall, and a powder comprising electrically conductive particles disposed in the crucible.

20. The apparatus of claim **19** wherein the powder contains boron enriched in boron-10 or lithium.

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