ELECTROLYSIS APPARATUS

Background of the Invention

[0001] The present invention relates to an apparatus for performing electrolysis, and in one example for performing electrolysis of water for the generation of hydrogen and heat.

Description of the Prior Art

[0002] The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that the prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

[0003] It is known to perform electrolysis of water, for example to generate hydrogen and/or oxygen. This has been proposed for a number of different scenarios, such as for generating usable energy from variable power supplies such as renewable sources.

[0004] For example, US-7,188,478 describes a power generation system comprising a liquid-cooled electrolyser operable to produce a supply of hydrogen from water. The power generation system may also comprise a steam turbine and a steam production device operable to produce a supply of steam to the steam turbine. The power generation system may also comprise a system operable to provide cooling liquid to the liquid-cooled electrolyser and to couple heated cooling liquid from the liquid-cooled electrolyser to the steam production device.

[0005] In EP-2,138,678 an energy storage system is disclosed, which comprises an electrolyser, hydrogen gas storage and a power plant, the electrolyser being connected to the hydrogen gas storage and the hydrogen gas storage being connected to the power plant. Moreover, a method for storing and supplying energy is described. The method comprises the steps of: delivering electrical energy to an electrolyser; decomposing water into oxygen and hydrogen gas by means of the electrolyser; storing the hydrogen gas; supplying the stored hydrogen gas to a power plant; and producing electrical energy by means of the power plant.

[0006] US2009/224546 describes a power generating system utilizing an electrolytic heating subsystem. The electrolytic heating subsystem is a pulsed electrolysis system that heats a heat transfer medium contained within a first conduit in thermal communication with the electrolytic heating subsystem and at least one heat exchanger. A second conduit coupled to the at least one heat exchanger contains a working fluid. As the working fluid is circulated through the second conduit and through the heat exchanger(s), it is heated to a temperature above its boiling point, causing at least a portion of the working fluid to be converted to vapour (e.g., steam). The vapour is circulated through a steam turbine, causing its rotation and, in turn, an electric generator coupled to the steam turbine.

[0007] US-5,273,635 describes a heater which uses the electrolysis of a liquid to produce heat from electricity and transfers the heat from the electrolyte by means of a heat exchanger. One embodiment includes electrodes of nickel and platinum and an electrolyte of potassium carbonate with a heat exchanger immersed in and transferring heat from the electrolyte.

[0008] US-5,628,887 describes an electrolytic system and cell for excess heating of water containing a conductive salt in solution. The electrolytic cell includes a non-conductive housing defining a substantially closed interior volume and spaced apart first and second conductive members positioned within the housing. A plurality of conductive particles each having a conductive metal which is readily combinable with hydrogen or an isotope of hydrogen to form a metallic hydride are positioned within the housing in electrical contact with the first conductive member and electrically spaced from said second conductive member. The conductive particles may be of any convenient regular or irregular shape. An electric power source in the system is operably connected across the first and second conductive members whereby electrical current flows therebetween and through the conductive particles within the liquid electrolyte.

[0009] However, the abovementioned arrangements do not describe electrolysis apparatus optimised for hydrogen and heat generation, whilst heat recovery mechanisms are limited.

[0010] US-5,632,870 describes an electrolytic cell apparatus and methods for generating a useful energy product from a plurality of energy sources. In a preferred embodiment, hydrogen gas is produced at a cathode by transmission of electrons through a low voltage potential barrier to electron flow achieved by careful control of electrolyte constituent

concentrations and surface materials on the cathode. A portion of the energy captured in the hydrogen gas is provided by heat transmitting activity of ions dissociated from water at an anode which catalytically dissociates the water and thereby transfers thermal energy from the anode to the ions and other constituents of the cell electrolyte. Thermal energy is replaced in the anode by absorption of heat from the surrounding environment. Again however, heat recovery mechanisms are limited.

Summary of the Present Invention

[0011] The present invention seeks to ameliorate one or more of the problems associated with the prior art.

[0012] In one broad form the present invention seeks to provide an apparatus for performing electrolysis and generating heat, the apparatus including an electrolysis cell including:

a) a cell housing defining an electrolyte cavity, the electrolyte cavity containing an electrolyte in use;
b) a plurality of substantially parallel spaced apart electrode plates provided within the electrolyte cavity, the electrode plates defining at least one anode and at least one cathode at least partially submersed within the electrolyte in use;
c) at least two connectors, which in use are connected to an electrical power supply thereby allowing an electrical current to be supplied to the electrolyte to thereby perform electrolysis and heating of the electrolyte;
d) at least one cell outlet in fluid communication with the electrolyte cavity, the at least one cell outlet being coupled to a heat recovery module in use; and,
e) at least one cell inlet allowing electrolyte to be supplied to the electrolyte cavity.

[0013] Typically the inlet is coupled to the heat recovery module so that electrolyte is recirculating through the electrolyte cavity and the heat recovery module.

[0014] Typically the inlet and outlet are arranged so that electrolyte supplied to the cavity flows between the electrode plates.

[0015] Typically the inlet and outlet are arranged on opposing sides of the electrolyte cavity facing edges of the electrode plates.

[0016] Typically the inlet and outlet are arranged in lower and upper ends of the cell housing respectively with the electrode plates aligned substantially vertically within the electrolyte cavity and spaced substantially horizontally, in use.

[0017] Typically the electrode plates are at least one of:

a) laminar;

b) curved; and,

c) undulating.

[0018] Typically the electrode plates are separated by a distance of at least one of:

a) between 0.1 mm and 10 mm;

b) between 1 mm and 2 mm; and,

c) between 2 mm and 5 mm.

[0019] Typically the electrode plates have thickness of at least one of:

a) between 0.1 mm and 10 mm;

b) between 1 mm and 2 mm; and,

c) between 2 mm and 5 mm.

[0020] Typically the anodes are thicker than the cathodes.

[0021] Typically the at least two connectors are electrically connected to electrode plates so that adjacent plates act as anodes and cathodes in use.

[0022] Typically each cathode is positioned between two anodes.

[0023] Typically the cell housing includes an opening and a cover removably mounted in the opening to allow at least some of the electrode plates to be removed from the electrolyte cavity.

[0024] Typically the apparatus includes an electrode support, the electrodes being coupled to the electrode support so that the electrodes are at least partially submerged in electrolyte in use.

[0025] Typically the electrode support is coupled to a cover allowing the electrodes to be removed from the electrolyte cavity.

[0026] Typically the cell housing defines a pressure vessel and wherein the pressure inside the electrolyte cavity is greater than atmospheric pressure.

[0027] Typically, in use, the apparatus operates at a temperature that is at least one of:

a) at least 40°C;

b) at least 60°C;

c) at least 80°C; and,

d) at least 100°C.

[0028] Typically the apparatus includes a heat recovery module.

[0029] Typically the heat recovery module acts as a condenser for condensing vaporised electrolyte.

[0030] Typically the heat recovery module acts as a separator for separating vaporised electrolyte from gaseous electrolysis products.

[0031] Typically the heat recovery module includes an outlet that allows gaseous electrolysis products to be extracted in use.

[0032] Typically the heat recovery module includes a heat exchanger for recovering heat from the electrolyte to at least one of:

a) condensed vaporised electrolyte; and,

b) perform work using recovered heat.

[0033] Typically the heat recovery module heats a heat transfer medium using heat recovered from the electrolyte.

[0034] Typically the recovered heat is used by a thermal engine including:

a) a boiler that in use generates pressurised vapour using the recovered heat; and,

b) a thermal engine coupled to a generator that in use generates electricity using pressurised vapour from the boiler.

[0035] Typically the heat recovery module includes a thermal engine.

[0036] Typically the apparatus includes a power supply for supplying the electrical current.

[0037] Typically the power supply includes a thermal engine.

[0038] Typically the electrical current is direct current having an electrical potential of at least one of:

a) at least 2 V;

b) at least 5 V;

c) at least 10 V;

d) between 15 and 25 V;

e) up to 30 V;

f) up to 40 V; and,

g) up to 60 V.

[0039] Typically the electrical current is applied to generate an electric field having a field strength of at least one of:

a) at least 3000 Volts per meter;

b) at least 12000 Volts per meter; and

c) at least 24000 Volts per meter.

[0040] Typically the electrical current is direct current having an electrical current of at least one of:

a) at least 0.5 A;

b) at least 1 A;

c) at least 2A;

d) between 2 A and 10 A;

e) about 5 A;

f) up to 10 A;

g) up to 20 A; and,

h) up to 50 A.

[0041] Typically the electrical current is applied to generate an electric field having a current density of at least one of:

a) at least 500 Ampere per square meter;

b) at least 1000 Ampere per square meter; and

c) about 3000 Ampere per square meter or higher.

[0042] Typically the apparatus includes:

a) a trigger circuit coupled to the at least two connectors;

b) a switch; and,

c) a load coupled to the at least two connectors via the switch, wherein in use, the trigger circuit selectively activates the switch to thereby couple the at least two connectors to the load.

[0043] Typically the trigger circuit includes:

a) a sensor for sensing at least one of:

i) current flow in the connectors and;

ii) electrical potential across the connectors; and

b) an electronic controller for controlling the switch in accordance with at least one of the sensed:

i) sensed current and;

ii) sensed electrical potential.

[0044] Typically, in use, the electronic controller:

a) compares the at least one sensed current and sensed electrical potential to a threshold; and

b) operates the switch to divert at least some current through the load in the event that the threshold is exceeded.

[0045] Typically the load is at least one of:

a) an electrolysis cell;

b) a resistive load;

c) a battery, and

d) an electrical machine.

[0046] Typically, in use, the electrolysis cell is adapted to operate at a temperature of at least 60°, a pressure of at least atmospheric pressure, and with a direct current having an applied electric field of at least 3000 V/m and a current density of at least $500A/m^2$.

[0047] Typically the apparatus include a pyroelectric material that in use generates electrical energy in response to temperature changes within the apparatus.

[0048] Typically the pyroelectric material is provided in the electrolyte cavity and is electrically connected to the at least two connectors.

[0049] Typically the pyroelectric material is at least one of electrically insulated and electrically connected to the electrolyte.

[0050] Typically at least one electrode is made of a pyroelectric material.

[0051] Typically electrodes are unevenly spaced to enhance the pyroelectric effect.

[0052] Typically the apparatus includes two dissimilar metals in electrical and thermal contact with the apparatus that in use generates electrical energy in response to temperature changes within the apparatus.

[0053] In a further broad form the present invention seeks to provide apparatus for use in electrolysis, the apparatus including:

a) an electrolysis cell including:
   i) a cell housing defining an electrolyte cavity, the electrolyte cavity containing an electrolyte and being pressurised in use;
   ii) at least one cell outlet in fluid communication with the electrolyte cavity so that in use electrolysis products can be collected therefrom;
   iii) a plurality of electrodes provided within the electrolyte cavity, the plurality of electrodes defining at least one anode and at least cathode; and
   iv) at least two connectors, which in use are connected to an electrical power supply thereby allowing electrical current to be supplied to the electrolyte; and,
b) a heat recovery module including:
   i) a module housing defining:
      (1) a cell cavity, the electrolysis cell being removably mounted within the cavity; and,
      (2) a medium cavity in thermal communication with the cell cavity, the medium cavity containing a heat recovery medium in use; and,

c) an inlet and an outlet in fluid communication with the medium cavity so that in use heat recovery medium can pass through the medium cavity to thereby recover heat from the electrolysis cell.

[0054] Typically the apparatus electrolysis cell includes a cell inlet in fluid communication with the electrolyte cavity so that in use electrolyte can be supplied thereto.

[0055] Typically the apparatus includes an electrolyte supply for supplying heated electrolyte to the cell inlet.

[0056] Typically the cell housing includes a base and cover, the cover being removably mounted to the base, and the cover and base being sealing engaged in use.

[0057] Typically the cell housing defines a pressure vessel.

[0058] Typically the electrodes include a plurality of substantially laminar electrode plates.

[0059] Typically the electrode plates are laterally spaced.

[0060] Typically the electrode plates are at least one of:

a) equidistantly spaced; and,

b) unevenly spaced.

[0061] Typically the electrode plates extend in first and second orthogonal directions, the electrode plates being spaced in a third orthogonal direction.

[0062] Typically the electrode plates are separated by a distance of between 0.1 and 10 mm.

[0063] Typically the electrode plates are arranged in use so that electrolysis products travel between the electrode plates to the cell outlet.

[0064] Typically the at least two connectors are electrically connected to electrode plates so that adjacent plates act as anodes and cathodes in use.

[0065] Typically the apparatus includes an electrode support, the electrodes being coupled to the electrode support so that the electrodes are at least partially submerged in electrolyte in use.

[0066] Typically the electrode support is coupled to a cover allowing the electrodes to be removed from the electrolyte cavity.

[0067] Typically the heat recovery module is positioned outwardly of the electrolysis cell.

[0068] Typically the medium cavity has a tubular shape and the cell housing has a substantially cylindrical shape.

[0069] Typically the module housing has an elongate substantially annular shape defining a cylindrical cell cavity and an annular medium cavity extending substantially circumferentially around the cell cavity.

[0070] Typically the apparatus includes an insulating jacket, the heat recovery module being provided within the insulating jacket in use.

[0071] Typically the insulating jacket includes a jacket housing, the jacket housing and module housing cooperating to define an insulation cavity that contains a thermally insulating material in use.

[0072] Typically the inlet and outlet are coupled to a thermal engine or thermal load in use.

[0073] Typically the thermal engine includes:

a) a boiler that in use generates steam using heat from the heat transfer medium; and,

b) a steam turbine coupled to a generator that in use generates electricity using steam from the boiler.

[0074] Typically the at least two connectors are coupled to a power supply in use.

[0075] Typically the apparatus includes:

a) a trigger circuit coupled to the at least two connectors;

b) a switch; and,

c) a load coupled to the at least two connectors via the switch, wherein in use, the trigger circuit selectively activates the switch to thereby couple the at least two connectors to the load.

[0076] Typically the trigger circuit includes:

a) a sensor for sensing at least one of:
   i) current flow in the connectors and;
   ii) electrical potential across the connectors; and
b) an electronic controller for controlling the switch in accordance with at least one of the sensed:
   i) sensed current and;
   ii) sensed electrical potential.

[0077] Typically, in use, the electronic controller:

a) compares the at least one sensed current and sensed electrical potential to a threshold; and
b) operates the switch to divert at least some current through the load in the event that the threshold is exceeded.

[0078] Typically the load is at least one of:

a) an electrolysis cell;
b) a resistive load;
c) a battery; and,
d) an electrical machine.

[0079] Typically the apparatus include a pyroelectric material that in use generates electrical energy in response to temperature changes within the apparatus.

[0080] Typically the pyroelectric material is provided in the electrolyte cavity and is electrically connected to the at least two connectors.

[0081] Typically apparatus includes two dissimilar metals in electrical and thermal contact with the apparatus that in use generates electrical energy in response to temperature changes within the apparatus.

[0082] Typically the pyroelectric material is at least one of electrically insulated and electrically connected to the electrolyte.

[0083] Typically at least one electrode is made of a pyroelectric material.

[0084] Typically electrodes are unevenly spaced to enhance the pyroelectric effect.

[0085] Typically the apparatus include a plurality of electrolysis cells removably mounted in respective cell cavities in the heat recovery module.

[0086] In a second broad form the present invention seeks to provide apparatus for use in electrolysis, wherein the apparatus includes:

a) an electrolysis cell including at least two connectors, which in use are connected to an electrical power supply thereby allowing electrical current to be supplied to an electrolyte;

b) a trigger circuit coupled to the at least two connectors;

c) a switch; and,

d) a load coupled to the at least two connectors via the switch, wherein in use, the trigger circuit selectively activates the switch to thereby couple the at least two connectors to the load.

[0087] Typically the trigger circuit includes:

a) a sensor for sensing current flow in the connectors; and

b) an electronic controller for controlling the switch in accordance with the sensed current.

[0088] Typically, in use, the electronic controller:

a) compares the sensed current to a threshold; and

b) operates the switch to divert at least some current through the load in the event that the threshold is exceeded.

[0089] Typically the load is at least one of:

a) an electrolysis cell;

b) a resistive load;

c) a battery; and,

d) an electrical machine.

[0090] It will be appreciated that the different broad forms of the invention, and their dependent features, can be used interchangeably or in conjunction, as desired.

Brief Description of the Drawings

[0091] An example of the present invention will now be described with reference to the accompanying drawings, in which: -

[0092] Figure 1A is a schematic side view of a first example of apparatus for performing electrolysis and generating heat with the electrolysis cell installed;

[0093] Figure 1B is a schematic side view of the apparatus in Figure 1A with the electrolysis cell removed;

[0094] Figure 2A is a schematic diagram of the connections of the apparatus of Figure 1A when used in generating hydrogen and heat;

[0095] Figure 2B is an alternative diagram for the fluid working cycle as described in Figure 2A;

[0096] Figure 3A is a schematic perspective external view of an example of apparatus for generating hydrogen and heat with an electrolysis cell removed from a heat recovery module;

[0097] Figure 3B is a schematic first side view of the apparatus of Figure 3A;

[0098] Figure 3C is a second side view of the apparatus in Figure 3A;

[0099] Figure 3D is a schematic plan view of the apparatus of Figure 3A with the electrolysis cell installed in the heat recovery module;

[0100] Figure 3E is a schematic perspective view of the apparatus of Figure 3D;

[0101] Figure 3F is a first schematic side view of the apparatus of Figure 3D;

[0102] Figure 3G is a second schematic side view of the apparatus of Figure 3D;

[0103] Figure 4A is a schematic cross-sectional view along the line A-A' of Figure 3B;

[0104] Figure 4B is a schematic cross-sectional view along the line B-B' of Figure 3C;

[0105] Figure 4C is a schematic cross-sectional view along the line C-C' of Figure 3G;

[0106] Figure 4D is a schematic cross-sectional view along the line D-D' of Figure 4C; and,

[0107] Figure 4E is a schematic expanded view of region A of Figure 4D;

[0108] Figure 5A is a schematic side view of an example of apparatus incorporating multiple electrolysis cells;

[0109] Figure 5B is a schematic plan view of the apparatus of Figure 5A;

[0110] Figure 5C is a second schematic side view of the apparatus of Figure 5A;

[0111] Figure 5D is a schematic perspective view of the apparatus of Figure 5A;

[0112] Figure 5E is a schematic cross sectional view along the line A-A' of Figure 5A;

[0113] Figure 6 is a schematic cross sectional view of a further example of apparatus for performing electrolysis;

[0114] Figure 7 is a schematic diagram of the apparatus of Figure 6 used in conjunction with a heat recovery module and storage vessel;

[0115] Figure 8A is a schematic perspective view of a specific example of an electrolysis cell;

[0116] Figure 8B is a schematic side view of the electrolysis cell of Figure 8A;

[0117] Figure 8C is a schematic plan view of the electrolysis cell of Figure 8A;

[0118] Figure 8D is a schematic end view of the electrolysis cell of Figure 8A;

[0119] Figure 8E is a second schematic end view of the electrolysis cell of Figure 8A;

[0120] Figure 8F is a schematic cross sectional view of the electrolysis cell of Figure 8E along the line A-A';

[0121] Figure 8G is a schematic cross sectional view of the electrolysis cell of Figure 8E along the line B-B';

[0122] Figure 8H is a schematic side view of the electrode support of the electrolysis cell of Figure 8A;

[0123] Figure 8I is a schematic end view of the electrode support of Figure 8H;

[0124] Figure 8J is a schematic plan view of the electrode support of Figure 8H;

[0125] Figure 8K is a schematic perspective view of the electrode support of Figure 8H;

[0126] Figure 8L is a first schematic perspective view of the electrode support of Figure 8H with the cathodes removed;

[0127] Figure 8M is a second schematic perspective view of the electrode support of Figure 8H with the cathodes removed;

[0128] Figure 8N is a schematic side view of the cell housing of the electrolysis cell of Figure 8A;

[0129] Figure 8O is a first schematic end view of the cell housing of Figure 8N;

[0130] Figure 8P is a schematic plan view of the cell housing of Figure 8N along the line C-C';

[0131] Figure 8Q is a second schematic end view of the cell housing of Figure 8N along the line D-D';

[0132] Figure 8R is a schematic perspective view of the cell housing of Figure 8N;

[0133] Figure 8S is a schematic end view of the anode end support block of the electrode support of Figure 8H;

[0134] Figure 8T is a schematic side view of the anode support block of Figure 8S along the line E-E';

[0135] Figure 8U is a schematic plan view of the anode support block of Figure 8S;

[0136] Figure 8V is a schematic perspective view of the anode support block of Figure 8S;

[0137] Figure 8W is a schematic rear view of the anode support block of Figure 8S;

[0138] Figure 8X is a schematic side view of the anode retainer bracket of the electrode support of Figure 8H;

[0139] Figure 8Y is a schematic end view of the anode retainer bracket of Figure 8X;

[0140] Figure 8Z is a schematic plan view of the anode retainer bracket of Figure 8X;

[0141] Figure 8ZA is a schematic perspective view of the anode retainer bracket of Figure 8X;

[0142] Figure 9A is a perspective view of a first specific example of a heat generation apparatus including the electrolysis cell of Figure 8A;

[0143] Figure 9B is a schematic side view of the apparatus of Figure 9A;

[0144] Figure 9C is a schematic end view of the apparatus of Figure 9A;

[0145] Figure 9D is a schematic plan view of the apparatus of Figure 9A;

[0146] Figure 9E is a schematic cross sectional view along the line A-A' of Figure 9D;

[0147] Figure 9F is a schematic perspective view of internal components of the condenser/separator of Figure 9A;

[0148] Figure 9G is a schematic plan view of a condensing plate of Figure 9F;

[0149] Figure 10A is a schematic perspective view of a second example of a heat generation apparatus including the electrolysis cell of Figure 8A;

[0150] Figure 10B is a schematic end view of the apparatus of Figure 10A;

[0151] Figure 10C is a schematic side view of the apparatus of Figure 10A;

[0152] Figure 10D is a second schematic end view of the apparatus of Figure 10A;

[0153] Figure 10E is a schematic plan view of the apparatus of Figure 10A;

[0154] Figure 10F is a schematic cross sectional view through the line A-A' of Figure 10D;

[0155] Figure 10G is a schematic plan view of the condensing plate of Figure 10F;

Detailed Description of the Preferred Embodiments

[0156] An example of apparatus for generating hydrogen and heat will now be described with reference to Figures 1A and 1B.

[0157] In this example, the apparatus 100 includes an electrolysis cell 110 and a heat recovery module 120. The electrolysis cell 110 includes a cell housing 111 defining an electrolyte cavity 112 containing an electrolyte 113 in use. The electrolyte cavity 112 is typically pressurised in use so that electrolysis is performed at a pressure greater than normal atmospheric pressure.

[0158] The electrolysis cell 110 further includes at least one cell outlet 114 in fluid communication with the electrolyte cavity 112, so that in use electrolysis products generated through electrolysis can be collected therefrom. A plurality of electrodes 115 is provided within the electrolyte cavity 112, the plurality of electrodes 115 defining at least one anode and at least one cathode. The electrodes 115 are connected to respective connectors 116, which are in turn connected to an electrical power supply (not shown) in use, thereby allowing electrical current to be supplied to the electrolyte, as will be described in more detail below.

[0159] The module 120 also includes a module housing 121 which defines a cell cavity 122 into which the cell housing 111 may be removably mounted. The module housing 121 also defines a medium cavity 123 containing a heat recovery medium in use. The medium cavity 123 is in thermal communication with the cell cavity 122, so that when the electrolysis cell 110 is positioned in the cell cavity 122, heat generated within the electrolysis cell 110 is transferred to the heat recovery medium.

[0160] The heat recovery module 120 also includes an inlet 124 and an outlet 125, in fluid communication with the medium cavity 123, so that heat recovery medium can pass through the medium cavity 123, allowing heat to be recovered from the electrolysis cell 110. The heat recovery medium can include any fluid that is capable of storing thermal energy, and typical examples include thermal oils, water or the like. The heat transfer medium may be provided under pressure depending on the operating temperature of the heat recovery module 120, and the nature of the heat transfer medium.

[0161] In one example, the electrolyte includes water, with the generated electrolysis products including at least hydrogen, and more typically a combination of hydrogen and oxygen. However, this is not essential and it will be appreciated that the electrolysis products generated will depend on the electrolyte used.

[0162] The generation of hydrogen provides a mechanism for storing energy, allowing energy to be used on demand, as opposed to on generation. This is particularly important in the case of renewable energy sources, such as photovoltaic or wind power, which rely on ambient conditions to generate energy and hence may only generate power on a periodic basis. However, by converting the generated electricity to hydrogen, this allows the energy to be stored and used as required, for example to generate electricity using fuel cells, for burning in thermal engines, or the like while developed heat could be immediately used in a process like the heating of a fluid for an industrial or home use like the provision of hot water or if heated enough be converted to a vapour and used in a process to convert thermal energy to mechanical and/or electrical power.

[0163] The above described arrangement provides a number of advantages over traditional electrolysis arrangements. Firstly, the electrolysis cell 110 is removable from the heat recovery module 120, allowing the electrolysis cell 110 to be removed therefrom for maintenance. This is important because the electrodes 115 typically degrade over time, meaning the electrodes 115 require periodic reconditioning. Accordingly, by allowing the electrolysis cell 110 to be easily removed from the heat recovery module 120, this allows the electrodes to be easily replaced or reconditioned. As part of this process, a spare electrolysis cell 110 can be provided into the heat recovery module, allowing electrolysis to be continued whilst the original electrolysis cell is reconditioned.

[0164] A further benefit of the above described arrangement is that the cell housing defines a pressurised electrolyte cavity in use. Use of pressure within the electrolyte cavity allows electrolysis to be performed at a temperature above the boiling point of the electrolyte at atmospheric pressure. This for example allows electrolysis of water to be performed at temperatures of over 100°C, including up to 200°C and above, vastly increasing the efficiency of the electrolysis process and allowing higher heating of the fluid passing through the heat recovery module.

[0165] Despite being pressurised, the arrangement includes an outlet 114 to allow hydrogen and other electrolysis products, such as oxygen to be easily collected, and transferred to a suitable pressurised storage vessel, allowing the hydrogen to be subsequently used or be directly extracted and used. It will also be appreciated that as the electrolysis cell is pressurised, this allows the hydrogen to be collected under pressure, reducing the need to further compress the hydrogen for storage.

[0166] The use of the heat recovery module 120 also allows excess heat to be recovered from the electrolysis cell 110, and converted to useful work, for example by using a thermal engine, such as a boiler and steam turbine or similar, to generate electricity, thereby further increasing the efficiency of the process or be applied as heat in another process.

[0167] An example of use of the apparatus 100 in generating hydrogen using electricity from a power supply will now be described in more detail with reference to Figure 2A.

[0168] In this example, the apparatus 100 is coupled to a power supply 200. The power supply 200 can be any form of power supply, but in one particular example is a power supply that generates a variable amount of electricity, such as a wave, wind or solar powered electricity supply or a supply connected to an electrical grid or a supply connected to a thermal machine converting heat into electrical power driven by the fluid passing through the heat recovery module 220.

[0169] The power supply 200 is electrically connected to the connectors 116, via respective connections 201, 202, such as electrical cables or the like. A trigger circuit 210 is provided coupled to the connections 201, 202, and hence the connectors 116. This trigger circuit 210 is coupled to a switch 211, which is in turn is used to selectively connect the connections 201, 202 to a load 212. The trigger circuit 210 typically includes a sensor 210.1 for sensing current flow and/or electrical potential flowing in or which exists across the connections 201, 202, and an electronic controller 210.2, such as a microcontroller, for controlling the switch 211 in accordance with the sensed current and/or electrical potential.

[0170] In use, this arrangement allows the trigger circuit 210 to detect current flow through the electrolysis cell 110 and/or electrical potential across the connections 116 and selectively operate the switch 211 to divert current through the load 212 as required. This can be used to

prevent damage to the electrolysis cell, for example in the event that an over potential scenario is detected. To achieve this, the controller 210.2 compares the sensed potential and/or current to a threshold representing a safe potential and/or current flow, and operates the switch 211 to divert at least some current through the load 212 in the event that the threshold is exceeded. This may be required for any one of a number of reasons, such as to accommodate variations in the power output by the power supply 200, or the like.

[0171] However, in another example, additional electrical energy can be generated through the pyroelectric or Seebeck effect. In this regard, changes in temperature generate an electrical potential within pyroelectric materials, such as pyroelectric crystals, pyroelectric metals, or the like. In the event that such materials are electrically connected to the connectors 116, this will add to the potential energy available across the connections 201, 202 resulting in additional available current.

[0172] In one example, this can occur if the electrodes are made of pyroelectric materials, such as austenitic stainless steel. In this instance, the current flow will reverse or increase depending on whether the cell is warming or cooling or the direction heat is flowing through any one electrode, meaning the actual potential applied to the electrolyte will either be greater or lesser than that of the power supply or of a reverse charge.

[0173] However, additional pyroelectric materials can purposefully be incorporated into the electrolysis cell, for example by providing pyroelectric crystals within the housing and coupling these to the connectors 116 via diodes to ensure current is added to the applied current regardless of whether the electrolyte is warming or cooling. This can be used to intentionally generate additional potential resulting in electrical current. In one example, the pyroelectric materials can be positioned anywhere within the electrolyte cavity, for example in an annular region surrounding the electrodes. However, alternatively these could replace selected electrodes, allowing these to be easily integrated into the apparatus, whilst maximising the use of temperature changes occurring within the vicinity of the electrodes to generate additional potential and/or current. It will be appreciated that the pyroelectric materials could be electrically insulated from the electrolyte, but that this is not essential, and the pyroelectric materials could be electrically connected to the electrolyte, for example if the material is used for the electrodes.

[0174] As an alternative to the use of pyroelectric materials, two dissimilar metals can be provided in thermal and electrical contact, so that a thermal gradient through the junction between the metals leads to the generation of an electrical current through the Seebeck effect. In one example, this is achieved by having the electrical connections to the electrodes include two dissimilar metals and when heat is conducted from the cell into the connections the actual potential applied to the electrolyte will either be greater or lesser than that of the power supply or of a reverse charge.

[0175] Temperature changes may arise for a number of reasons. For example, activating and deactivating the cell will cause warming and cooling cycles, whilst changing the rate of flow of heat transfer medium through the heat recovery module will also influence the electrolysis cell operating temperature. Temperature variations may also arise inadvertently during normal operation of the electrolysis cell, for example due to unequal heat generation or flow within the cell, as well as during activation and deactivation of the cell. In either event, the load 212 can act as a buffer in the event that excess potential and/or current is generated, whilst any additional current generated below an excess threshold will simply contribute to the electrolysis process.

[0176] The nature of the load 212 may vary depending upon the preferred implementations. In one example, the load 212 is in the form of a resistive load which converts excess current resulting from elevated or reverse potentials due to the pyroelectric or Seebeck effect into heat, which is then dissipated. However, alternatively excess current can be used to perform useful work. For example, the load 212 could be in the form of a chemical battery for storing energy, an electrical machine, a heating element for heating electrolyte, or water in a boiler, or the like.

[0177] In a further example, the load 212 represents another electrolysis apparatus similar to the apparatus 100. In this example, the two sets of apparatus 100 are provided in parallel with the second apparatus only being utilised when sufficient current flow is available due to over or reverse potentials developing across 201,202. This particularly arrangement provides a number of additional benefits. For example, this allows additional electrolysis to be performed during over potential events, further enhancing the ability of the apparatus to generate hydrogen and heat. Additionally, by suitable configuration the two sets of apparatus 100 can be used interchangeably. This allows the relative usage of each set of apparatus 100

to be controlled, to thereby extending the operating life of the system, increase operational efficiency and/or system output.

[0178] It will further be appreciated from the above described example, that the use of a trigger circuit and load can be used with other electrolysis systems, and that its explanation with respect to the apparatus 100 is for illustrative purposes only and is not intended to be limiting.

[0179] In any event, further features when the apparatus 100 is used as the electrolysis system will now be described.

[0180] In particular, in this example, the inlet 124 and outlet 125 are typically coupled to a thermal engine. The thermal engine includes a super heater 220, which could be a boiler or other type of heat exchanger, coupled to the inlet 124 and outlet 125 via a connecting pipe 221, and pump 222. This allows heat recovery medium to be circulated through the pipe 221 using the pump 222, thereby enabling heat to be transferred from the heat recovery module 120 into the super heater 220.

[0181] The super heater 220 is used to boil a working medium, such as water, and generate a vapour under pressure, such as steam. The steam is transferred via a pipe 231 to a thermal engine like a steam turbine and generator 230, which is used to supply electricity via an output 234. Steam passing through the turbine and generator 230 is condensed in a condenser 232, and returned to the boiler using a pump 233, allowing the water to be reused and part of the developed heat recycled. Whilst the example focuses on the use of water and steam as the working medium, it will be appreciated that other fluids can be used. Instead of a separate working fluid, the electrolyte can be used as the working medium.

[0182] In another example as shown in Figure 2B, heated heat transfer medium from the apparatus 100 is supplied via the outlet 125 to the super heater 220, where additional heat is added by a heat source 235 thereby increasing the heat transfer medium's temperature and pressure. The heat transfer medium then flows through pipe 231 to the turbine and generator 230, allowing energy to be supplied at 234, with the heat transfer medium being further condensed in a condenser 232 and returned to the apparatus 100 by the pump 236. Thus, in this example, it will be appreciated that the heat transfer medium can also act as the working

medium for driving the turbine 230 or heated electrolyte could be used, or a combination of both.

[0183] Returning to Figure 2A, the apparatus typically includes a reservoir 240 for supplying electrolyte via a connecting pipe 241, to a cell inlet, which is in fluid communication with the electrolyte cavity as will be described in more detail below.

[0184] The cell outlet 114 may be coupled to a pressurised storage vessel 250 via a connecting pipe 251 and optional compressor 252, allowing hydrogen and other gaseous products generated by the electrolysis process to be stored therein. In this regard, it will be noted that the above described arrangement does not separate the anodes and cathodes, meaning that the electrolysis products will be mixed. Accordingly, in one example, the electrolysis products include a combination of hydrogen and oxygen, which are stored together in the form of oxyhydrogen, which can be subsequently used as required, for example in a combustion engine, fuel cell, or the like. Alternatively, the oxygen and hydrogen can be separated using known separation mechanisms, allowing the oxygen and hydrogen to be used and/or stored independently as required. It will be appreciated that avoiding the need to separate the anode and cathode, for example using electrolysis membranes, greatly simplifies the arrangement, and significantly reduces the cost of manufacture.

[0185] In one example, the oxygen and hydrogen can be used to generate electricity on demand, for example by burning the oxygen and hydrogen to heat the super heater 220 or alternatively the reservoir 240. It will be appreciated that in this configuration, the apparatus provides a self-contained system for storing energy generated by a power supply in the form of oxyhydrogen and then converting this into electricity for use on demand.

[0186] This arrangement is particularly suitable for use with renewable sources, such as photovoltaic solar power systems, which only periodically generate electricity. For example, during daylight hours, excess electricity not required for immediate use can be converted into oxygen and hydrogen, with these being converted back into electricity when demand rises above supply, such as at night.

[0187] A second example of an electrolysis apparatus will now be described with reference to Figures 3A to 3G and 4A to 4E, with Figures 3A to 3G showing external features and Figures 4A to 4E showing internal features.

[0188] In this example, the apparatus 300 includes an electrolysis cell 310 having a cell housing made of first and second portions 311.1, 311.2, acting as a cover and base, respectively. The cover and base 311.1, 311.2 are sealingly engaged in order to allow the cell housing to act as a pressure vessel, and may be coupled together in any suitable manner, such as through cooperating screw threads, or the use of additional connecting bolts, or the like.

[0189] The cover and base 311.1, 311.2 are typically made of a thermally conductive material that is sufficiently strong to withstand typical operating pressures. In one example, the cover and base 311.1, 311.2 are made of stainless steel, but it will be appreciated that other suitable materials could be used.

[0190] The base 311.2 defines an electrolyte cavity 312 containing an electrolyte (not shown), in use. The cover 311.1 includes an outlet 314, which coupled to an outlet pipe 314.1 ending in flange 314.2, allowing the outlet 314 to be connected to external equipment, such as a pressurised collection system, similar to the pressurised storage vessel arrangement described above with respect to Figure 2A. The outlet 314 is provided in fluid communication with the electrolyte cavity 312 via a passage 314.3, extending through the cover 311.1.

[0191] The electrolysis cell 310 further includes a plurality of electrodes 315 in the form of a number of laterally spaced substantially laminar electrode plates, supported by an electrode support 415. The electrode plates 315 can be made of any suitable material that is capable of conducting electricity and optionally acting to provide a catalyst effect to facilitate the electrolysis process. The electrodes may therefore be made of stainless steel, palladium, platinum, gold, or the like, or a material plated with an element like platinum, palladium gold or the like.

[0192] In this example, the electrodes 315 are coupled to the electrode support 415 by respective bolts 415.1, 415.2, extending laterally outwardly therefrom, with the electrodes being held in place using retaining nuts 415.3, 415.4, allowing these to be removed from the

support as required. The support 415 is in the form of a support plate, which is in turn coupled to the cover 311.1 and which is electrically insulated from the cover. This arrangement allows the electrodes 315 to be suspended within the electrolyte cavity 312, so that in use the electrodes are at least partially suspended in electrolyte. Additionally, by coupling the support 415 to the cover 311.1, this allows the electrodes to be removed from the electrolysis cell when the cover is removed, thereby facilitating replacement or reconditioning of the electrodes. It will be appreciated however that other suitable mounting arrangements could be used.

[0193] In the current example, the electrode plates extend in first and second orthogonal directions and are separated in a third orthogonal direction to form a sandwich type arrangement. In this example, alternating plates are connected to respective connectors 316.1, 316.2, which extend through the cover 311.1, allowing the electrodes to be connected to a power supply. In this regard, each connector 316.1, 316.2 is coupled via connecting members 316.3, 316.4 to every other electrode 315, so that adjacent electrodes 315 act as anodes 315.1 and cathodes 315.2, respectively, as shown in Figure 4E. Accordingly, it will be appreciated that this plate electrode arrangement provides a number of anodes and cathodes adjacent to each other allowing electrolysis to occur therebetween.

[0194] In one example, the electrodes have a surface area of approximately 10 cm^3, and are separated by a distance of approximately 0.1-10 mm and more typically 1.2 mm, which is ideal for maximising the amount of surface area to which electrolyte is exposed, whilst ensuring optimal current flow between the electrodes through the electrolyte, thereby maximising efficiency of the electrolysis process. The electrodes are typically between 0.2 and 20 mm thick and more typically 1.2 mm thick. It will be appreciated however that other configurations could be used.

[0195] For example, it will be appreciated that the current that will flow during an electrolysis process is partly determined by the conductiveness and properties of the electrolyte. Accordingly, the optimum distance between the electrodes will be partly dependant on the conductiveness and properties of the electrolyte used, the magnitude of the applied current, or the like. Furthermore, an electrolysis cell could be scaled according to a required output and application which could result in electrodes being miniaturised or increased to have large individual surface areas. In scaling an electrolysis cell down, or

miniaturising it, the spacing between the electrodes will accordingly potentially decrease and could potentially be as little as fractions of a millimetre. The same accounts for the electrode thickness. In cases where a larger electrolysis cell is constructed the spacing between electrodes and thickness of individual electrodes could potentially be increased accordingly. Thus, spacings could be as low as 0.1 mm or less and may increase to up to several centimetres, depending on the circumstances.

[0196] In another example electrodes could be unevenly spaced in order to maximise or adjust the pyroelectric generating properties with or without a membrane or insulating material incorporated between some electrodes or applied to the surface covering parts or whole of some electrodes. Some electrodes could also be contained inside a separate containing body or bodies resulting in these electrodes not being in direct contact with the surrounding electrolyte, yet be thermally coupled with it resulting in these acting as pyroelectric receptors. Pyroelectric receptor bodies could be filled with electrically neutral gas or a material inhibiting electrical discharge to the containing material or be evacuated of any gas or air.

[0197] It will also be appreciated that one or more bodies of pyroelectric material (pyroelectric receptors) could be positioned inside or outside the cell cavity, as well as inside or outside of the heat transfer medium cavity, or in a super heater 220 or the like. Where a plurality of pyroelectric receptors are incorporated, these can be arranged either as evenly spaced bodies or can be distributed or randomly spaced. Utilisation of uneven spacing can help enhance the pyroelectric effect. It will be appreciated that the pyroelectric receptors could be provided near or around the electrodes such that they are in thermal communication with the electrolyte, or could be provided in or around the heat transfer medium cavity so they are in thermal communication with the heat transfer medium.

[0198] The pyroelectric receptors could be connected to the same electric circuit as the electrodes or to a separate electric circuit in either a parallel or series electrical configuration or any parallel/series electrical configuration where the purpose of the separate electric circuit is to moderate and/or extract electrical potential and/or electrical current from them to perform electrical work or be stored as electrical energy.

[0199] Furthermore, in the current example, the electrode plates 315 are arranged in use so that electrolysis products travel between the electrode plates to the outlet 314. In one example this is achieved by arranging the electrode plates in a substantially vertical orientation, but it will be appreciated that other arrangements could be used.

[0200] In this example, the cover 311.1 may also define a thermal installation cavity 411, containing a thermally insulating material to thereby reduce heat losses via the cover 311.1. A level control port 318 by which the electrolyte level could be monitored and/or controlled may be provided within the electrolyte cavity 312, whilst a sensing port 416 is provided to allow a thermostat or other temperature sensor to be located inside the electrolysis cell allowing the temperature therein to be monitored. This can be used for controlling operation of the apparatus, as well as for monitoring efficiency or the like.

[0201] The electrolysis cell also includes an inlet 317 including an inlet pipe ending in an inlet pipe flange 317.1, allowing the inlet 317 to be provided in fluid communication with an electrolyte reservoir, so that electrolyte can be supplied to the electrolyte cavity 312 as required or circulated either via a convection flow circuit or a pump. In this example, the inlet 317 is provided in an underside of the cell housing 311, allowing electrolyte to be supplied into a bottom of the cavity 312 under pressure, thereby maintaining pressure within the electrolyte cavity 312. However, it will be appreciated that other suitable arrangements may be used.

[0202] In one example, the electrolyte reservoir is designed to supply heated electrolyte to thereby help maintain the temperature of the electrolysis cell, and optionally to induce heat variations within the electrolyte cavity to thereby generate electrical energy through the pyroelectric effect outlined above. In one example, electrolyte can be supplied from a solar thermal heating system, such as a solar powered hot water system, or the like.

[0203] The electrolysis cell 310 is mounted in a heat recovery module 320, having a module housing 321, defining a cell cavity 322 for receiving the electrolysis cell 310. The heat recovery module also defines a medium cavity 323 containing a heat recovery medium. The housing 321 is typically made of a thermally conductive material that is sufficiently strong to withstand typical operating pressures. In one example, the housing 321 is made of stainless steel, but it will be appreciated that other suitable materials could be used.

[0204] The medium cavity 323 is typically positioned outwardly of the cell cavity 322. In this example, the medium cavity 323 has a tubular shape whilst the cell housing 311 has a substantially cylindrical shape. Accordingly, the module housing 321 has an elongate substantially annular shape defining a cylindrical cell cavity 322 and an annular medium cavity 323 extending substantially circumferentially around the cell cavity 322. This arrangement helps maximise transfer of heat from the electrolysis cell to the heat transfer medium, whilst allowing the electrolysis cell to maintain a desired operating temperature, although it will be appreciated that other arrangements may be used.

[0205] In this example, the apparatus also includes an insulating jacket 340 which extends around the heat recovery module 320. In this example arrangement, the insulation jacket includes a jacket housing 341 defining an insulation cavity 343 between the jacket housing 341 and the module housing 321, the insulation cavity 342 containing a thermally insulating material to thereby reduce heat losses from the heat recovery module 320. A lid 342 is coupled to the jacket housing 341, via connecting bolts or the like, allowing the heat recovery module to be retained therein.

[0206] To allow heat to be recovered from the heat transfer medium, the heat recovery module 320 includes two inlets 324.1, 324.2 and four outlets 325.1, 325.2, 325.3, 325.4, which are in fluid communication with the medium cavity 323, via respective inlet and outlet connecting tubes 324.3 324.4; 325.5, 325.6, 325.7, 325.8, extending through the insulating jacket. The inlets 324.1, 324.2 are provided in a bottom of the medium cavity 323, whilst the outlets 325.1, 325.2, 325.3, 325.4 are provided in a top of the medium cavity. This ensures cooler medium is supplied to the bottom of the cavity 323 and removed from the top 323, which will generally be hotter due to convective processes or forced via an applied pump.

[0207] The use of a plurality of inlets and outlets allows multiple and/or optional sensing apparatus to be connected in order to sense, measure and/or control the process or could be used to connect such as to ensure a sufficient flow of heat transfer medium through the cavity to prevent overheating of the electrolysis cell 310 or allow maximum heat extraction. It will be appreciated that other arrangements could be used. In this regard, it will be appreciated that the rate of flow of heat transfer medium through the medium cavity 323 can be used to control the rate at which heat is extracted from the electrolysis cell, thereby allowing the temperature of the electrolysis cell 310 to be controlled.

[0208] A further example of an electrolysis apparatus will now be described with reference to Figures 5A to 5E. For the purpose of this example, similar features to the previous example are denoted by similar reference numerals increased by 200.

[0209] In this example, the apparatus 500 includes a plurality of electrolysis cells 510 arranged in a single heat recovery module. Each electrolysis cell 510 is generally of a similar form to the electrolysis cell 310 described above, and will not therefore be described in detail. However, it will be appreciated that each cell includes a housing 511 defining an electrolyte cavity 512 containing an electrolyte, an outlet 514 and an outlet pipe 514.1 for removing electrolysis products, and an inlet 517 for supplying replacement electrolyte. Each electrolysis cell 510 contains a number of laterally spaced substantially laminar electrode plates 515 supported in the electrolyte cavity and coupled to connectors 516. Additional features, such as thermal insulating materials, a thermal well, sensing ports and the like are provided, but not labelled for clarity.

[0210] Each electrolysis cell 510 is mounted in the heat recovery module 520, having a module housing 521, defining a plurality of cell cavities 522 for receiving the electrolysis cells 510. The heat recovery module also defines a medium cavity 523 including inlets 524 and outlets 525 to allow heat recovery medium to be circulated therethrough. The medium cavity 523 substantially surrounds the electrolysis cells 510 to maximise transfer of heat from the electrolysis cell to the heat transfer medium. An insulating jacket may be provided extending around the heat recovery module, although this is not shown for the purpose of clarity only.

[0211] In this example, seven electrolysis cells 510 are shown, but it will be appreciated that this is for the purpose of example only, and is not intended to be limiting. Accordingly, any combination of electrolysis cells 510 provided in a common heat recovery module 520 could be used.

[0212] The use of such a modular arrangement including a plurality of electrolysis cells can provide a number of advantages. For example, some of the electrolysis cells could be used to generate electrolysis products, whilst other ones of the cells act as loads to buffer over potential events, as required, thereby ensuring all usable electricity is used in performing electrolysis.

[0213] Additionally, electrolysis cells can be selectively used, depending on the magnitude of current available from the power supply. This allows additional electrolysis cells to be activated as available current increases, enabling each cell to operate at an optimal current, whilst allowing different magnitudes of supply current to be used.

[0214] A further benefit is in the event that an electrolysis cell requires maintenance, for example if electrodes require reconditioning, this allows individual cells to be removed and repaired whilst other cells continue to operate.

[0215] Additionally, different electrolysis cells could be activated in turn to thereby induce temperature variations across other electrolysis cells, so that additional electricity can be generated through the use of the pyroelectric effect.

[0216] Accordingly, it will be appreciated that the above described modular arrangement can provide a number of further benefits.

[0217] An example of an apparatus for performing electrolysis and generating heat will now be described with reference to Figure 6.

[0218] In this example, the apparatus includes an electrolysis cell 610 including a cell housing 611, defining an electrolyte cavity 612 containing an electrolyte 613 in use. A plurality of substantially parallel spaced apart electrode plates 615.1, 615.2 are provided within the electrolyte cavity 612, the electrode plates 615 defining at least one anode 615.1 and at least one cathode 615.2 at least partially submerged within the electrolytes 613 in use. At least two connectors 616.1, 616.2 are provided, which in use are connected to an electrical power supply thereby allowing the electrical current to be supplied to the electrolyte 613 to thereby perform electrolysis and heating of the electrolytes 613.

[0219] The electrolysis cell further includes at least one cell outlet 614 in fluid communication with the electrolyte cavity 612, the at least one cell outlet being coupled to a heat recovery module in use, and at least one cell inlet 617 in fluid communication with the electrolyte cavity 612, the at least one cell inlet allowing electrolyte 613 to be supplied to the electrolyte cavity.

[0220] The above described electrolysis cell operates to electrolyse the electrolyte, such as water, or a solution of an aqueous salt or hydroxide, such as sodium chloride, potassium chloride, sodium hydroxide or normal water without containing a salt or hydroxide if a strong enough electrical field is applied, or the like, thereby producing electrolysis products. It will be appreciated that the electrolysis products produced will depend on the electrolyte used, so for example if the electrolyte is water, the electrolysis products include hydrogen and oxygen.

[0221] Additionally the electrolysis module generates heat, which acts to heat the electrolyte. The electrolyte is transferred to a heat recovery module allowing the generated heat to be recovered and used in performing work. The use of parallel spaced apart plates creates a large volume of electrolyte undergoing electrolysis, leading to the generation of significant heat which can in turn operate to increase the efficiency of the electrolysis process or the amount of heat which can be extracted to perform work.

[0222] In particular, the electrolysis apparatus can generate sufficient heat to generate electricity, for example using a steam turbine or similar as well as producing hydrogen and oxygen which can be used as desired, for example in a fuel cell or the like to generate additional energy or the heat can be used without conversion in a process. Accordingly, this allows energy from a variety of sources, such as solar cells or the like to be converted into electrolysis products, which can then be used as required, for example to generate electricity on demand, as well as generating heat for more immediate use.

[0223] It has further been discovered that an electrolysis cell constructed from evenly spaced, alternately connected electrodes, exhibits specific characteristics dependent on a number of factors, meaning that selection of appropriate operating parameters can have an impact on the efficiency of the system.

[0224] For example, the current such a cell will draw from a power supply is a function of the electrolyte specific conductivity, electrolyte temperature and the combined total electrode surface area. Thus:

- I_C – Cell Current;
- A – Electrode Surface Area;
- T_E – Electrolyte Temperature;

- C_E – Electrolyte Conductivity;
- H – Electrode Height;
- W – Electrode Width;
- n – Number of Electrodes.

[0225] Thus the cell current is given by:

$I_C = f(A, T_E, C_E)$

where: A is a function of the Electrode Height, Width and Number of Electrodes ($A = f(H,W,n)$)

[0226] If a sufficiently large electric field is present between the anodes and cathodes during electrolysis, positive ions, such as hydrogen ions liberated from water molecules, are transported towards the cathode by virtue of the electric fields generated between the anode and cathode. Furthermore, increasing the potential can increase the rate at which ions are both liberated and transported.

[0227] If the rate of liberation of these hydrogen ions is higher than the rate at which they will recombine with electrons from the cathode, or adjacent hydrogen ions to form hydrogen gas at the cathode, a percentage will start to load into the cathode crystal structure and/or start forming a positive skin-like barrier at the cathode. As a result, hydrogen ions present in the vicinity of the cathode will present a strong coulomb barrier, meaning approaching positive ions will undergo elastic collisions and be repelled, in turn causing these to collide with further oncoming ions. These collisions result in a release of energy within the electrolyte, which in turn causes heating of the electrolyte.

[0228] In order for these conditions to occur, both the current density as well as the electric field strength needs to be high enough. Thus, at a low current density, the rate at which positive ions combine to form hydrogen molecules will exceed or be in equilibrium with the rate at which hydrogen ions are liberated from the electrolyte and be removed from the electrolyte near the cathode thus preventing a coulomb barrier from forming. Additionally at a small applied electric field, the velocity of approaching hydrogen ions will be too low to experience elastic collisions. Instead, oncoming protons will simply be slowed down as they approach the cathode where they will reach a low enough velocity to combine and form hydrogen gas molecules.

[0229] Thus, if the applied electric field is high enough, the momentum of each accelerated ion, which in the case of hydrogen ions are essentially protons, will be higher than what can be absorbed to bind with near electrons and other ions to form molecules and effectively will rather experience elastic collisions as described, with each collision causing some of the kinetic energy to be converted into heat.

[0230] The hydrogen ion (proton) collisions can under certain conditions be high enough to result in protons being accelerated towards the anode with enough momentum to overcome the positive charge barrier at the anode and actually collide with atoms on the surface of the anode. In some instances the hydrogen ions penetrate the lattice structure of the anode and collide with atoms of the inner structure of the anode or even pass right through the anode, exiting on the opposite side, resulting in substantial amounts of kinetic energy being converted into heat. When this occurs, areas of high localised heat will form on the surface and/or inside the anode's lattice resulting in physical damage to the anode. This damage leads to decomposition of the anode, which in turn results in formation of a sediment within the electrolyte.

[0231] High speed temperature measurements conducted of the developed temperature near the outer surface of the outer anode in an anode-cathode parallel array demonstrate high frequency temperature fluctuations taking place near the outer anode under certain high current density and high applied electrical field conditions, and typically after a period of operation and once the cell reached a high enough temperature.

[0232] It is further apparent that the collisions and ion transport can lead to additional interactions, such as low energy nuclear reactions, thereby further enhancing the heating functionality of the electrolysis cell.

[0233] In this regard, operation of an electrolysis cell configured as described above leads to thermal events, exemplified by heat spikes in and or near electrodes and hence electrolyte temperature. It has further been identified that some of these thermal events cause the generation of an electrical potential in the form of a back EMF originating in the electrolysis cell. In one example, in order to mitigate the effect of this back EMF, a low impedance surge arrestor can be connected across the electrolysis cell terminals, which in turn redirect developed electrical surges to a high capacity low impedance load, which could be in the

form of a load and trigger circuit similar to that described above in the example of Figure 2. This can be used to prevent damage to electronic measurement and control equipment, as well as the power supply and/or used to extract the developed electrical energy to perform work or be stored for later use.

[0234] Based on the above, it is apparent that with the cell operating under appropriate conditions, the electrolysis cell's output performance is enhanced with excess heat and gas development occurring as a result of:

- Proton collisions with other protons, molecules and electrode atoms;
- Proton acceleration due to high enough applied electric field;
- Kinetic energy being converted to heat when collisions occur.

[0235] Analysis demonstrates that the power generated by each cell is proportional to the surface area of the electrodes, the applied current, the voltage and inversely proportional to the distance between the electrodes, so that the output power of the cell is given by:

$$P \propto \frac{A.I.V^2\sqrt{V}}{d}$$

where: P is the output power of the cell;

A is the electrode surface area;

I is the current through the cell;

V is the potential across the cell; and,

d is the spacing between the electrodes.

[0236] It will also be appreciated that each physical cell construction has a specific performance coefficient which depends on the cell and system's heat transfer efficiency and construction, steady state operational temperature, which is in turn dependent on the cell internal and transfer fluid operational pressures and specific heat transfer coefficients, electrode material, electrode thicknesses and cell and system thermal insulation efficiency. The performance coefficient can be determined empirically for each construction based on a control experiment and the output verified against experiments where certain operational parameters, such as, Cell Current, Applied Cell Electrical Potential and Electrode Spacing is varied.

[0237] In any event, it is apparent from this that the electric potential of the applied electrical current has a large impact on the output power developed by the electrolysis cell, and that increasing the applied potential can result in significant increases in the operating efficiency. In this regard, this is contrasted with traditional techniques in which it has been understood that the applied potential should be minimised to avoid ohmic losses, whilst ensuring this is sufficient to allow electrolysis to be performed.

[0238] As a result, whereas traditionally electrolysis of water is performed at applied voltages of above 1.45 V or lower, the above apparatus is typically adapted to operate at higher voltages, such as at least 5 V, at least 10 V and more typically in the region of 10-25 V and even higher. This can cause enhanced thermal effects, for example due to collisions of accelerated ions with other atoms, or ions, thereby leading to increased heating and hence efficiency of operation.

[0239] In some circumstances, it is preferable that the potential does not exceed an electrical breakdown potential of the electrolyte, which can lead to arcing between the electrodes, and hence short circuiting of the electrodes. This maximum operating potential will typically depend on factors, such as the nature of the electrolyte and the size and spacing of the electrodes. Accordingly, the potential is less than 100V, less than 80 V and more typically less than 60 V. However, this is not essential, and will depend on the preferred implementation, so for example arcing may be beneficial in some arrangements.

[0240] The applied electric field strength which is a function of the applied electric potential and the spacing between adjacent anodes and cathodes should be high enough to result in effective ion acceleration. Typically the above apparatus is operated at an applied electric field of at least 3000 Volts per meter, at least 12000 Volts per meter and more typically at least 24000 Volts per meter and even higher.

[0241] The operating current density of the electrolysis cell will depend on the resistivity of the electrolysis cell, which will in turn depend on the conductivity and hence nature of the electrolyte, as well as on the surface area and spacing of the electrodes and the operating temperature. Accordingly, the physical configuration of the cell and the electrolyte used are selected to match the capabilities of the electrical supply, and to ensure the desired operating potential is achieved or the vice versa, the supply is matched to the cell or designed for a

specific output. In general however the electrolysis cell is operated at a current density of at least 500 Ampere per square meter, at least 1000 Ampere per square meter, and more typically about 3000 Ampere per square meter or higher.

[0242] In one example, the electrode plates 615 are separated by distance of at least one of between 0.1 millimetres and 10 millimetres, between 1.8 and 2 millimetres, and between 2 millimetres and 5 millimetres. The electrode plates also typically have a thickness of between 0.1 millimetre and 10 millimetres, between 1 millimetre and 2 millimetres, and between 2 millimetres and 5 millimetres, although any suitable thicknesses can be used with the anode electrode thickness being same or different from the cathode electrode thickness.

[0243] In general, for some anode materials, the anodes undergo corrosion and/or degradation during the electrolysis process, which can lead to a reduction in anode volume. Accordingly, in one example the anodes are thicker than the cathodes and may also be designed to be easily replaceable as will be described in more detail below.

[0244] The electrodes can be formed from any suitable material depending on the preferred implementation. In one example, the electrodes include transition metals, and more particularly transition metals having an atomic number of 26-28, 44-46 or 76-78 (eg: Iron, Cobalt, Nickel, Ruthenium, Rhodium, Palladium, Osmium, Iridium or Platinum). The metals may be pure, or alternatively combined with other elements in the form of alloys, such as stainless steel, or the like.

[0245] Additionally, the electrolysis cell can include pyroelectric materials, as well as dissimilar metals, to thereby allow additional current to be generated through thermoelectric effects, such as the pyroelectric effect, Seebeck effect, or the like.

[0246] Furthermore, in one example, the higher the operating temperate of the electrolysis cell, the more efficient it's operation, and in particular the more work that can be performed with the recovered heat. The operating temperature will typically be limited by the boiling point of the electrolyte at the cell operational pressure, so whilst the cell can be operated at atmospheric pressure, this tends to limit the operating temperature. Accordingly, the electrolysis cell typically operates as a pressure vessel allowing the boiling point of the electrolyte, and hence the operating temperature to be increased. Accordingly in one

example, the operating temperature is at least 60°C, at least 80°C and more typically at least 100°C, and preferably at least 120°C or higher.

[0247] However, it will be appreciated that the above described values are for the purpose of example only and are not intended to be limiting. In this regard, as has already been discussed above, the power output from such an electrolysis cell is proportional to the electrodes physical dimensions, the number of electrodes, the applied electric field across electrodes and the resultant current density between the electrodes. The applied electric field is in turn dependant on the distance between electrodes and the applied electrical potential, whilst the resultant current density is dependant on the electrolyte composition and conductivity, as well as the applied current and total surface area of the electrodes. Consequently, ratios of these parameters will allow effective scaling of such a cell, ranging from a micro version to very large and extremely powerful cells.

[0248] It will be appreciated that scaling of the cell will be subject to certain physical constructional limitations, such as the number of electrodes, surface area of electrodes, thickness of electrodes and spacing between electrodes, that can be achieved for a certain physical size of cell (either when being scaled up or scaled down).

[0249] As an example, a cell could be constructed capable of delivering a power output in the hundreds of mega watts and in doing so, very thick electrodes of large surface area might be required which will be governed by the mechanical strength of the electrode material to be self-supporting. Furthermore, such large electrodes might have to be spaced further apart and therefore will require a much higher applied electrical potential in order to achieve a minimum desired electrical field strength. Similarly, a sufficiently high cell current would be required to achieve a high enough current density. The same applies for miniaturization right down to the nano scale where all parameters could be rationally scaled to achieve the desired output power for a desired size of cell.

[0250] Thus, it will be appreciated that the example values provided above are intended to reflect a 1 kW device suitable for bench-top testing. However, these values may be required to be scaled significantly when producing larger or smaller scale devices, and these should not therefore be thought of as limiting.

[0251] In one example, the inlet 617 is coupled to the heat recovery module so that electrolyte is recirculated through the electrolyte cavity and heat recovery module. However this is not essential and other arrangements, such as supplying new electrolyte to the electrolyte cavity from a reservoir or similar can be used.

[0252] The inlet 617 and outlet 614 may also be arranged so that the electrolyte supplied to the electrolyte cavity 612 flows between the electrode plates 615. In one example this is performed by providing the inlet and outlet 617, 614 arranged on opposing sides of the electrolyte cavity 612 facing edges of the electrode plates 615 so that electrolyte flowing into the cavity flows directly between the electrode plates. This maintains a flow of electrolyte between the electrode plates, which helps prevents build-up of contaminants, such as corrosion and other products, on the electrode surfaces, further helping to improve the efficiency of electrolysis process.

[0253] In one particular example, the inlet 617 and outlet 614 are arranged in upper and lower ends of the cell housing respectively, with the electrode plate 615 aligned substantially vertically within the electrolyte cavity 612 and spaced apart substantially horizontally. In this instance, as the electrolyte is heated this will tend to rise towards the electrolyte cavity so that convection within the electrode system can further enhance electrolyte flow between the electrode plates 615.

[0254] The electrode plates 615 are typically laminar but alternatively could be curved, cylindrical, undulating, or the like and in general any shape could be used as long as this provides substantially parallel spaced apart surfaces allowing the electrolysis to be performed.

[0255] Typically the at least two connectors are electrically connected to the electrode plates so that adjacent plates act as anodes and cathodes in use. In one particular example an odd number of electrodes are provided so that each cathode is positioned between two anodes, which can further enhance the total efficiency and output of the cell in both electrolysis products and heat.

[0256] In one example the cell housing includes an opening and a cover removably mounted within the opening to allow at least some of the electrode plates to be removed from the

electrolyte cavity 612. In one example the apparatus includes an electrode support, with the electrodes being coupled to the electrode support so that the electrodes are at least partially submerged in electrolyte in use with the support being coupled to the cover allowing at least some of the electrodes, such as the anodes, to be removed from the electrolyte cavity.

[0257] The electrolysis cell is typically operated in conjunction with a heat recovery module, condenser, gas storage vessel and control system as will now be described in more detail with reference to Figure 7.

[0258] In this example, the electrolysis cell 610 is connected via an outlet conduit 721 to the heat recovery module 720. The heat recovering module 720 includes a heat exchanger including a heat exchanger outlet pipe 731 that typically is connected to a heat engine in a manner similar to that described above with respect to Figure 2.

[0259] A heat recovery module outlet pipe 723 extends to the electrolysis cell inlet allowing electrolyte to be recirculated through the heat recovery module 720. The heat recovery module outlet pipe 723 may include a pump 722 for forced recirculation, although alternatively this can occur through convection processes, for example due to suitable relative positioning of the heat recovery module 720 and the electrolysis cell 610. In the event that a pump 722 is used, the pump can be controlled via an electronic controller (not shown), allowing the flow rate of electrolyte to be controlled, for example based on the temperature of the electrolyte. It will be appreciated from this that a controller can be coupled to the pump and temperature sensors provided in thermal communication with the electrolyte, for example in the electrolyte cavity 612, thereby allowing the flow rate to be controlled based on the electrolyte temperature or by a controlled valve before or after the pump restricting flow passing through the electrolysis cell 610.

[0260] The use of the pump 722 can also be used to maintain a minimum flow rate which can further enhance the flow of electrolyte between the electrodes 615 thereby ensuring that the surfaces of the electrodes 615 are maintained free of contaminants, such as corrosion products.

[0261] The heat recovery module 720 is also connected via a gas outlet pipe 751 and an optional compressor 752, to at least one storage vessel 750, which can act to store electrolysis products such as hydrogen and oxygen as mixed or pre separated product.

[0262] The electrolysis cell 610 is also coupled to a power supply 700 which may be a renewable or otherwise variable energy source such as solar panels, wind turbines or the like or another form of conventional electrical power source such as an electrical grid or the electrical outlet of a thermal machine and generator combination. A trigger circuit 710 is provided electrically coupled to the connectors 716 and power supply 700, the trigger circuit 710 being coupled to a switch 711, which is in turn used to selectively connect the power supply to a load 712. The trigger circuit 710 typically includes a sensor for sensing current flow and/or electrical potential across the anode-cathode connection, and an electronic controller, such as a microcontroller, for controlling the switch 711 in accordance with the sensed current and/or electrical potential. As in the example of Figure 2, the arrangement allows the trigger circuit 710 to detect current flow through or potential across the electrolysis cell 610 and selectively operate the switch 711 to divert current through the load 712 as required.

[0263] In this example, heat generated by the electrolysis process is sufficient to boil the electrolyte generating vaporised electrolyte, such as steam. The steam is transferred to the heat recovery module 720 which acts as a condenser to condense the vaporised electrolyte allowing this to be pumped back into the electrolysis cell 610. The heat recovery module 720 can also act as a separator for separating vaporised electrolyte from gaseous electrolysis products, such as hydrogen and oxygen.

[0264] In one example, the heat recovery module 720 includes a heat exchanger, through which flows a heat transfer medium such as water, thereby allowing heat to be recovered from the electrolyte. This in turn allows the vaporised electrolyte to be condensed, as well as allowing work to be performed using the recovered heat. Thus, heat transfer medium can then be provided via the heat exchange outlet pipe 731 to a thermal engine or other similar system allowing electricity to be generated, or other work to be performed whilst separated gaseous electrolysis products are removed from the recovery module 720 for full or partial storage or immediately used via a combustion process to enhance the heat in the heat transfer medium.

[0265] In the event that a heat transfer medium is used, then the pressure in the electrolyte cavity should be higher than the pressure in the heat exchanger to enhance recovering of heat. Alternatively, a heat transfer medium can be selected that has a lower boiling point than the electrolyte at equal pressures.

[0266] Alternatively, the heat recovery module 720 is in the form of a thermal engine to develop power whilst condensing or extracting heat from the electrolyte, so that cooling of the vaporised electrolyte as heat is converted into work is substantially enough for condensation of the vaporised electrolyte to take place. A thermal engine can also be positioned before the heat recovery unit to not only assist in the heat extraction/condensing, but to perform work while doing so.

[0267] A specific example of an electrolysis cell will now be described with references to Figures 8A-8ZA.

[0268] In this example, the electrolysis cell 800 includes a hollow electrolysis cell body 811, having a general square cross-section, including cell flanges 812, 813 at opposing open ends of the cell body 811. The inlet 817 and outlet 814 are provided in lower and upper faces of the body 811 respectively. An annular cover mounting plate 816 is coupled to and spaced apart from the end flange 812 via a spacer 815, with the cover mounting plate 816 being held in position via retaining screws 816.2 mounted in apertures 816.1. A mounting nut 813.1 is coupled to the end flange 813 or can be mechanically attached by means of a weld to the outer rims of 816, 815 and 812.

[0269] The electrolysis cell 800 further includes anode and cathode assembly mountings 820, 830 for respectively supporting anodes 821.1, 821.2, 821.3 and cathodes 831.1, 831.2, in a parallel spaced apart arrangement.

[0270] The anode assembly mounting 820 includes an anode mounting body 826 that supports a generally U-shaped anode retainer bracket 822 and cover 827. In use, the anode mounting body 826 is inserted into the open end of the cavity body 810 through the flange 812, with the mounting body sealingly engaging with the flange 812 or body 810, via seal 840. The cover 827 is coupled to the mounting body via bolts 827.2 extending through elongate apertures 827.3 in the cover 827, allowing for relative rotational movement of the

cover 827. The cover 827 is further biased by a spring 829, outwardly from the anode mounting body 826.

[0271] The cover 827 includes a handle 828 and a number of mounting lugs 827.1 circumferentially spaced around an outer perimeter of the cover 827. The spacer 815 and cover mounting plate 816 include corresponding recesses 815.1, 816.1 which in use receive the lugs 827.1 of the cover 827, allowing the cover 827 to be rotated so that the lugs 827.1 engage an inner surface of the cover mounting plate 816, thereby retaining the cover 827 in position, and biasing the anode mounting body 826 into the cavity opening, to thereby effect a seal via the seal 840. During this process, a recess 826.1 in the anode mounting body 826 aligns with a locking pin 818.1 in the cell body 811, thereby retaining the anode mounting body 826 in a desired origination during insertion into the body.

[0272] First and second anode end spacers 823, 824 are mounted at opposing ends of the anode retainer bracket 822, with the end spacers 823 including substantially parallel spaced apart recesses 823.1, 823.2, 823.3, 824.1, 824.2, 824.3 facing each other, thereby allowing the anodes 821.1, 821.2, 821.3 to be mounted therein. The second end spacer 824 includes apertures 824.11 and 824.31 allowing the cathodes 831.1, 831.2 to be slidably received therein, whilst the anode retainer bracket 822 is coupled to the anode mounting body 826, so that when the anode retainer body 826 is removed from the cell body 811, the anodes can be easily extracted and replaced, whilst the cathodes 831.1, 831.2 can be retained in the cell cavity.

[0273] The anode retainer bracket 822 includes cut-outs 822.21, 822.22, 822.23 extending from the U-portion, and which extend through an aperture 823.4 in the first end spacer 823, to thereby engage the anodes 821.1, 821.2, 821.3 and electrically couple these to the anode retainer bracket 822. A mounting lip 822.1 extending from the U-shaped portion further operates to support the anodes 821.1, 821.2, 821.3 in use.

[0274] The anode retainer bracket 822 includes an anode connector 825.1, which when inserted into the cell body 811, engages with and electrically couples to a corresponding anode connector 835.1, mounted in a cathode mounting body 834, thereby providing an external electrical connection to the anodes.

[0275] The cathode mounting assembly 830 includes a cathode mounting body 834, which in use is inserted into the open end of the cell body 811, through the cell flange 813, and secured into sealing engagement with the flange 813 or cell body 811 using a seal 850, using the mounting nut 813.1. The cathode mounting body 834 includes a recess 834.1 for engaging a locking pin 818.2 in the cell body 811, thereby aligning the cathode mounting body 834, relative to the cell body 811. The cathode mounting body 834 supports the cathodes 831.1, 831.2 which project from the cathode mounting body 834 in a parallel spaced apart manner. The cathodes 831.1, 831.2 are electrically coupled to connector bolts 832.1, 832.2 to provide electrical connections to the cathodes.

[0276] In use, the cathode assembly mounting 830 is fixed to the cell body 811, whilst the anode assembly mounting 820 is inserted into and removed from the cell body 811 by selective engagement and disengagement of the cover 827 and the cover mounting plate 816, thereby allowing the anodes to be replaced.

[0277] An example of a heat generating apparatus including the electrolysis cell of Figure 8A will now be described with reference to Figures 9A to 9G.

[0278] In this example, the apparatus 900 includes an electrolysis cell jacket 910 containing the electrolysis cell 800 in the use. A combined condenser/separator 920 is provided for condensing vaporised electrolyte and separating this from electrolysis products, such as hydrogen and oxygen. An electrolyte holding tank 930 is provided for holding electrolyte prior to it being supplied to the electrolysis cell 800.

[0279] In more detail, the electrolysis cell jacket 910 includes a cylindrical body 911, defining a jacket cavity 912, within which is positioned the electrolysis cell 800. The jacket cavity 912 is used to contain heat transfer medium, allowing this to be preheated prior to it being supplied to the condenser/separator 920.

[0280] The condenser/separator 920 includes an outer condenser/separator body 921 and an inner condenser/separator body 922. In this example, the outer and inner condenser/separator bodies 921, 922 are generally cylindrical and co-axially positioned, to thereby define a cylindrical inner condenser/separator cavity 924 and annular outer condenser/separator cavity 923 extending therearound. The inner condenser/separator cavity 924 includes a condensing

plate support 925 for supporting a number of condensing plates 926, with condensing plate support 925 being held in position by a supporting foot 927. Each condensing plate 926 includes a central opening 926.1 for receiving the support 925, as well as lower and upper notches 926.2, 926.3 in the outer circumferential edge, as will be described in more detail below. The condenser/separator body 921 includes end plates 921.1, 921.2 including openings 921.3, 921.4, 921.5, 912.6 for the electrolysis product and electrolyte pipes, as will be described in more detail below.

[0281] The holding tank 930 includes an outer holding tank body 931 and inner holding tank body 932. The inner and outer holding tank bodies 931, 932 are generally cylindrical and co-axial to define inner and outer cavities 934, 933. In use, heat transfer medium is provided to the inner holding tank cavity 934 for preheating, with the inner holding tank cavity including a separating plate 935 dividing the inner cavity 934 so the heat transfer medium flows through the inner holding tank cavity via an aperture 935.1. Electrolyte is held in the outer holding tank cavity 933 ensuring that sufficient electrolyte is available for supply to the electrolysis cell.

[0282] The apparatus 900 also includes an electrolyte circuit including first, second, third, fourth and fifth electrolyte pipes 941, 942, 943, 944, 945, electroyte inlet and outlet valves 946, 947 and an electrolyte level sensor 948. The first electrolyte pipe 941 extends from the electrolysis cell outlet to the opening 921.3 in the condenser/separator end plates 921.1. The second electrolyte pipe 942 extends from the opening 921.5 in the condenser/separator end plates 921.2 to the outer holding tank cavity 933. The third electrolyte pipe 943 extends from the outer holding tank cavity 933 to the electrolysis cell inlet, whilst the fourth and fifth electrolyte pipes 944, 945 extend to the outer holding tank cavity 933. A pump may be provided in the electrolyte circuit , typically in the third electrolyte pipe 943, to urge electrolyte round the electrolysis circuit, although alternatively flow may be achieved by convection only.

[0283] A first electrolysis product pipe 951 extends from the opening 921.4 in the condenser/separator end plates 921.1, via a pressure release valve 953 to a second electrolysis product pipe 952.

[0284] Heat transfer medium is circulated via a heat transfer medium circuit including first, second, third, fourth and fifth heat transfer medium pipes 961, 962, 963, 964, 965 and a pressure release valve 966. The first heat transfer medium pipe enters a lower part of the inner holding tank cavity 934, whilst the second heat transfer medium pipe 962 extends from an upper part of the inner holding tank cavity 934 to a lower part of the jacket body 911. The third heat transfer medium pipe 963 extends from an upper part of the jacket body 911 to an opening in 921.1 having optionally fitted to it an inlet pipe 963, whilst the fourth heat transfer medium pipe 964 extends from the opening 921.4 in the condenser/separator end plate 921.1, via a pressure relief valve 966 to the fifth heat transfer medium pipe 965.

[0285] In use, the electrolysis cell 800 operates substantially as described above to heat and hence boil the electrolyte, to thereby generate vaporised electrolyte and gaseous electrolysis products, which are supplied via the first electrolyte pipe 941 to the inner condenser/separator cavity 924. The vaporised electrolyte condenses on the condensing plates 926, and passes through a channel defined by notches 926.2 in a lower part of the condensing plates 926, to the second electrolyte pipe 942, which transfers condensed electrolyte to the holding tank 930.

[0286] Meanwhile, electrolysis products pass through notches 926.3 to the first electrolysis product pipe 951, via the opening 921.6. This allows the electrolysis products to be supplied via the pressure relief valve 953 and the second electrolysis product pipe 952 to a pressure vessel or like to allow for storage, or alternatively coupled to a system that immediately uses the electrolysis products, such as a burner, fuel cell or the like.

[0287] The electrolyte is held in the outer holding tank cavity 933 and then is supplied from via the third electrolyte pipe 943, to the inlet of the electrolysis cell 800, as required. The outer holding tank cavity 933 allows for the electrolyte to be held enabling sediment to settle out of the electrolyte. In this regard it will be noted that electrolyte pipe 943 which transfers electrolyte to the electrolysis cell inlet extracts electrolyte from an upper area of the outer holding tank cavity 933 ensuring that this is not contaminated with sediment.

[0288] During this process, the electrolyte level sensor 948 is used to sense a level of electrolyte in the outer holding tank cavity 933, with further electrolyte being supplied via the fourth electrolyte pipe 944 and inlet valve 946 if required. It will be appreciated that

although the electrolyte level sensor 948 is shown coupled to the fourth electrolyte pipe 944, this is not essential and in practice the level sensor can be provided at any appropriate part of the electrolyte circuit.

[0289] Electrolyte can also be released from the electrolyte circuit, via the fifth electrolyte pipe 945 and outlet valve 947, for example when anodes within the electrolyte cell 800 are to be replaced, or in the event that sediment is to be removed from the electrolyte circuit. In this regard, it will be appreciated that the holding tank 930 ensures that electrolyte is available for the electrolysis cell 800, whilst also allowing sediment to be collected and extracted from the system.

[0290] During the above process, heat transfer medium is supplied via the first heat transfer medium pipe 961 to the inner holding tank cavity 934, where it passes through the aperture 935.1 to the second heat transfer medium pipe 962. This acts to pre-heat the heat transfer medium, which is then supplied to the jacket cavity 912, surrounding the electrolysis cell 800, via the second heat transfer medium pipe 962, where it is further pre-heated. The pre-heated heat transfer medium is then supplied to the outer condenser/separator cavity 924, via the third heat transfer medium pipe 963, where heat is extracted from the electrolyte. Heated heat transfer medium is then supplied via the fourth and fifth heat transfer medium pipes 964, 965 and pressure relief valve 966, allowing work to be performed, as previously described.

[0291] A second example of heat generating apparatus including the electrolysis cell 800 described with reference to Figure 10A to 10G.

[0292] In this example, the electrolysis cell 800 is physically coupled to a holding tank 1030 and a condenser/separator 1020. The holding tank 1030 includes a holding tank body 1031 defining a holding tank cavity 1032, with a holding tank drain 1033 being provided to allow the holding tank 1030 to be drained.

[0293] The condenser/separator 1020 includes a condenser/separator tank body 1021 and an inner body 1022, defining inner and outer condenser/separator cavities 1024, 1023. The inner condenser/separator cavity 1024 includes a condensing plate 1026 positioned to define an electrolysis product cavity 1027, in fluid communication with the inner condenser/separator cavity 1024 via a condensing plate aperture 1026.1.

[0294] In this example, an electrolyte circuit is defined by first, second, third and fourth electrolyte pipes 1041, 1042, 1043 1044. The first electrolyte pipe 1041, extends from the electrolysis cell outlet to the inner condenser/separator cavity 1024 and the second electrolyte pipe 1042, extends from the inner condenser/separator cavity 1024 to the holding tank cavity 1032. The third electrolyte pipe 1043 is in fluid communication with the holding tank cavity 1032 and a pump (not shown), which is in turn coupled via the fourth electrolyte pipe 1044 to the electrolysis cell inlet. It will be noted that the pump can be omitted by coupling the third electrolyte pipe 1043 directly to the electrolysis cell inlet, or by omitting the third and fourth electrolyte pipes 1043, 1044 allowing electrolyte to be recirculated under convection.

[0295] The condenser/separator 1020 also includes an electrolyte level sensing port 1045 and drain port 1046 in fluid communication with the inner condenser/separator cavity 1024, an electrolysis product port 1051 in fluid communication with the electrolysis product cavity 1027. First and second heat transfer medium ports 1061, 1062 are provided in fluid communication with lower and upper part of the outer condenser/separator cavity 1024, respectively.

[0296] In use electrolyte supplied from the electrolysis cell outlet is supplied via the first electrolyte pipe 1041 into the inner cavity 1024, where the vaporised electrolyte condenses on the condensing plate 1026. Condensed electrolyte then returns via the second conduit 1042 to the holding tank cavity 1032, allowing this to be recirculated via the pump, to the electrolysis cell. Heat transfer medium can be recirculated via the heat transfer medium ports 1061, 1062, allowing heat to be recovered from the electrolyte, whilst electrolysis products can be extracted via the opening 1051.

[0297] It will be appreciated that otherwise the arrangement functions in a generally similar manner to the example of Figures 9A to 9G, and this will not therefore be described in further detail.

[0298] Accordingly, the above examples describe electrolysis apparatus that are suitable for generating hydrogen, allowing energy to be stored, whilst also allowing heat recovery to be performed, thereby enhancing the efficiency of the system. In the example of Figure 6 onwards, this is achieved by using electrolyte to extract heat from the electrolysis cell, whereas in the examples of Figures 1 to 5, a heat recovery module is used to extract heat

from the electrolysis cell. Otherwise, however, the principles of operation are broadly similar and it will be appreciated that features used in the different arrangements can be used interchangeably.

[0299] Throughout this specification and claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers or steps but not the exclusion of any other integer or group of integers.

[0300] Persons skilled in the art will appreciate that numerous variations and modifications will become apparent. All such variations and modifications which become apparent to persons skilled in the art, should be considered to fall within the spirit and scope that the invention broadly appearing before described.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1) Apparatus for performing electrolysis and generating heat, the apparatus including an electrolysis cell including:
   a) a cell housing defining an electrolyte cavity, the electrolyte cavity containing an electrolyte in use;
   b) a plurality of substantially parallel spaced apart electrode plates provided within the electrolyte cavity, the electrode plates defining at least one anode and at least one cathode at least partially submersed within the electrolyte in use;
   c) at least two connectors, which in use are connected to an electrical power supply thereby allowing an electrical current to be supplied to the electrolyte to thereby perform electrolysis and heating of the electrolyte;
   d) at least one cell outlet in fluid communication with the electrolyte cavity, the at least one cell outlet being coupled to a heat recovery module in use; and,
   e) at least one cell inlet allowing electrolyte to be supplied to the electrolyte cavity wherein the apparatus further includes:
      i) a switch; and,
      ii) a load coupled to the at least two connectors via the switch,
      iii) a trigger circuit coupled to the at least two connectors, the trigger circuit including:
         (1) a sensor for sensing at least one of:
            (a) current flow in the connectors and;
            (b) electrical potential across the connectors; and
         (2) an electronic controller for selectively activating the switch by:
            (a) comparing the at least one sensed current and sensed electrical potential to a threshold; and
            (b) operating the switch to thereby couple the at least two connectors to the load to divert at least some current through the load in the event that the threshold is exceeded to thereby prevent damage to the electrolysis cell.
2) Apparatus according to claim 1, wherein the inlet is coupled to the heat recovery module so that electrolyte is recirculating through the electrolyte cavity and the heat recovery module.

3) Apparatus according to claim 1 or claim 2, wherein the inlet and outlet are arranged so that electrolyte supplied to the cavity flows between the electrode plates.
4) Apparatus according to claim 3, wherein the inlet and outlet are arranged on opposing sides of the electrolyte cavity facing edges of the electrode plates.
5) Apparatus according to claim 4, wherein the inlet and outlet are arranged in lower and upper ends of the cell housing respectively with the electrode plates aligned substantially vertically within the electrolyte cavity and spaced substantially horizontally, in use.
6) Apparatus according to any one of the claims 1 to 5, wherein the electrode plates are at least one of:
   a) laminar;
   b) curved; and,
   c) undulating.
7) Apparatus according to any one of the claims 1 to 6, wherein the electrode plates are separated by a distance of at least one of:
   a) between 0.1 mm and 10 mm;
   b) between 1 mm and 2 mm; and,
   c) between 2 mm and 5 mm.
8) Apparatus according to any one of the claims 1 to 7, wherein the electrode plates have thickness of at least one of:
   a) between 0.1 mm and 10 mm;
   b) between 1 mm and 2 mm; and,
   c) between 2 mm and 5 mm.
9) Apparatus according to any one of the claims 1 to 8, wherein the anodes are thicker than the cathodes.
10) Apparatus according to any one of the claims 1 to 9, wherein the at least two connectors are electrically connected to electrode plates so that adjacent plates act as anodes and cathodes in use.
11) Apparatus according to claim 10, wherein each cathode is positioned between two anodes.
12) Apparatus according to any one of the claims 1 to 11, wherein the cell housing includes an opening and a cover removably mounted in the opening to allow at least some of the electrode plates to be removed from the electrolyte cavity.

13) Apparatus according to any one of the claims 1 to 12, wherein the apparatus includes an electrode support, the electrodes being coupled to the electrode support so that the electrodes are at least partially submerged in electrolyte in use.

14) Apparatus according to claim 13, wherein the electrode support is coupled to a cover allowing the electrodes to be removed from the electrolyte cavity.

15) Apparatus according to any one of the claims 1 to 14, wherein the cell housing defines a pressure vessel and wherein the pressure inside the electrolyte cavity is greater than atmospheric pressure.

16) Apparatus according to any one of the claims 1 to 15, wherein, in use, the apparatus operates at a temperature that is at least one of:

a) at least 40°C;

b) at least 60°C;

c) at least 80°C; and,

d) at least 100°C.

17) Apparatus according to any one of the claims 1 to 16, wherein the apparatus includes a heat recovery module.

18) Apparatus according to claim 17, wherein the heat recovery module acts as a condenser for condensing vaporised electrolyte.

19) Apparatus according to claim 17 or claim 18, wherein the heat recovery module acts as a separator for separating vaporised electrolyte from gaseous electrolysis products.

20) Apparatus according to any one of the claims 17 to 19, wherein the heat recovery module includes an outlet that allows gaseous electrolysis products to be extracted in use.

21) Apparatus according to any one of the claims 17 to 20, wherein the heat recovery module includes a heat exchanger for recovering heat from the electrolyte to at least one of:

a) condensed vaporised electrolyte; and,

b) perform work using recovered heat.

22) Apparatus according to any one of the claims 17 to 21, wherein the heat recovery module heats a heat transfer medium using heat recovered from the electrolyte.

23) Apparatus according to claim 22, wherein the recovered heat is used by a thermal engine including:

a) a boiler that in use generates pressurised vapour using the recovered heat; and,

b) a thermal engine coupled to a generator that in use generates electricity using pressurised vapour from the boiler.

24) Apparatus according to any one of the claims 17 to 23, wherein the heat recovery module includes a thermal engine.

25) Apparatus according to any one of the claims 1 to 24, wherein the apparatus includes a power supply for supplying the electrical current.

26) Apparatus according to claim 25, wherein the power supply includes a thermal engine.

27) Apparatus according to any one of the claims 1 to 26, wherein the electrical current is direct current having an electrical potential of at least one of:

a) at least 2 V;

b) at least 5 V;

c) at least 10 V;

d) between 15 and 25 V;

e) up to 30 V;

f) up to 40 V; and,

g) up to 60 V.

28) Apparatus according to any one of the claims 1 to 27, wherein the electrical current is applied to generate an electric field having a field strength of at least one of:

a) at least 3000 Volts per meter;

b) at least 12000 Volts per meter; and

c) at least 24000 Volts per meter.

29) Apparatus according to any one of the claims 1 to 28, wherein the electrical current is direct current having an electrical current of at least one of:

a) at least 0.5 A;

b) at least 1 A;

c) at least 2A;

d) between 2 A and 10 A;

e) about 5 A;

f) up to 10 A;

g) up to 20 A; and,

h) up to 50 A.

30) Apparatus according to any one of the claims 1 to 29, wherein the electrical current is applied to generate an electric field having a current density of at least one of:

a) at least 500 Ampere per square meter;

b) at least 1000 Ampere per square meter; and

c) about 3000 Ampere per square meter or higher.

31) Apparatus according to any one of the claims 1 to 30, wherein the load is at least one of:

a) an electrolysis cell;

b) a resistive load;

c) a battery, and

d) an electrical machine.

32) Apparatus according to any one of the claims 1 to 31, wherein, in use, the electrolysis cell is adapted to operate at a temperature of at least 60°C, a pressure of at least atmospheric pressure, and with a direct current having an applied electric field of at least 3000 V/m and a current density of at least $500A/m^2$.

33) Apparatus according to any one of the claims 1 to 32, wherein the apparatus include a pyroelectric material that in use generates electrical energy in response to temperature changes within the apparatus.

34) Apparatus according to claim 33, wherein the pyroelectric material is provided in the electrolyte cavity and is electrically connected to the at least two connectors.

35) Apparatus according to claim 34, wherein the pyroelectric material is at least one of electrically insulated and electrically connected to the electrolyte.

36) Apparatus according to any one of the claims 33 to 35, wherein at least one electrode is made of a pyroelectric material.

37) Apparatus according to claim 36, wherein electrodes are unevenly spaced to enhance the pyroelectric effect.

38) Apparatus according to any one of the claims 1 to 37, wherein the apparatus includes two dissimilar metals in electrical and thermal contact with the apparatus that in use generates electrical energy in response to temperature changes within the apparatus.