

ELECTROLYSIS SYSTEM

TECHNICAL FIELD

[001] The invention generally relates to an electrolysis process and apparatus for carrying out said electrolysis process to produce clean gases such as hydrogen and oxygen. The invention is particularly applicable for low temperature gas electrolysis cell systems for electrolysing water and it will be convenient to hereinafter disclose the invention in relation to that exemplary application. However, it is to be appreciated that the invention is not limited to that application and could be used in other electrolysis applications.

BACKGROUND OF THE INVENTION

[002] The following discussion of the background to the invention is intended to facilitate an understanding of the invention. However, it should be appreciated that the discussion is not an acknowledgement or admission that any of the material referred to was published, known or part of the common general knowledge as at the priority date of the application.

[003] Low temperature gas electrolysis cell systems have a substantial amount of heat generated in the membrane electrode assembly (particularly on the anode side) as a result of the exothermic reaction in water electrolysis under operational conditions. Cooling systems must therefore be used to maintain the low operational temperature of the membrane electrode assembly and overall electrolysis cell.

[004] One water electrolysing apparatus that utilises a heat exchange system is taught in United State Patent Publications No. 3,917,520 (Katz *et al.*) and 3,905,884 (Edmund *et al.*) and is illustrated in Figure 1. As shown in Figure 1, the apparatus includes an electrolysis cell that comprises a porous matrix 18 sandwiched between a cathode 14 and an anode 16, and filled with an aqueous electrolyte. Heat removal from the cell is through porous backup plate 20 (which also includes an electrolyte storage matrix) adjacent the anode 16, and thermal exchange portion 22. The cell also includes gas spaces 24, 26 on the nonelectrolyte side of the cathode and anode respectively.

[005] During operation an electric potential is applied by the power source 30 causing electrolysis of the water and liberating oxygen on the anode side of the cell into gas space 26 and hydrogen on the cathode side of the cell into gas space 24 and through outlet 32. The gases are removed using conduits 34 and 36 respectively. Pressure regulating means are used to maintain substantially equivalent pressure in the gas spaces 24 and 26. A portion of the hydrogen gas is recirculated through the cell by a pump 39 and re-enters the cell the gas space 24 at the inlet 38.

[006] Heat is removed from the cell by a pump 46 recirculating a coolant fluid through a loop 41 which passes through thermal exchange portion 22 using coolant inlet 42 and coolant outlet 44. The loop 41 also includes bypass loop 48 with bypass control valve 50, thermal element 52 and radiator 54. The coolant is circulated through the cell in counter current flow direction to the recirculating hydrogen gas.

[007] Water from a storage compartment 56 is supplied to the recirculating hydrogen stream using metering device 58 in an amount sufficient to replace the water used by the cell and the water which exits with gases through conduits 34, 36. The water is vaporized using evaporator 60 with the heat of evaporation provided by the hot liquid coolant leaving thermal exchange portion 22.

[008] The water electrolysis cell system apparatus of US 3,905,884 and 3,917,520 therefore includes a separate heat exchange section to be attached to the electrolysis cell. This section has to be isolated from the anode chamber to avoid gas crossover. Resultingly, this system has the following disadvantages:

(A) A separate thermal exchange portion is required to be attached to the cell introducing additional complexity to the overall system and introducing thermal losses through the connection materials;

(B) High cost and complexity of the cell heat management system that includes thermal sensors and control equipment that provides circulation and maintains temperature of the liquid coolant at various operating conditions; and

(C) Low reliability due to water condensation within the gas recirculation loop. The heat from the cell is removed using the liquid coolant loop and is released through the bypass loop or used to vaporise water in the evaporator. The system maintains a constant temperature of the liquid coolant entering the cell. The recirculated hydrogen gas is used to transport the water in a vapour form from the evaporator to the cell. However, the described system does not have means to maintain substantially constant temperature in the gas recirculation loop. It should be appreciated that to transmit substantial amount of water in a vapour form the process should be conducted at elevated temperature. With temperature variations within the gas recirculation loop, a portion of the water can condense locally within the gas recirculation loop. Water supply is limited by the amount of water leaving the cell. Thus, such temperature variations can eventually lead to the electrolyte drying out and subsequent failure of the device.

[009] It would therefore be desirable to provide an alternate and/or improved method and apparatus for carrying out an electrolytic process to produce clean gases such as hydrogen and oxygen. Such a system would preferably reduce cost and complexity of cell heat management and control equipment required to operate the apparatus.

SUMMARY OF THE INVENTION

[010] The present invention provides a new electrolysis system, preferably a low temperature gas electrolysis cell system, for producing hydrogen and oxygen from water.

[011] A first aspect of the present invention provides an electrolysis cell system for producing hydrogen and oxygen product gas from water comprising:

at least one electrolysis cell including a membrane electrode assembly which comprises at least one pair of gas permeable electrodes comprising an

anode and a cathode, and an ion conductive electrolyte arranged between each pair of anode and cathode;

an electrode gas space on the non-electrolyte side of each electrode at least one electrode gas space including an inlet and an outlet;

a recirculating loop for recirculating at least a portion of at least one of the produced oxygen or hydrogen product gas from the outlet of the respective electrode gas space to the inlet of that electrode gas space;

a water supply vessel in fluid communication with the recirculating loop, the water supply vessel vaporising water from a water supply utilising heat of vaporisation provided by the product gas and introducing said water vapour into the recirculating loop; and

a heat transfer arrangement for transferring heat between the membrane electrode assembly and gas in the gas space located in the electrode gas space fluidly connected to the recirculating loop through the inlet and outlet thereof, wherein the heat transfer arrangement is in contact with the membrane electrode assembly and also allows for gas circulation between the membrane electrode assembly and the respective electrode gas space.

[012] Unlike prior art electrolysis cell configurations (for example discussed above), the present invention includes a heat transfer arrangement in the electrode gas space of either the cathode or the anode which is in contact, preferably physical contact, with the membrane electrode assembly to allow for efficient heat transfer between the respective hydrogen or oxygen product gas and membrane electrode assembly. The respective product gas circulates through electrode gas space over the heat transfer arrangement to remove heat from that electrode gas space.

[013] The water required to maintain electrolysis is supplied in vapour form with the recirculating product gas. The water vapour is fed to the membrane electrode assembly via the fluidly connected electrode gas space. Advantageously, the recirculating loop enables the heat generated during water electrolysis to be used to evaporate water (from the water supply) needed for electrolysis in the membrane electrode assembly. It should be appreciated that the remainder of the heat generated during water electrolysis is utilised to

maintain and where required, increase the temperature in the electrolysis cell system.

[014] It should be appreciated that the efficiency of an electrolysis cell increases with increasing operational temperature. Thus, as the temperature in the system increases, at a constant rate of hydrogen production (i.e. a constant current supply), the electrolysis cell will generate less heat. As a result, equilibrium will be reached where the heat generated during electrolysis will be used to maintain elevated temperature within the system and provide energy to evaporate water required for electrolysis in the electrolysis cell.

[015] The heat transfer arrangement can comprise any suitable body, system or arrangement which can transfer heat from the membrane electrode assembly to the gas in the electrode gas space housing the heat transfer arrangement. In some embodiments, the heat transfer arrangement comprises a heat sink in direct physical contact with the respective anode or cathode. More preferably, the heat sink is in abutting contact or is physically connected to at least one portion of the respective anode or cathode. Suitable heat transfer arrangements preferably include apertures or openings, preferably multiple apertures/ openings for gas flow between the respective electrode gas space and the membrane electrode assembly. The heat transfer arrangement is therefore gas permeable, preferably in direction parallel to the longitudinal axis of the membrane electrode assembly. Suitable heat transfer arrangement includes a mesh, preferably a corrugated mesh section or a perforated sheet. Heat transfer arrangements of this type typically have a sheet or a plate form. The heat transfer arrangement may also in some embodiments be electrically conductive. The heat transfer arrangement is therefore preferably formed from a conductive metal, for example nickel or stainless steel. Corrosion resistance is also preferred, particularly for certain corrosive electrolytes. Accordingly, in some embodiments the heat transfer arrangement is preferably formed from a corrosion resistant metal, preferably corrosion resistant stainless steel. This corrosion resistance may result from alloy composition, corrosion resistance coating or the like.

[016] The membrane electrode assembly can comprise any number of configurations. For example, in one embodiment each electrolysis cell contains a pair of gas porous electrodes pressed on each side of the electrolyte. The electrolyte preferably comprises any suitable electrolytic composition having a lower saturated water pressure over its surface compared to that of pure water at identical temperature and pressure. In some embodiments, the electrolyte may comprise a solid ion exchange membrane or a liquid electrolyte embedded in a variety of porous matrixes. The electrodes for the anode and the cathode are preferably composed of materials well known to catalyse water oxidation and reduction, in either acidic or alkaline medium depending on the type of the electrolyte. A variety of suitable materials are well known in the art.

[017] Depending on the desired electrolysis cell configuration, either the electrode gas space of the anode or the electrode gas space of the cathode can include the heat transfer arrangement and be fluidly connected to the recirculating loop. Thus in some embodiments, the electrode gas space including the inlet and the outlet fluidly connected to the recirculating loop is the electrode gas space of the anode and the product gas comprises oxygen. In such embodiments, oxygen product gas is circulated through the recirculating loop and provides heat of vaporisation for vaporisation of water fed into the humidifier. In other embodiments, the electrode gas space including the inlet and the outlet fluidly connected to the recirculating loop is the electrode gas space of the cathode and the product gas comprises hydrogen. In such embodiments, hydrogen product gas is circulated through the recirculating loop and provides heat of vaporisation for vaporisation of water fed into the humidifier.

[018] The water supply vessel comprises any vessel in which heat/ energy can be transferred from a gaseous phase (the recirculated gas flow) to a liquid phase (supply water) so to vaporise the water. Various heat transfer arrangements are possible. In preferred embodiments, the water supply vessel comprises a humidifier. The humidifier preferably directly mixes the product oxygen or hydrogen gas in the recirculating loop and water supplied into and flowing through the humidifier. The recirculated oxygen or hydrogen product

gas can therefore pass through the humidifier and entrains water vapour therein. In such embodiments, the heat of vaporisation for water vaporisation is provided by the product gas in the recirculating loop.

[019] The humidifier, and more particularly the outlet of the humidifier, is preferably located close to the inlet of the fluidly connected electrode gas space. Close proximity between the humidifier and inlet of the fluidly connected electrode gas space minimises heat loss between the humidifier and electrode gas space and the possibility of condensation in any fluid connection therebetween.

[020] The system is preferably a low temperature electrolysis system, and is therefore preferably operated at a temperature of between 0 to 300 °C, preferably between 100 and 200 °C, more preferably between 120 and 160 °C.

[021] Water is used in the system in electrolysis to produce hydrogen and oxygen. Water is preferably supplied to the water supply vessel at a rate needed to replenish water used in the system by electrolysis. In this respect, a control system can be used to control the amount of water fed to the water supply vessel. In such embodiments, the amount of water that is equivalent to the amount used during the electrolysis as sensed (for example by an ammeter or other appropriate sensor) plus the amount of water lost from the cell with the gases through the outlet of the respective electrode gas space and with the recirculated product gas and a suitable/ equivalent amount is fed to the water supply vessel.

[022] In embodiments of the invention, the electrode gas space is housed in an electrode chamber having inlet and outlet openings which are located along a gas flow axis which is orientated perpendicular to longitudinal axis of the membrane electrode assembly of the respective electrolysis cell. The inlet and outlet openings are preferably sized to maintain a sufficient gas flow through the electrode gas space and respective electrode chamber. In some embodiments, the ratio between the total active planar surface area of the membrane electrode assembly perpendicular to the longitudinal axis of the membrane

electrode assembly and the planar area of each of the inlet and outlet openings of the electrode chamber is between 1 and 5.

[023] The size of the inlet and outlet openings of the electrode chamber facilitate gas flowing and being circulated through the electrode gas space at a preferred velocity of between 0.1 to 20 m/s, preferably between 1 and 20 m/s, more preferably between 5 and 20 m/s. A lower circulation velocity can be used at high operating temperature and pressure of the gas in the system, in which smaller volumes of the circulated gas are required to provide effective heat transfer and supply a sufficient amount of water as a feedstock for electrolysis. A higher velocity is required to maintain a desired system efficiency at lower temperature and gas pressure.

[024] In some embodiments, the system includes at least two electrolysis cells stacked together. In some embodiments, the system includes multiple electrolysis cells stacked together. Such a system comprises a cell stack, with the stacked electrolysis cells functioning in parallel to produce the desired product gases from the fed water.

[025] A second aspect of the present invention provides a process of producing hydrogen and oxygen from water using at least one electrolysis cell including a membrane electrode assembly which comprises at least one pair of gas permeable electrodes comprising an anode and a cathode, and an ion conductive electrolyte arranged between each pair of anode and cathode, the or each gas permeable electrodes including an electrode gas space on the non-electrolyte side thereof, at least one of the electrode gas spaces of the anode and cathode including an inlet and an outlet, said process comprising:

- supplying current and water vapour to the membrane electrode assembly to produce hydrogen gas from the cathode and oxygen gas from the anode;

- recirculating a portion of at least one of the produced oxygen gas or hydrogen gas from the outlet of the respective electrode gas space through a recirculating loop to the inlet of said respective gas space and through said respective gas space;

- vapourising water supplied into the recirculating loop from a water supply utilising energy provided by at least a portion of the respective oxygen or

hydrogen product gas in said recirculating loop to provide the requisite heat of vaporisation; and

transferring heat between the membrane electrode assembly and product gas in said respective electrode gas space using a heat transfer arrangement located in said respective electrode gas space which is in contact with the membrane electrode assembly and also allows for gas circulation between the membrane electrode assembly and said respective electrode gas space.

[026] As discussed above, depending on the desired configuration, either the electrode gas space of the anode or the electrode gas space of the cathode can include the heat transfer arrangement and be fluidly connected to the recirculating loop. Thus in some embodiments, said respective gas space is the electrode gas space of the anode and the product gas comprises oxygen. In other embodiments, said respective gas space is the electrode gas space of the cathode and the product gas comprises hydrogen.

[027] Similarly, as discussed above, the step of vapourising water preferably occurs in a humidifier. In this step, water is preferably mixed into the recirculating a portion of produced oxygen gas thereby transferring heat from the produced oxygen product gas to water in said mixture for water vaporisation.

[028] It should be appreciated that the process according to the second aspect of the present invention can be performed using a system according to the first aspect of the present invention. Accordingly, the features discussed in relation to the first aspect of the present invention equally apply to the second aspect of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[029] The present invention will now be described with reference to the Figures of the accompanying drawings, which illustrate particular preferred embodiments of the present invention, wherein:

[030] Figure 1 is a view of the electrolysis cell system corresponding to the prior art and as described in the introduction to the specification.

[031] Figure 2 is a view of the electrolysis cell system corresponding to the invention.

[032] Figure 3 provides a general design schematic of the oxygen chamber of an electrolysis cell according to one embodiment of the present invention.

[033] Figure 4 shows a perspective view of a portion of an electrolysis cell according to one embodiment of the present invention without oxygen chamber (shown in Figure 3).

[034] Figure 5 shows a perspective view of the assembled electrolysis cell according to the embodiment shown in Figures 3 and 4.

[035] Figure 6 provides a perspective view of a number of electrolysis cells as shown in Figure 5 forming a cell stack.

DETAILED DESCRIPTION

[036] The present invention provides an electrolysis cell which produced hydrogen and oxygen product gases from a water supply. The electrolysis cell of the present invention generally includes a membrane electrode assembly containing an anode, a cathode and electrolyte therebetween.

[037] One development provided by the present invention is the use of a heat transfer arrangement that facilitates efficient heat transfer between the membrane electrode assembly and either the oxygen gas or hydrogen product gas produced by the membrane electrode assembly. The heat transfer arrangement of the present invention is housed in an electrode gas chamber on the non-electrolyte side of the anode or cathode depending on the desired configuration of the electrolysis cell. The heat transfer arrangement is physically connected to the respective anode or cathode. Product oxygen or hydrogen product gas circulates through electrode gas chamber over the heat transfer arrangement to remove heat from the chamber and supply water for the electrolysis. A portion of this heated product gas is recirculated through a recirculation loop connected between an outlet and inlet of the electrode gas

chamber. The recirculation loop includes a humidifier into which supply water is feed in sufficient quantity to maintain electrolysis. The humidifier utilises the heat of the product gas in the recirculation loop to supply the required energy (heat of vaporisation) to vaporise the supplied water. The water required for electrolysis is therefore supplied to the membrane electrode assembly in vapour form from the recirculation loop with recirculating product gas.

[038] Figures 1 to 6 show one form of an electrolysis cell system or electrolyser 100 according to the present invention.

[039] Referring firstly to Figure 2, which shows a process schematic of one electrolysis cell system 100 according to an embodiment of the subject invention. The illustrated electrolysis cell system 100 comprises at least one electrolysis cell 101. Each electrolysis cell 101 includes a membrane electrode assembly 102 having gas permeable electrodes comprising an anode 107 and a cathode 109 which are arranged on either side of an ion conductive electrolyte 108. The membrane electrode assembly 102 is constructed by means well known in the art. For example, in one embodiment of the present invention the electrolysis cell 101 contains a pair of gas porous electrodes pressed on each side of the electrolyte 108.

[040] The electrolyte 108 is preferably either a solid ion exchange membrane (a commercially available proton exchange membrane, for example NAFION® or an anion exchange membrane, for example Tokuyama's A201 available from Tokuyama America : Arlington Heights, IL 60005, United States of America) or a liquid electrolyte embedded in a variety of porous matrixes (for example as described in the US patents 5,843,297 and 4,895,634 the contents of which should be understood to be incorporated into the specification by this reference). The main requirement for the electrolyte 108 is to have a lower saturated water pressure over its surface compared to that of pure water at identical temperature and pressure.

[041] The electrodes for the anode 107 and the cathode 109 are preferably composed of materials well known to catalyse water oxidation and reduction, in

either acidic or alkaline medium depending on the type of the electrolyte. For example, the electrodes for the anode 107 and the cathode 109 may either form nanoparticles dispersed on the surface of an ion exchange membrane (as for example described in *Energy Environ. Sci.*, 2011, 4, 2993 the contents of which should be understood to be incorporated into the specification by this reference), or be manufactured as a perforated sheet or mesh (for example as described in *Int. Journal of Hydrogen Energy* 37 (2012) 10992-11000 the contents of which should be understood to be incorporated into the specification by this reference).

[042] The electrolysis cell 101 uses gas spaces 104, 106 on the non-electrolyte side of the cathode 109 and the anode 107. Oxygen gas produced by electrolysis is collected in anode gas space 104. Hydrogen produced by electrolysis is collected in cathode gas space 106. The produced oxygen and hydrogen gases exit the respective gas spaces 104, 106 via outlets 132 and 132A. As explained below, the anode gas space 104 also include water vapour used to supply water to the electrolysis cell 101 for electrolysis. The cell gas spaces 104, 106 are formed in the cell by a cathode chamber 128 and anode chamber 129, as shown in Figures 3 and 4. The anode chamber 129 has an inlet 130 and an outlet 132.

[043] The cathode chamber 128 can be manufactured by any well-known means that allows for electric current to be supplied to the cathode 109 and preferably contains a plurality of channels on the electrolyte side (not illustrated) for the hydrogen gas to be removed from the system 100 as for example described in *Energy Environ. Sci.*, 2011, 4, 2993 the contents of which should be understood to be incorporated into the specification by this reference.

[044] One embodiment of an electrolysis cell 101 according to the present invention is shown in Figures 3 to 6. A general design of the anode chamber 129 used in this embodiment of the presented invention is shown in Figure 3. The illustrated anode chamber 129 consists of a thin hollow plate with two openings comprising inlet 130 and an outlet 132 on opposing sides 131A and 131B to allow for gas circulation in and out of the anode chamber 129 and an

opening 133 on the base 131C, to which the membrane electrode assembly 102 (including the anode) is mounted via the anode 107.

[045] A heat transfer arrangement comprising heat exchanger or heat sink 105 is located within the anode gas space 104. Heat sink 105 is in direct physical contact with the anode 107 while maintaining a gas circulation/gas diffusion between the anode 107 and the gas in the anode gas space 104. Heat sink 105 can comprise a metal perforated plate or mesh section. However, it should be appreciated that the heat sink 105 can be have any suitable construction able to maintain high volumes of gas circulation and provide an efficient heat transfer from the anode 107 to the gas in the anode gas space 104.

[046] A portion of this embodiment of the electrolysis cell 101 illustrated without the anode chamber 129 is shown in Figure 4. Heat sink 105 is used to remove heat from the anode 107 and is pressed onto the anode 107 of the membrane electrode assembly 102 that is placed over the cathode chamber 128. In the preferred embodiment, the heat sink 105 can be made from a metal sheet or metal mesh. In the illustrated embodiment, the heat sink 105 comprises a corrugated metal plate (square corrugations) having a perforated contact area 107A with the anode 107 and solid corrugated fins 107B. The area of the heat sink 105 in contact with the anode 107 of the membrane electrode assembly 102 has a number of openings 145 to allow for heat and water transfer between the membrane electrode assembly 102 and oxygen product gas in the anode chamber 129. The heat sink 105 can be made of nickel or corrosion resistant stainless steel in the case of an alkaline membrane or stainless steel with corrosion resistant coating (for example the carbon coating taught in in JP 2013082985 A Watanabe et al. 9 May 2013, the contents of which should be understood to be incorporated into the specification by this reference) in the case of an acidic membrane.

[047] The heat sink 105 may have various designs to enhance heat transfer between the membrane electrode assembly 102 and the gas circulating in the anode chamber 129. Electrical current can be directly supplied to the anode

107 or alternatively through the heat sink 105 if a conductive material is being used.

[048] A full cell assembly 101 is shown in Figure 5. In the preferred embodiment the anode chamber 129 (the outer side thereof) has a direct electrical contact with the anode 107, while the cathode chamber 128 (the outer side thereof) has a direct electrical contact with the cathode 109.

[049] The inlet 130 and outlet 132 openings of the anode chamber 129 are located on the side of the anode chamber 129 with the inlet openings orientated perpendicular to the longitudinal axis X-X of the electrolysis cell 101. The flow of gas through the inlet 130 and outlet 132 of the anode chamber 129 are located along a flow axis which is orientated perpendicular to longitudinal axis X-X of the membrane electrode assembly 102. The inlet 130 and outlet 132 openings are sized to maintain a sufficient gas flow through the anode chamber 129. For this purpose, it is preferred for the ratio between the active surface of the membrane electrode assembly 102 (the planar surface area of the electrodes, electrolyte and the like perpendicular to the longitudinal axis X-X) and the inlet area A of the inlet 130 and outlet 132 to the anode chamber 129 is preferably between 1 and 5.

[050] During operation of the system 100, an electric potential is applied between each cathode 109 and anode 107 from a power source 113 causing the electrolysis of the fraction of the water retained in the electrolyte 108, thus liberating oxygen into the anode gas space 104 and hydrogen into the cathode gas space 106. The oxygen and hydrogen product gases are removed from the system 100 while maintaining substantially equivalent pressure within the gas spaces 104 and 106 through the pressure control outlet 115. Due to inefficiencies of the water oxidation process, most of the heat is generated at the interface between the anode 107 and the electrolyte 108 during electrolysis. The generated heat from the electrolyte 108 is transferred through the anode 107 into the heat sink 105.

[051] A portion of the oxygen gas produced from electrolysis in the electrolysis cell 101 is recirculated by a pump 111 within the electrolysis cell

101 and is used to remove heat from the heat sink 105. The recirculating oxygen leaves the electrolysis cell 101 at the outlet 146 of the anode gas space 104 and re-enters the electrolysis cell 101 at the inlet 148.

[052] The gas is circulated through the anode chamber 129 and anode gas space 104 therein at a velocity between 0.1 to 20 m/s. A lower circulation velocity can be used at high operating temperature and pressure of the gas in the system, in which smaller volumes of the circulated gas are required to provide effective heat transfer and supply a sufficient amount of water as a feedstock for electrolysis. A higher velocity is required when it is important to maintain the system 100 efficiency at lower temperatures and gas pressures.

[053] It should be noted that a higher ratio between the active surface of the membrane electrode assembly 102 (the planar surface area perpendicular to the longitudinal axis X-X) and the inlet area A of the inlet 130 and outlet 132 to the anode chamber will require a higher circulation velocity of the gas to maintain effective heat transfer and supply a sufficient amount of water as a feedstock for electrolysis.

[054] A portion of the produced oxygen and hydrogen gas is circulated from the outlet of the anode gas space 104 through humidifier 142 and back to the inlet of the anode gas space 104 via recirculating loop 143. The humidifier 142 is fluidly connected to the recirculating loop 143, with the oxygen product gas (from electrolysis) flowing therethrough. The humidifier 142 is also fed water from a water supply 144. The supplied water is vaporised (i.e. transferred the requisite energy (heat of vaporisation) and thereby heated to the requisite temperature) in the humidifier 142 using the energy provided by the heated oxygen product gas stream in the recirculating loop 143 and therefore flows from the outlet of the humidifier 142 in a vapour form entrained the oxygen product gas. The recirculated oxygen therefore passes through the humidifier 142 and entrains water vapour therein. Water vapour is resultingly feed into the anode gas space 104 of each electrolysis cell 101 from the recirculating loop 143.

[055] The water is supplied to the system 100 from the water supply at a rate needed to replenish water used the system 100 by electrolysis. A portion of the produced oxygen and hydrogen gas is circulated from the outlet of the anode gas space 104 through humidifier 142 and back to the inlet of the anode gas space 104 via recirculating loop 143. The humidifier 142 is fluidly connected to the recirculating loop 143, with the oxygen product gas (from electrolysis) flowing therethrough. The humidifier 142 is also fed water from the water supply 144 which is vaporised in the humidifier 142 using the energy/ heat provided by the heated oxygen product gas stream in the recirculating loop 143. Water vapour therefore flows from the outlet of the humidifier 142 entrained the oxygen product gas. Water vapour is resultingly feed into the anode gas space 104 of each electrolysis cell 101 from the recirculating loop 143. The water is supplied to the system 100 from the water supply at a rate needed to replenish water used the system 100 by electrolysis.

[056] A control system (not illustrated) can be used to control the flow of water into the humidifier 142 from the water supply 144. The control system ensures that the amount of water that is equivalent to the amount used during the electrolysis as sensed by the ammeter 152 plus the amount of water lost from the cell with the gases through outlet 115 (i.e. not cycling through the recirculation loop 143) is fed into the humidifier 142 and then vaporised into the recirculated oxygen. Dotted line 149 shows the general control line between the ammeter 152 and water supply 144. It should be appreciated that water supply 144 would include a control valve or similar flow limiting/ control device which can control the amount of water being fed to the humidifier 142.

[057] The energy of vaporisation for vapouring the water fed into the humidifier 142 is provided by the temperature/ heat of the recirculated oxygen. If there is insufficient heat available from the circulated product oxygen gas, it will not be able to vaporise water in the humidifier 142. Thus, water vapour in excess of energy levels of the system 100 cannot enter the recirculation loop 143, and thus condensation of such water vapour in the recirculation loop 143 does not occur.

[058] The heat generated during water electrolysis in the electrolysis cell 101 is used to evaporate water needed for electrolysis with the remainder increasing the temperature in the electrolysis cell system 100. As the temperature of the electrolysis cell 101 increases, the efficiency of the process will increase and, thus, the heat generated by the electrolysis cell 101 will become sufficient for the water vaporisation, whereby compensating for the heat loss within the system 100. It is well known that efficiency of an electrolysis cell increases with increasing operational temperature. Thus, as the temperature in the system increases, at a constant rate of hydrogen production (i.e. a constant current supply), the cell will generate less heat. As a result, equilibrium will be reached where the heat generated during the electrolysis will be used to maintain elevated temperature within the system 100 and provide energy to evaporate water required for electrolysis. Additionally, the electrolysis cell 101 is maintained at a higher temperature compared to that of the humidifier 142 to allow for the heat transfer through the recirculated oxygen. Overall, the system 100 can be operational between 0 to 300 °C, with preferred mode of operation being between 120 and 160 °C.

[059] The electrolysis cell 101 operates at a substantially equal pressure between the oxygen and hydrogen gases. Depending on the type of the membrane and required purity of gases, the system 100 can operate from ambient pressure to high pressure exceeding 30 bar.

[060] It is noted that in the illustrated system, the heat sink 105 is located in anode gas space 104. However, it should be appreciated that in other embodiments the heat sink 105 could alternatively be located in the cathode gas space 106 with the cathode gas space 106 fluidly connected to the recirculating loop 143. In such embodiments, the configuration of the electrolysis cell system 100 would be similar to that illustrated in Figure 2, with the cathode 109 and anode 107 interchanged or swapped position within the membrane electrode assembly 102 and the corresponding electrical connections interchanged accordingly. This would result in hydrogen product gas circulating through recirculating loop 143. Similarly, the configuration of the anode chamber 129 could equally be used for the cathode chamber in this

alternate embodiment. It should be understood that the discussion of the illustrated embodiment equally applies to this embodiment, with the above alternations or variations.

[061] Several cells 101 according to the invention can be connected in a series and stacked with one another to form a stack. For example, individual cells 101 can be stacked together in a cell stack 160 as shown in Figure 6. The openings 162 of each cell (comprising has inlets 130 and outlets 132 to the anode chambers 129) can comprise a significant portion of surface area of the stacked sides 164 of the cells 101. The ratio between the total area of the sides 164 and the area of the openings 130, 131 on/ in those sides 164 is typically between 1 and 5.

[062] Those skilled in the art will appreciate that the invention described herein is susceptible to variations and modifications other than those specifically described. It is understood that the invention includes all such variations and modifications which fall within the spirit and scope of the present invention.

[063] Where the terms "comprise", "comprises", "comprised" or "comprising" are used in this specification (including the claims) they are to be interpreted as specifying the presence of the stated features, integers, steps or components, but not precluding the presence of one or more other feature, integer, step, component or group thereof.

CLAIMS

1. An electrolysis cell system for producing hydrogen and oxygen product gas from water comprising:

at least one electrolysis cell including a membrane electrode assembly which comprises at least one pair of gas permeable electrodes comprising an anode and a cathode, and an ion conductive electrolyte arranged between each pair of anode and cathode;

an electrode gas space on the non-electrolyte side of each electrode at least one electrode gas space including an inlet and an outlet;

a recirculating loop for recirculating at least a portion of at least one of the produced oxygen or hydrogen product gas from the outlet of the respective electrode gas space to the inlet of the respective electrode gas space;

a water supply vessel in fluid communication with the recirculating loop, the water supply vessel vaporising water from a water supply utilising heat of vaporisation provided by the product gas and introducing said water vapour into the recirculating loop; and

a heat transfer arrangement for transferring heat between the membrane electrode assembly and gas in the gas space located in the electrode gas space fluidly connected to the recirculating loop through the inlet and outlet thereof, wherein the heat transfer arrangement is in contact with the membrane electrode assembly and also allows for gas circulation between the membrane electrode assembly and the respective electrode gas space.

2. An electrolysis cell system according to claim 1, wherein the heat transfer arrangement comprises a heat sink in direct physical contact with the respective anode or cathode.

3. An electrolysis cell system according to claim 2, wherein the heat sink is in abutting contact or is physically connected to at least one portion of the respective anode or cathode.

4. An electrolysis cell system according to any preceding claim, wherein the heat transfer arrangement comprises a mesh, preferably a corrugated mesh section, or a perforated sheet.
5. An electrolysis cell system according to any preceding claim, wherein the heat transfer arrangement comprises a sheet or a plate.
6. An electrolysis cell system according to any preceding claim, wherein the heat transfer arrangement is gas permeable, preferably in direction parallel to the longitudinal axis of the membrane electrode assembly.
7. An electrolysis cell system according to any preceding claim, wherein the heat transfer arrangement is electrically conductive.
8. An electrolysis cell system according to any preceding claim, wherein the heat transfer arrangement is formed from metal, preferably nickel or stainless steel, more preferably corrosion resistant stainless steel.
9. An electrolysis cell system according to any one of claims 1 to 8, wherein the electrode gas space including the inlet and the outlet fluidly connected to the recirculating loop is the electrode gas space of the anode and the product gas comprises oxygen.
10. An electrolysis cell system according to any one of claims 1 to 8, wherein the electrode gas space including the inlet and the outlet fluidly connected to the recirculating loop is the electrode gas space of the cathode and the product gas comprises hydrogen.
11. An electrolysis cell system according to any preceding claim, wherein the water supply vessel comprises a humidifier.
12. An electrolysis cell system according to claim 11, wherein the humidifier directly mixes the product gas and water supplied into and flowing through the humidifier.

13. An electrolysis cell system according to any preceding claim, wherein the recirculated oxygen or hydrogen product gas passes through the humidifier and entrains water vapour therein.
14. An electrolysis cell system according to any preceding claim, wherein the heat of vaporisation for water vaporisation is provided by the product gas in the recirculating loop.
15. An electrolysis cell system according to any preceding claim, wherein water is supplied to the water supply vessel at a rate needed to replenish water used in the system by electrolysis.
16. An electrolysis cell system according to any preceding claim, wherein the electrode gas space is housed in an electrode chamber having inlet and outlet openings are located along a gas flow axis which is orientated perpendicular to longitudinal axis of the membrane electrode assembly of the respective electrolysis cell.
17. An electrolysis cell system according to claim 16, wherein the ratio between the total active planar surface area of the membrane electrode assembly perpendicular to the longitudinal axis of the membrane electrode assembly and the planar area of each of the inlet and outlet openings of the respective electrode chamber is between 1 and 5.
18. An electrolysis cell system according to any preceding claim, wherein gas flows and is circulated through the electrode gas space fluidly connected to the recirculation loop at a velocity of between 0.1 to 20 m/s.
19. An electrolysis cell system according to any preceding claim, wherein the system is operated at a temperature of between 0 to 300 °C, preferably between 120 and 160 °C.
20. An electrolysis cell system according to any preceding claim, including at least two electrolysis cells stacked together.

21. A process of producing hydrogen and oxygen from water using at least one electrolysis cell including a membrane electrode assembly which comprises at least one pair of gas permeable electrodes comprising an anode and a cathode, and an ion conductive electrolyte arranged between each pair of anode and cathode, the or each gas permeable electrodes including an electrode gas space on the non-electrolyte side thereof, at least one of the electrode gas spaces of the anode and cathode including an inlet and an outlet, said process comprising:

supplying current and water vapour to the membrane electrode assembly to produce hydrogen gas from the cathode and oxygen gas from the anode;

recirculating a portion of at least one of the produced oxygen gas or hydrogen gas from the outlet of the respective electrode gas space through a recirculating loop to the inlet of said respective gas space and through said respective gas space;

vapourising water supplied into the recirculating loop from a water supply utilising energy provided by at least a portion of the respective oxygen or hydrogen product gas in said recirculating loop to provide the requisite heat of vaporisation; and

transferring heat between the membrane electrode assembly and product gas in said respective electrode gas space using a heat transfer arrangement located in said respective electrode gas space which is in contact with the membrane electrode assembly and also allows for gas circulation between the membrane electrode assembly and said respective electrode gas space.

22. A process according to claim 21, wherein the step of vapourising water occurs in a humidifier.

23. A process according to claim 21 or 22, wherein the step of vapourising water includes mixing water into the recirculating a portion of produced oxygen gas thereby transferring heat from the produced oxygen product gas to water in said mixture for water vaporisation.

24. An electrolysis cell system according to any one of claims 21 to 23, wherein said respective gas space is the electrode gas space of the anode and the product gas comprises oxygen.

25. An electrolysis cell system according to any one of claims 21 to 23, wherein said respective gas space is the electrode gas space of the cathode and the product gas comprises hydrogen.

26. A process according to any one of claims 21 to 25 using a system according to any one of claims 1 to 20.