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(54) APPARATUS AND METHOD FOR REDUCING INSTANCES OF PUMP DE-PRIMING

(76) Inventors: **Ali Rusta-Sallehy**, Richmond Hill (CA); **Michael Vale**, Brampton (CA)

Correspondence Address:
BERESKIN AND PARR
40 KING STREET WEST
BOX 401
TORONTO, ON M5H 3Y2 (CA)

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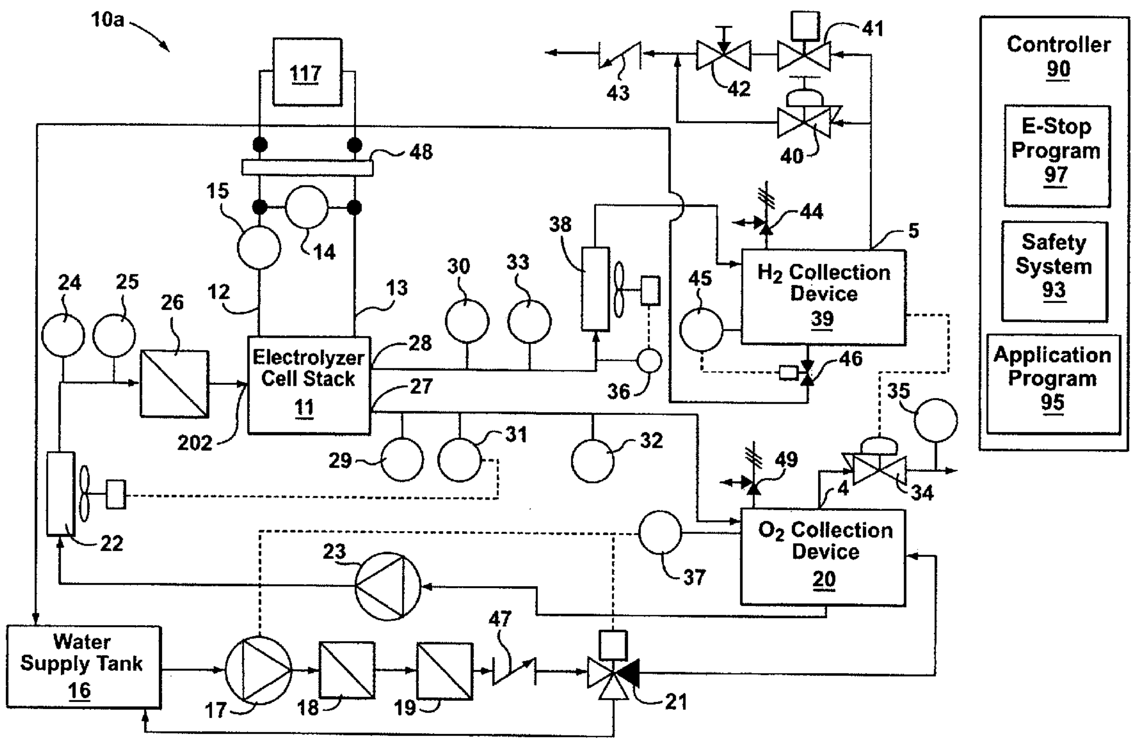
(57) **ABSTRACT**

Abruptly shutting down an electrolyzer cell module during normal operation may, in some instances, be necessary when one or more process and operating parameters uncontrollably deviate into an unsafe range. However, abruptly shutting down an electrolyzer cell module may have residual effects that make it difficult to restart the electrolyzer cell module. In particular, in some instances a circulation pump is de-primed by the accumulation of gas bubbles within the circulation pump, which normally do not exist during normal operation since a fluid containing dissolved gas molecules is pressurized to ensure that the gas remains dissolved. In some embodiments of the invention there is provided a modified safety system that can controllably shutdown an electrolyzer cell module in an emergency situation so as to prevent instances of pump de-priming.



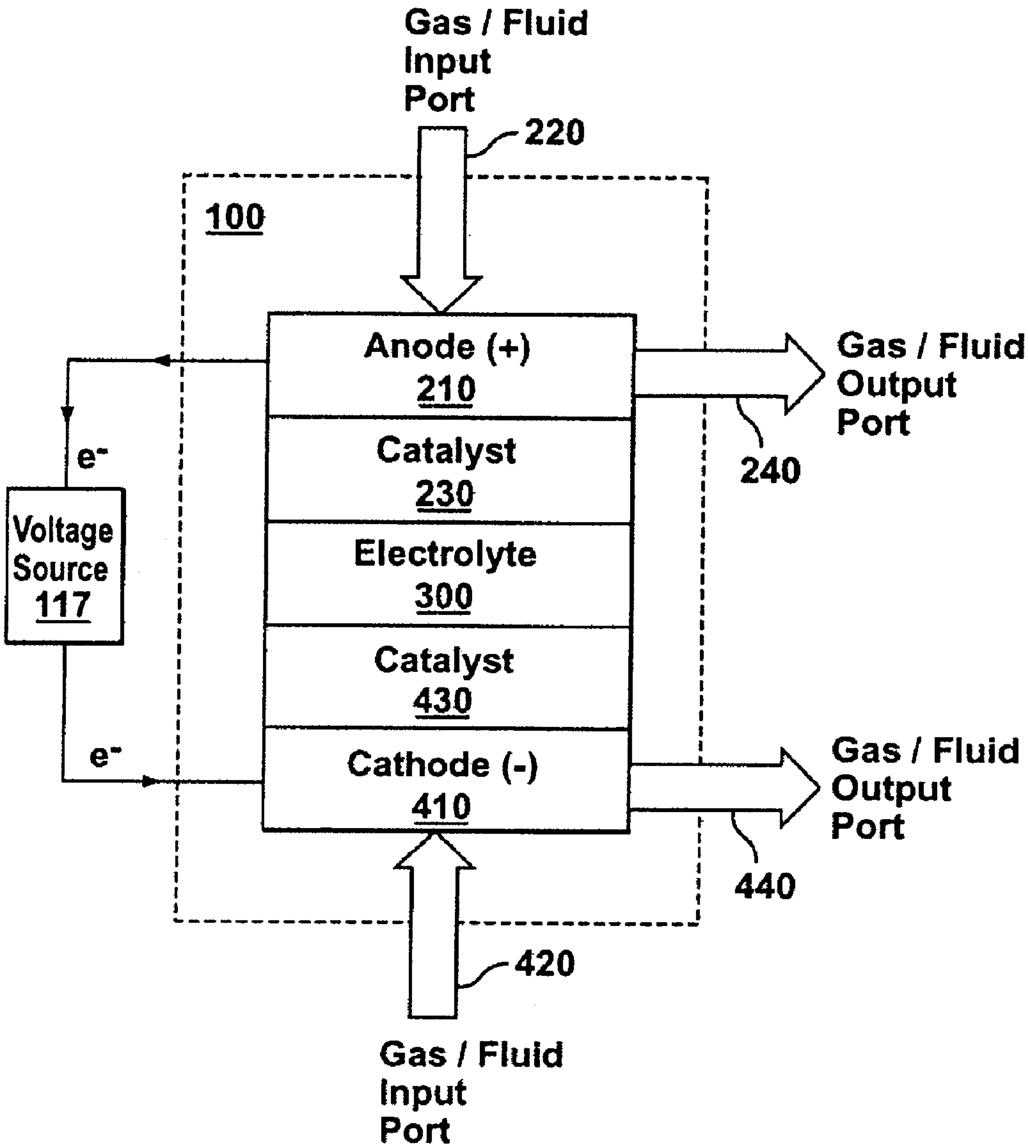

Gas / Fluid
Input
Port
220
100
Anode (+)
210
Catalyst
230
Electrolyte
300
Catalyst
430
Cathode (-)
410
Gas / Fluid
Output
Port
240
Gas / Fluid
Output
Port
440
e-
Voltage
Source
117
e-
420
Gas / Fluid
Input
Port

FIG. 1

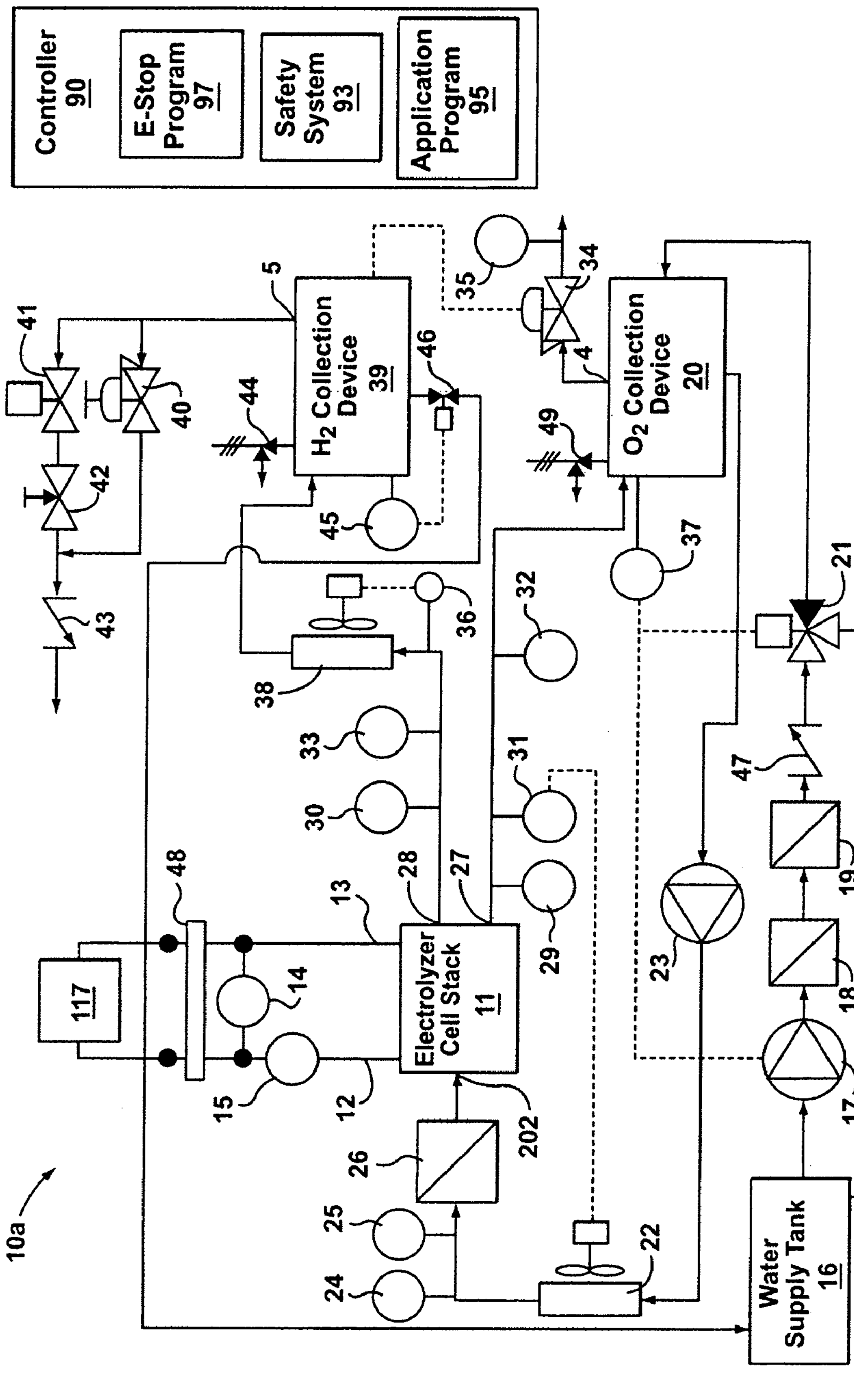

Controller
90
E-Stop
Program
97
Safety
System
93
Application
Program
95
H_2 Collection
Device
39
O_2 Collection
Device
20
Electrolyzer
Cell Stack
11
Water
Supply Tank
16
117
10a

FIG. 2

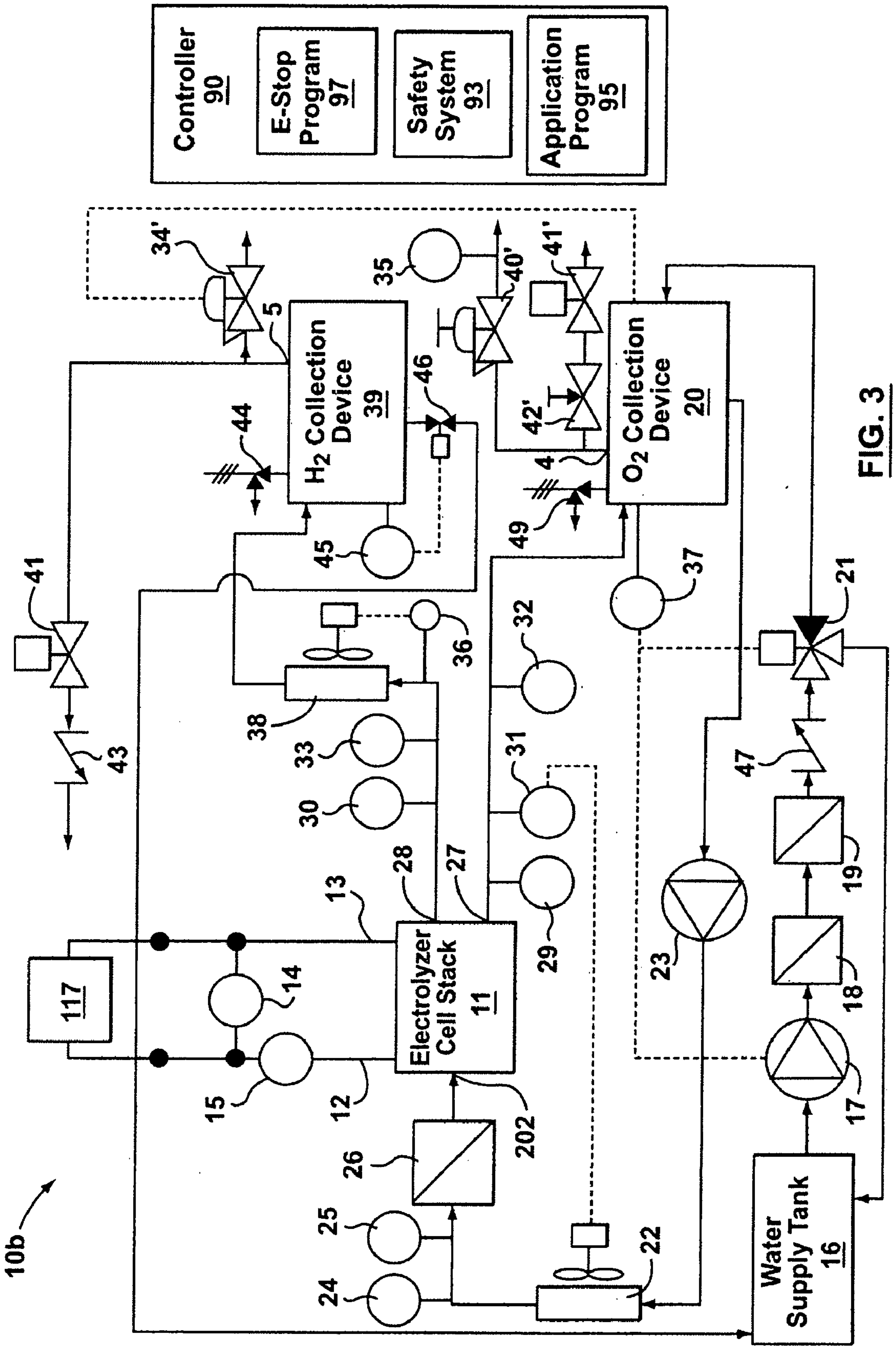

Controller
90
E-Stop
Program
97
Safety
System
93
Application
Program
95
H_2 Collection
Device
39
O_2 Collection
Device
20
Electrolyzer
Cell Stack
11
Water
Supply Tank
16
117
10b
5
4
12
13
14
15
17
18
19
21
22
23
24
25
26
27
28
29
30
31
32
33
34'
35
36
37
38
40'
41
41'
42'
43
44
45
46
47
49
202

FIG. 3

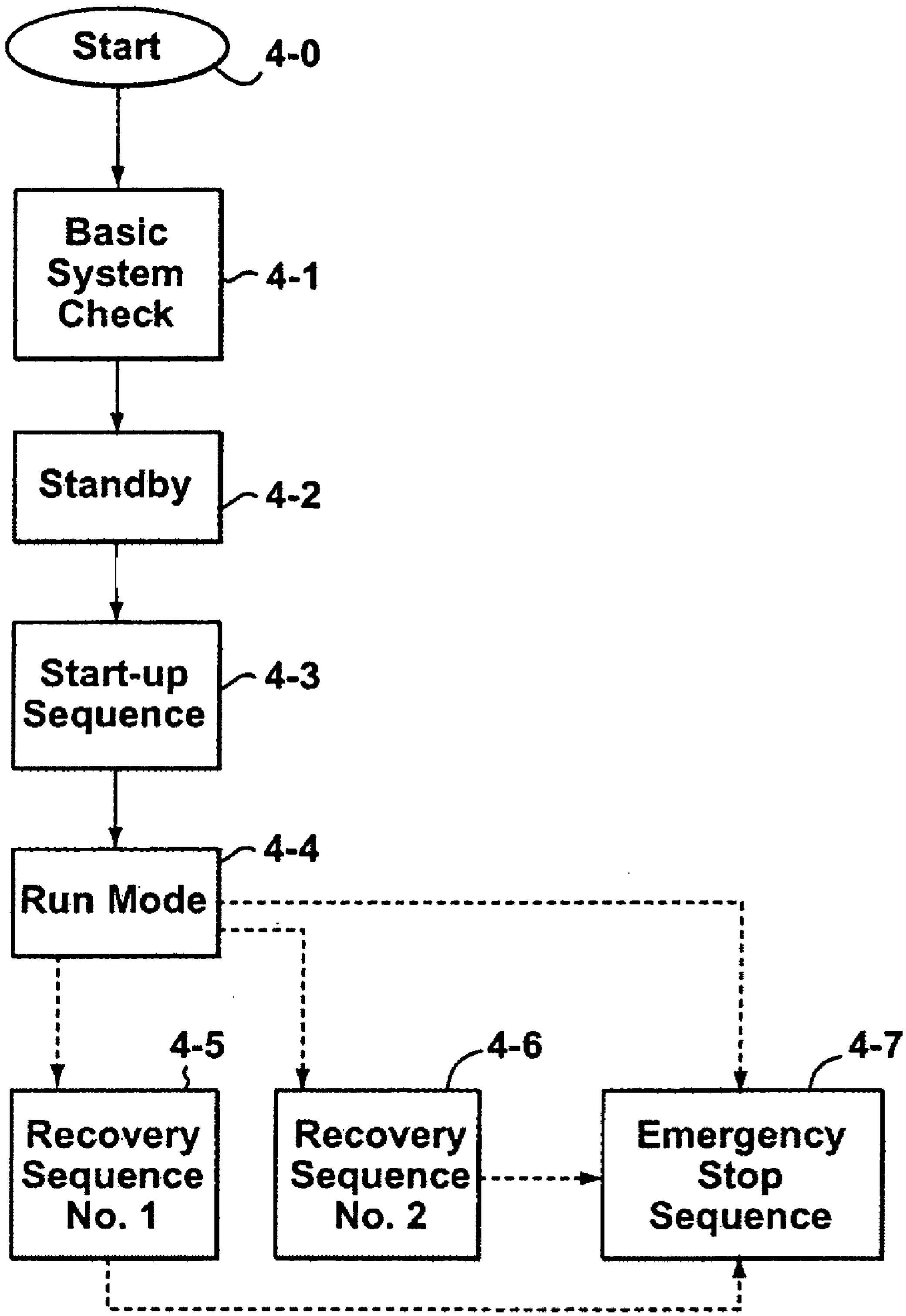

Start
4-0
Basic System Check
4-1
Standby
4-2
Start-up Sequence
4-3
Run Mode
4-4
Recovery Sequence No. 1
4-5
Recovery Sequence No. 2
4-6
Emergency Stop Sequence
4-7

FIG. 4

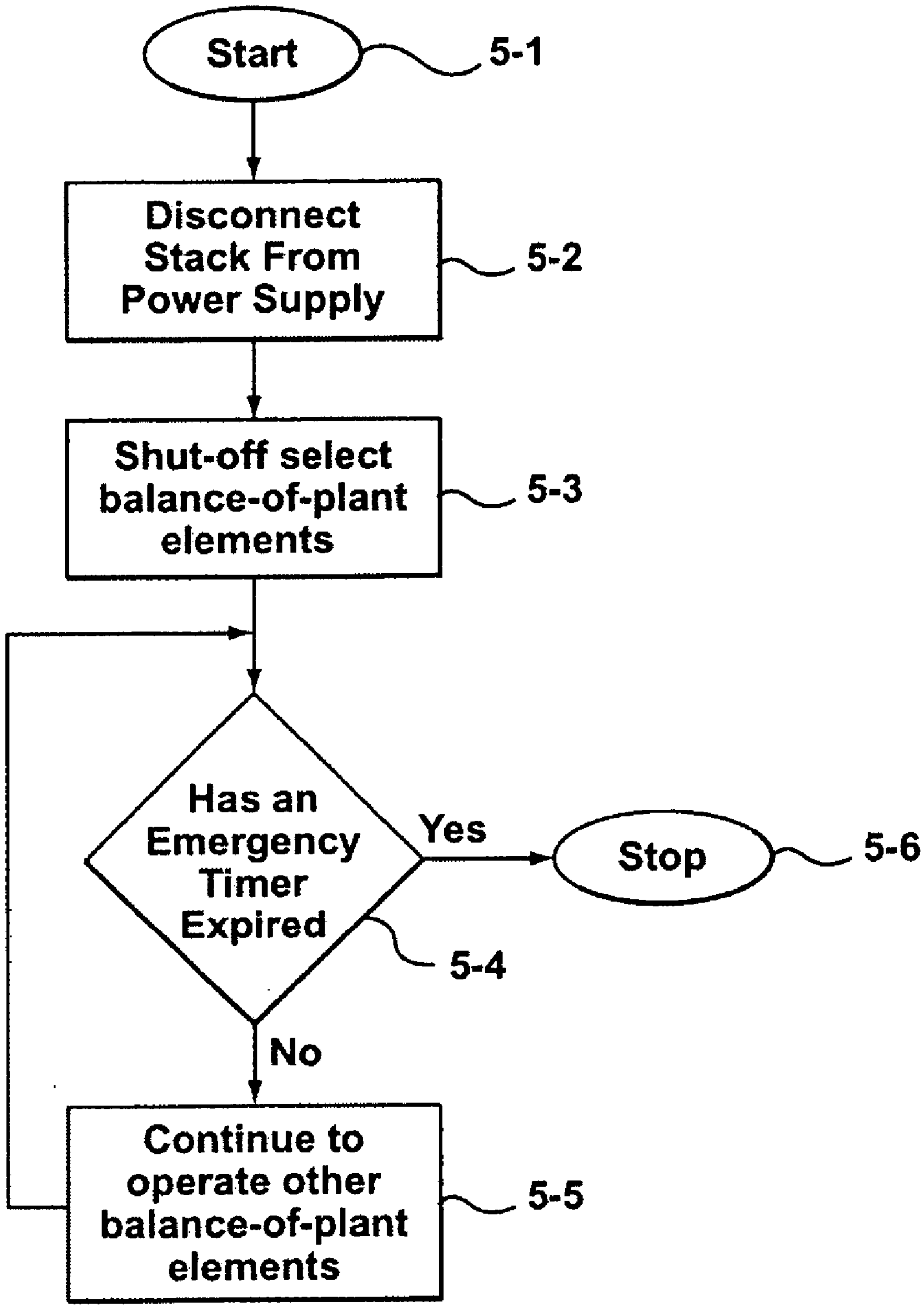

Start
5-1
Disconnect Stack From Power Supply
5-2
Shut-off select balance-of-plant elements
5-3
Has an Emergency Timer Expired
5-4
Yes
Stop
5-6
No
Continue to operate other balance-of-plant elements
5-5

FIG. 5

APPARATUS AND METHOD FOR REDUCING INSTANCES OF PUMP DE-PRIMING

PRIORITY CLAIM

[0001] This application claims the benefit, under 35 USC 119(e), of U.S. Provisional Application No. 60/504,218 that was filed on Sep. 22, 2003, and the entire contents of which is hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] The invention relates to electrolyzer cells and, in particular to an apparatus and method suited for controlling an electrolyzer cell module.

BACKGROUND OF THE INVENTION

[0003] An electrolyzer cell is a type of electrochemical device that uses energy to dissociate a compound liquid into its components. For example, water can be dissociated into hydrogen and oxygen (e.g. $H_2O \rightarrow H_2 + O_2$).

[0004] In practice, a number of electrolyzer cells are arranged into a stack to produce sizable amounts of one or more of the components of a compound liquid. To this end, the electrolyzer cell stack is included in a module that includes a suitable combination of supporting elements, collectively termed a balance-of-plant system, which is specifically configured to maintain operating parameters related to the operation of the stack.

[0005] Typically, during the normal operation of an electrolyzer cell module, process gases and fluids are pressurized. For example, the water within the electrolyzer cell module is pressurized so that oxygen produced in the stack remains dissolved within the water, since large gas bubbles will reduce efficiency. In some emergency situations, the operation of an electrolyzer cell module is abruptly halted and power provided to the balance-of-plant elements is cut-off. As a result, the pressure in the various gas/fluid lines is released, which causes the formation of relatively large gas bubbles that sometimes make it difficult to restart the electrolyzer cell module.

SUMMARY OF THE INVENTION

[0006] According to aspects of an embodiment of the invention there is provided an electrolyzer cell module having: an electrolyzer cell stack for electrolysing a compound liquid to produce at least one gas; a plurality of balance-of-plant elements connected to the electrolyzer cell stack, for regulating the operation of the electrolyzer cell stack; a safety system connected to at least some of the balance-of-plant elements and the electrolyzer cell stack, for monitoring at least one process and operating parameter related to the operation of the electrolyzer cell module and evaluating whether or not at least one alarm threshold has been violated by the at least one process and operating parameter; a computer usable medium, in communication with the safety system, having computer program readable code means embodied therein for emergency stoppage of the normal operation of the electrolyzer cell module when the at least one alarm threshold has been violated, the computer program readable code means including: instructions for stopping the electrolysis of the compound liquid within the electrolyzer cell stack, thereby stopping the production of the at least one gas; instructions for operating the electrolyzer cell module so as to flush out residual amounts of the at least one gas dissolved in the compound liquid over a time period; and, instructions for cutting-off power, at the end of the time period, to all of the elements included in the electrolyzer cell module required for flushing out residual amounts of the at least one gas dissolved in the compound liquid, to shut-down the electrolyzer cell stack.

[0007] In some embodiments the computer program readable code means also includes: instructions for cutting-off power to some of the balance-of-plant elements included in the electrolyzer cell module, while continuing to provide power to other balance-of-plant elements required to flush out the residual amounts of the at least on gas dissolved in the compound liquid within the electrolyzer cell module. In some related embodiments the balance-of-plant elements that continue to receive power during an emergency stoppage include a circulation pump and pressure regulating devices.

[0008] In some embodiments the electrolyzer cell module also includes a pressure release means that is operable to slowly and controllably release the pressure within the electrolyzer cell module as it is being turned off. In some specific instances the pressure release means in comprised of a combination of valves that includes, without limitation, a need/orifice valve and a second valve connected in series, wherein the second valve is opened when the electrolyzer cell module is shut down.

[0009] According to other aspects of an embodiment of the invention there is provided an emergency stoppage method of operating an electrolyzer cell module that includes a number of balance-of-plant elements and an electrolyzer cell stack, the method including: stopping electrolysis of a compound liquid, thereby stopping the production of at least one gas dissolved in the compound liquid; flushing out residual amounts of the at least one gas evolved from the compound liquid by operating some of the balance-of-plant elements included in the electrolyzer cell module and not others; and, cutting-off power, to all of the elements included in the electrolyzer cell module required for flushing out the residual amounts of the at least one gas dissolved in the compound liquid, to shut-down the operation of the electrolyzer cell stack.

[0010] In some embodiments the method also includes a step of controllably releasing the pressure within the electrolyzer cell module as the residual amounts of the at least one gas are flushed from the electrolyzer cell module. In some specific instance the method also includes the step of cutting-off power to some of the balance-of-plant elements included in the electrolyzer cell module, while continuing to provide power to other balance-of-plant elements required to flush out the residual amounts of the at least on gas dissolved in the compound liquid within the electrolyzer cell module.

[0011] Other aspects and features of the present invention will become apparent, to those ordinarily skilled in the art, upon review of the following description of the specific embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] For a better understanding of the present invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example, to the accompanying drawings that illustrate aspects of embodiments of the present invention and in which:

[0013] **FIG. 1** is a simplified schematic drawing of an electrolyzer cell;

[0014] **FIG. 2** is a first detailed schematic drawing of an electrolyzer cell module according to aspects of an embodiment of the invention;

[0015] **FIG. 3** is a second detailed schematic drawing of an electrolyzer cell module according to aspects of an alternative embodiment of the invention;

[0016] **FIG. 4** is a flow chart illustrating a high-level method of operating an electrolyzer cell module according to aspects of an embodiment of the invention; and

[0017] **FIG. 5** is a flow chart depicting the general steps provided in an emergency stop program according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Abruptly shutting down an electrolyzer cell module during normal operation may, in some instances, be necessary when one or more process and operating parameters uncontrollably deviate into an unsafe range. However, abruptly shutting down an electrolyzer cell module may have residual effects that make it difficult to restart the electrolyzer cell module. In particular, in some instances a circulation pump is de-primed by the accumulation of gas bubbles within the circulation pump, which normally do not exist during normal operation since a fluid containing dissolved gas molecules is pressurized to ensure that the gas remains dissolved. In some embodiments of the invention there is provided a modified safety system that can controllably shut down an electrolyzer cell module in an emergency situation so as to prevent instances of pump de-priming.

[0019] There are a number of different electrochemical cell technologies and, in general, this invention is expected to be applicable to all types of electrochemical cells. Very specific example embodiments of the invention have been developed for use with Proton Exchange Membrane (PEM) electrolyzer cells. Various other types of electrolyzer cells also include, without limitation, Solid Polymer Water Electrolyzers (SPWE). Similarly, various types of fuel cells include, without limitation, Alkaline Fuel Cells (AFC), Direct Methanol Fuel Cells (DMFC), Molten Carbonate Fuel Cells (MCFC), Phosphoric Acid Fuel Cells (PAFC), Solid Oxide Fuel Cells (SOFC) and Regenerative Fuel Cells (RFC).

[0020] Referring to **FIG. 1**, shown is a simplified schematic diagram of a Proton Exchange Membrane (PEM) electrolyzer cell, simply referred to as electrolyzer cell **100** hereinafter, that is described herein to illustrate some general considerations relating to the operation of electrochemical cells. It is to be understood that the present invention is applicable to various configurations of electrochemical cell modules that each include one or more electrochemical cells.

[0021] The electrolyzer cell **100** includes an anode electrode **210** and a cathode electrode **410**. The anode electrode **210** includes a water input port **220** and a water/oxygen output port **240**. Similarly, the cathode electrode **410** includes a water input port **420** and a water/hydrogen output port **440**. An electrolyte membrane **300** is arranged between the anode electrode **210** and the cathode electrode **410**.

[0022] The electrolyzer cell **100** also includes a first catalyst layer **230** arranged between the anode electrode **210** and the electrolyte membrane **300**, and a second catalyst layer **430** arranged between the cathode electrode **410** and the electrolyte membrane **300**.

[0023] In order to energize the electrolyzer cell **100**, a voltage source **117** is coupled between the anode and cathode electrodes **210**, **410**.

[0024] In operation, water is introduced into the anode electrode **210** via the water input port **220**. The water is dissociated electrochemically according to reaction (1), given below, in the presence of the electrolyte membrane **300** and the first catalyst layer **230**.

$$H_2O \rightarrow 2H^+ + 2e^- 1/2O_2 \quad (1)$$

[0025] The chemical products of reaction (1) are hydrogen ions (i.e. cations), electrons and oxygen. The hydrogen ions pass through the electrolyte membrane **300** to the cathode electrode **410** while the electrons are drawn through the voltage source **117**. Water containing dissolved oxygen molecules is drawn out through the water/oxygen output port **240**. The water is pressurized to ensure that the oxygen molecules remain dissolved in the water and do not form relatively large gas bubbles.

[0026] Simultaneously, additional water is introduced into the cathode electrode **410** via the water input port **420** in order to provide moisture to the cathode side of the electrolyte membrane **300**.

[0027] The hydrogen ions (i.e. protons) are electrochemically reduced to hydrogen molecules according to reaction (2), given below, in the presence of the electrolyte membrane **300** and the second catalyst layer **430**. That is, the electrons and the ionized hydrogen atoms, produced by reaction (1) in the anode electrode **210**, are electrochemically consumed in reaction (2) in the cathode electrode **410**.

$$2H_2^+ + 2e^{31} \rightarrow H_2 \quad (2)$$

[0028] The water containing dissolved hydrogen molecules is drawn out through the water/hydrogen output port **440**. The electrochemical reactions (1) and (2) are complementary to one another and show that for each oxygen molecule (O_2) that is electrochemically produced two hydrogen molecules (H_2) are electrochemically produced.

[0029] Although only one electrolyzer cell is illustrated in **FIG. 1**, it is commonly understood that in practice a number of electrochemical cells, all of one type, can be arranged in stacks having common elements, such as process gas/fluid feeds, drainage, electrical connections and regulation devices. That is, an electrochemical cell module is typically made up of a number of singular electrochemical cells connected in series to form an electrochemical cell stack. The electrochemical cell module also includes a suitable combination of structural elements, mechanical systems, hardware, firmware and software that is employed to support the function and operation of the electrochemical cell stack. Such items include, without limitation, piping, sensors, regulators, current collectors, seals, insulators, actuators, switches and electromechanical controllers.

[0030] Referring now to **FIG. 2**, illustrated is a simplified schematic diagram illustrating an electrolyzer cell module

10*a* that is configured to dissociate water (H_2O) into hydrogen (H_2) and oxygen (O_2). The electrolyzer cell module **10***a* includes an electrolyzer cell stack **11**, a power supply **117**, a hydrogen collection device **39**, an oxygen collection device **20**, a water supply tank **16** and a suitable combination of balance-of-plant elements.

[**0031**] Those skilled in the art will appreciate that shown in **FIG. 2** are only those balance-of-plant elements necessary to describe aspects of this example embodiment of the invention. Generally, balance-of-plant elements can be roughly divided into two groups. A first group may be defined as a suitable combination of supporting apparatus and electromechanical systems that includes, without limitation, elements such as heaters, filters, pumps, humidifiers, valves and the like. A second group may be defined as a suitable combination of control and sensor systems that includes, without limitation, sensors, switches, valves, hardware, software, firmware and the like.

[**0032**] In some embodiments, the control and sensor systems include a centralized control system including for example a microcontroller and/or a computer program readable code means for monitoring and regulating the operation of an electrolyzer cell module, including portions of the supporting apparatus and electromechanical systems. In alternative embodiments, distributed control systems/controllers are provided along with or in place of a centralized control system. Generally, the sensors and the switches are electronically coupled to the aforementioned centralized and/or distributed control systems, which process sensor readings and signal the switches and other electromechanical devices accordingly in order to regulate and in some cases shut down an electrolyzer cell module.

[**0033**] With specific reference to **FIG. 2**, the electrolyzer cell module **10***a* includes a controller **90** that is used to manage the operations of the electrolyzer cell module **10***a*. Although the controller **90** is not shown specifically connected to any of the other elements included in the electrolyzer cell module **10***a* of **FIG. 2**, those skilled in the art will generally appreciate that a controller can be connected to any suitable combination of elements included in an electrolyzer cell module.

[**0034**] The controller **90** includes a modified safety system **93**, an emergency stop program **97** and at least one application program **95** used to manage the normal operations of the electrolyzer cell module **10***a*. To that end, in the present embodiment of the invention, the controller **90** includes a memory for storing a computer program readable code means having instructions for the modified safety system **93**, the emergency stop program **97** and the at least one application program **95**.

[**0035**] The modified safety system **93**, in accordance with an embodiment of the invention, is capable of calling an alarm recovery sequence and/or calling the emergency stop program **97**, in the event that an alarm threshold has been violated. Details relating to various embodiments of modified safety programs are provided in the applicant's co-pending U.S. patent application Ser. No.______[Attorney Ref: 9351-493], which was filed on the same day as this application and is hereby incorporated by reference.

[**0036**] The electrolyzer cell stack **11** shown in **FIG. 2** includes one or more PEM electrolyzer cells (not shown). Each PEM electrolyzer cell includes an electrolyte membrane arranged between an anode electrode and a cathode electrode as schematically illustrated in **FIG. 1**. The electrolyzer cell stack **11** has a cathode outlet port **28**, an anode inlet port **202** and an anode outlet port **27**. The cathode outlet port **28** is fluidly connected to each of the respective cathode electrodes included in the electrolyzer cell stack **11**. Similarly, the anode inlet and outlet ports **202**, **27** are fluidly connected to each of the respective anode electrodes included in the electrolyzer cell stack **11**. The electrolyzer cell stack **11** also includes respective electrical connections **12**, **13** to the anode and cathode terminals of the electrolyzer cell stack **11**.

[**0037**] The power supply **117** is coupled to the electrical connections **12**, **13** of the electrolyzer cell stack **11** to energize the electrolyzer cell stack **11**. A stack disconnect device **48** is also coupled between the electrical connections **12**, **13** of the electrolyzer cell stack **11** and the power supply **117**. Additionally, a current **15** and a voltage sensor **14** are appropriately arranged between the stack disconnect device **48** and the power supply **117** to measure the current drawn by the electrolyzer cell stack **11** and the voltage across the electrical connections **12**, **13**.

[**0038**] The stack disconnect device **48** is operable between two states. In a first state, the stack disconnect device **48** electrically couples the power supply **117** to the electrolyzer cell stack **11**. In a second state, the stack disconnect device **48** electrically isolates the power supply **117** from the electrolyzer cell stack **11**. In some embodiments, switching the stack disconnect device **48** between the two states is, for example, controlled by a central and/or local distributed control system, which may use readings from the current and voltage sensors **15**, **14** in this process.

[**0039**] The hydrogen collection device **39** includes an output port **5**; another output port and an input port. In some embodiments, the output port **5** serves as a tap for hydrogen collected by the hydrogen collection device **39**, and is also connectable to other downstream components (not shown). The input of the hydrogen collection device **39** is coupled to the cathode outlet port **28** to accept a combination of water and hydrogen from the electrolyzer cell stack **11**. The other output port is coupled to the water supply tank **16** to return water separated from hydrogen during operation.

[**0040**] The oxygen collection device **20** includes an output port **4**; another output port and two input ports. In some embodiments, the output port **4** serves as a tap for oxygen collected by the oxygen collection device **20**, and is also connectable to other downstream components (not shown). The other output port is coupled to provide water to the anode inlet port **202**, and one of the input ports is coupled to receive a combination of water and oxygen from the anode outlet port **27**. The other input port is coupled to receive water from the water supply tank **16**. That is, according to this specific example, water is provided to the electrolyzer cell stack **11** from the water supply tank **16** via the oxygen collection device **20**, which also recycles water received back from the electrolyzer cell stack **11**.

[**0041**] Optionally, in other embodiments, the water supply tank **16** is also coupled to a cathode inlet port of the electrolyzer cell stack **11** to hydrate the respective cathode sides of the membranes included in the electrolyzer cell stack **11**.

[0042] In some embodiments, the hydrogen and oxygen collection devices **39**, **20** each include a condenser, such as, for example, the apparatus described in the applicant's issued U.S. Pat. No. 6,619,054, which is hereby incorporated by reference.

[0043] In some embodiments, the hydrogen collection device **39** has a volume that is about twice the volume of the oxygen collection device **20**. This difference in size accommodates the relative rates of hydrogen and oxygen evolution that will occur according to reactions (1) and (2) described above.

[0044] The anode and cathode outlet ports **27**, **28** of the electrolyzer cell stack **11** are respectively connected to the oxygen and hydrogen collection devices **20**, **39** through respective combinations of balance-of-plant elements.

[0045] Specifically, in this example embodiment, there is a second pressure sensor **30**, a first pressure safety switch **33**, a first temperature sensor **36** and a first heat exchanger **38** arranged along the fluid pathway from the cathode outlet port **28** to the hydrogen collection device **39**. The first pressure safety switch **33** is operable to send an alarm signal to a central and/or distributed control system if the pressure of the stream of hydrogen and water exiting the cathode outlet port **28** reaches a predetermined high value. In some embodiments, the first pressure safety switch **33** is configured to override and halt the operation of the electrolyzer cell module **10***a* in the event that the pressure is too high, which may imply that there is a severe problem with the electrolyzer cell module **10***a*.

[0046] The first temperature sensor **36** is coupled to provide the first heat exchanger **38** with a regulation signal. Using the regulation signal from the first temperature sensor **36**, the first heat exchanger **38** is operable to cool the stream of hydrogen and water exiting the cathode outlet port **28**, thereby initiating condensation of the water to separate it from the hydrogen within the hydrogen collection device **39**.

[0047] Similarly, in this example embodiment, there is a first pressure sensor **29**, a second temperature sensor **31** and a first temperature safety switch **32** arranged along the fluid pathway from the anode outlet port **27** to the oxygen collection device **20**. The first temperature safety switch **32** is operable to send an alarm signal to a centralized and/or distributed control system if the temperature of the stream of oxygen and water exiting the anode outlet port **27** reaches a predetermined high value. In some embodiments, the first temperature safety switch **32** is configured to override and halt the operation of the electrolyzer cell module **10***a* in the event that the temperature is too high, which may imply that there is a severe problem with the electrolyzer cell module **10***a*.

[0048] The anode inlet port **202** of the electrolyzer cell stack **11** is connected to receive water from the oxygen collection device **20** through a respective combination of balance-of-plant elements as well. Specifically, a circulation pump **23**, a second heat exchanger **22**, a resistivity meter **24**, a flow switch **25** and preferably a de-ionizing filter **26** are arranged along the fluid pathway to the anode inlet port **202** from the oxygen collection device **20**. The second heat exchanger **22** is also coupled to receive a regulation signal from the second temperature sensor **31** arranged on the fluid pathway originating from the anode outlet port **27**.

[0049] The circulation pump **23** is operable to force the flow of water into the electrolyzer cell stack **11**. In some embodiments, the circulation pump is of a high-temperature/high-pressure type, and is constructed with materials such as Teflon® or Peek®. Using the regulation signal from the second temperature sensor **31**, the second heat exchanger **22** is operable to adjust the temperature of the water stream entering the electrolyzer cell stack **11**. The resistivity meter **24** is operable to measure the resistivity of the water flowing into the electrolyzer cell stack **11**. The flow switch **25** is operable to send an alarm signal to a central and/or local distributed control system if the water level is too low. In some embodiments, the de-ionizing filter **26** incorporates organic and particulate filtering functions.

[0050] As a side note, in different embodiments the first and second heat exchangers **38**, **22** are made up of different components. For example, in one embodiment the first and second heat exchangers **38**, **22** include fans for temperature regulation by air-heating/cooling, whereas in other embodiments the first and second heat exchangers **38**, **22** include pumps and coolant fluids for temperature regulation by liquid-heating/cooling. Those skilled in the art will generally appreciate that a heat exchanger can be embodied in a number of different forms, but in each embodiment the function of a heat exchanger is to serve as a temperature regulation means.

[0051] There are also a number of balance-of-plant elements arranged along the fluid pathway from the water supply tank **16** to the oxygen collection device **20**. Specifically, the water supply tank **16** is connected to the oxygen collection device **20** through a fill pump **17**, an organic filter **18**, a particulate and a de-ionizing filter **19**, a check valve **47** and a three-way valve **21**. An output of the three-way valve **21** is also coupled back to the water supply tank **16**. The check valve **47** is arranged to prevent back flow of water through the fill pump **17** and filters **18**, **19**.

[0052] A first water level indicator **37** is coupled to the oxygen collection device **20** and to the fill pump **17** and the three-way valve **21**. The first water level indicator **37** is operable to measure the water level in the oxygen collection device **20** and provide a feedback control signal to the fill pump **17** and the three-way valve **21**. For example, when the water level in the oxygen collection device **20** is higher than a pre-set high level value, the three-way **21** valve is set to re-circulate water back to the water supply tank **16**; or, when the water level is lower than a pre-set low level value, the fill pump **17** is signalled to increase the rate of water flow.

[0053] Comparatively, the balance-of-plant setup between the hydrogen collection device **39** and the water supply tank **16** is quite simple. A second water level indicator **45** is coupled to the hydrogen collection device **39** and a purge valve **46** is connected between the hydrogen collection device **39** and the water supply tank **16**. The purge valve **46** is operated by a control signal received from the second water level indicator **45** coupled to the hydrogen collection device **39**. When the water level in the hydrogen collection device **39** is higher than a pre-set level value, the purge valve **46** opens after receiving the control signal from the second water level indicator **45**. Once the purge valve **46** is opened, water can flow from the hydrogen collection device **39** to the water supply tank **16**. Alternatively, the purged water can be dumped out of the system or used for other purposes (i.e. as a coolant).

[0054] The hydrogen collection device **39** also has a safety valve **44** that automatically vents gas from the hydrogen collection device **39** when the pressure inside reaches a pre-set upper threshold. Accordingly, the safety valve **44** aids in the regulation of the hydrogen pressure, which in this embodiment, is followed by the oxygen pressure via the operation of the pressure following device **34**.

[0055] In this particular embodiment, the output port **5** of the hydrogen collection device **39** is coupled to a combination of valves. Specifically, the output port **5** is coupled to a backpressure valve **40** that is in parallel with a normally open venting valve **41** that is arranged in series with a needle/orifice valve **42**. The outputs of the backpressure valve **40** and the needle/orifice valve **42** are coupled in parallel into a check valve **43**.

[0056] The backpressure valve **40** is arranged to regulate the hydrogen pressure within the hydrogen collection device **39** during the operation of the electrolyzer cell module **10***b*. The hydrogen is preferably stored in a large low-pressure (e.g. around 100 psi) tank having water drainage to remove whatever small amount of water that could still be present with the hydrogen. Alternatively, the hydrogen could be stored in low-pressure storage devices such as metal hydrides. The hydrogen could also be further compressed into higher-pressure storage vessels.

[0057] The combination of the normally open valve **41** and the needle/orifice valve **42** cooperate to controllably release the pressure within the electrolyzer cell module **10***a* when it is shut down. The normally open venting valve **41** is preferably closed during start-up and opens when the electrolyzer cell module **10***b* shuts down. The normally open valve **41** also functions as an emergency pressure relief path when the electrolyzer cell module **10***b* is suddenly stopped in emergency situations, which reduces the chances that any of the pumps in the electrolyzer cell modules **23** will be de-primed by the sudden formation of gas bubbles in the system. The needle/orifice valve **42** is arranged after the normally open valve **41** to slowly lower the hydrogen pressure to the ambient pressure, after the electrolyzer cell module **10***b* is shut down, again, in order not to de-prime any of the circulation pumps.

[0058] The check valve **43** is arranged to prevent back flow into the hydrogen collection device **39** and isolate the hydrogen pressure from pressures downstream.

[0059] A hydrogen gas sensor **35** is arranged on the output port **4** of the oxygen collection device **20** to detect irregularly high levels of hydrogen in the oxygen stream, which may indicate that there is a leak somewhere in the system. The oxygen collection device **20** also has a safety valve **49** arranged to vent oxygen should the pressure inside reach a pre-set high value.

[0060] With continued reference to **FIG. 3**, the pressure following device **34** is arranged between the output port **4** of the oxygen collection device **20** and the hydrogen collection device **39**. Specifically, the pressure following device **34** includes a pressure sensor connected to measure the hydrogen pressure in the hydrogen collection device **39**, and a dome-loaded pressure valve, which is configured as a negative bias pressure regulator, that is connected to the output port **4** of the oxygen collection device **20**. The pressure following device **34** measures/senses the hydrogen pressure and sets the oxygen pressure via control of the dome-loaded pressure valve. Aspects of pressure following arrangements according to aspects of embodiments of the invention are described in greater detail in the applicant's co-pending U.S. patent application Ser. No.______ [Attorney Ref. No: 9351-460], which was filed on the same day as this application and is hereby incorporated by reference.

[0061] During an emergency shutdown process it is preferable that the pressure following device **34** continues operation so as to permit the circulation pumps to flush out gases dissolved in the water so that they do not accumulate in relatively large bubbles within the electrolyzer cell module **10***a*. This is desirable since the accumulation of relatively large gas bubbles within the electrolyzer cell module **10***a* may lead to a de-priming of the circulation pumps.

[0062] In this particular embodiment, the hydrogen side of the electrolyzer cell stack **11** does not include a pump, and, accordingly the hydrogen pressure is primarily established using the backpressure valve **40**. It is beneficial to the overall system efficiency to keep the hydrogen pressure relatively high in order to reduce the size of hydrogen gas bubbles, which will in turn increase the active reaction area and reduce the amount of current fed to the electrolyzer cell stack **11**. Having smaller hydrogen bubbles improves efficiency and counteracts any decrease in efficiency caused by the relatively high pressure(s) of the system.

[0063] The operation of the electrolyzer cell stack **11** (in **FIG. 2**) is similar to that of the electrolyzer cell module **100** (in **FIG. 1**). To briefly reiterate, the power supply **117** supplies the requisite energy for reactions (1) and (2). Oxygen is produced in the anode electrodes according to reaction (1) and then a combination of water and oxygen flows out of the anode outlet port **27** into the oxygen collection device **20** where the oxygen is separated from the water. Hydrogen is produced in the cathode electrodes according to reaction (2) and then a combination of water and hydrogen flows out of the cathode outlet port **28** into the hydrogen collection device **39** where the hydrogen is separated from the water.

[0064] Referring now to **FIG. 3**, shown is an electrolyzer cell module **10***b*, which includes an alternative pressure following arrangement to that included in the electrolyzer cell module **10***a* shown in **FIG. 2**. Specifically, the electrolyzer cell module **10***b* is configured so that the hydrogen pressure follows the oxygen pressure, but remains higher. To this end, a pressure following device **34'** is arranged between the output port **5** of the hydrogen collection device **39** and the oxygen collection device **20**. The pressure following device **34'** includes a pressure sensor connected to measure the oxygen pressure in the oxygen collection device **20**, and a dome-loaded pressure valve, which is configured as a positive bias pressure regulator, that is connected to the output port **5** of the hydrogen collection device **39**. As described above, the pressure following device **34'** measures/senses the oxygen pressure and sets the hydrogen pressure via control of the dome-loaded pressure valve. Again, aspects of pressure following arrangements according to aspects of embodiments of the invention are described in greater detail in the applicant's co-pending U.S. patent application Ser. No.______[Attorney Ref. No: 9351-460], which was incorporated by reference above.

[0065] During an emergency shutdown process it is preferable that the pressure following device **34'** continues operation so as to permit the circulation pumps to flush out gases dissolved in the water so that they do not accumulate in relatively large bubbles within the electrolyzer cell module **10***b*. This is desirable since the accumulation of relatively large gas bubbles within the electrolyzer cell module **10***b* may lead to a de-priming of the circulation pumps.

[**0066**] Moreover, the output port **5** of the hydrogen collection device **39** is now only connected to the normally open venting valve **41** that is arranged in series with the check valve **43**. The normally open venting valve **41** and the check valve **43** operate as described above. Additionally, the output port **4** of the oxygen collection device **20** is connected to a needle/orifice valve **42'** that is further connected in series to another normally open valve **41'**. The needle/orifice valve **42'** and the normally open valve **41'** operate to regulate the oxygen pressure during the operation of the electrolyzer cell module **10***c*.

[**0067**] The combination of the normally open valve **41'** and the needle/orifice valve **42'** cooperate to controllably release the pressure within the electrolyzer cell module **10***b* when it is shut down, in a similar manner to the combination of the normally open valve **41** and the needle/orifice valve **42** descrfibed above. The normally open venting valve **41** is preferably closed during start-up and opens when the electrolyzer cell module **10***b* shuts down. The normally open valve **41** also functions as an emergency pressure relief path when the electrolyzer cell module **10***b* is suddenly stopped in emergency situations, which reduces the chances that any of the pumps in the electrolyzer cell modules **23** will be de-primed by the sudden formation of gas bubbles in the system. The needle/orifice valve **42** is arranged after the normally open valve **41** to slowly lower the hydrogen pressure to the ambient pressure, after the electrolyzer cell module **10***b* is shut down, again, in order not to de-prime any of the circulation pumps.

[**0068**] **FIG. 4** is a flow chart illustrating a high-level method of operating an electrolyzer cell module according to aspects of an embodiment of the invention. At step **4-0**, the electrolyzer cell module is energized and an initialization sequence, including basic checks, occurs at step **4-1**. The basic checks include, without limitation, checks for control system readiness, the presence of electric power and pneumatic air pressure.

[**0069**] After the basic system checks are complete, the electrolyzer cell module enters a standby mode in step **4-2**. During the standby mode, the control system waits for a start-up command from an operator or another automated machine.

[**0070**] Once a start-up command has been received, a start-up sequence is commenced at step **4-3**. During the start-up sequence the electrolyzer cell module is readied for normal operation. Examples of operations that occur during a start-up sequence include, without limitation, a water fill process, priming of pumps, water polishing, pressurization, and hydrogen purging.

[**0071**] After the start-up sequence **4-3**, a run mode is started at step **4-4**. The run mode can end in at least three different ways, which include, without limitation, normal shutdown initiated by an operator or another automated machine, through an alarm recovery sequence at steps **4-5** and **4-6**, and by an emergency stoppage at step **4-7**. The alarm recovery sequences and emergency stoppages result from safety system logic that is included in the control system for an electrolyzer cell module. Examples describing how the safety system logic can be incorporated into the control system for an electrolyzer cell module are described in the applicant's copending U.S. patent application Ser. No.______[Attorney Ref: 9351-493], which was incorporated by reference above. It is worth noting here that an alarm recovery sequence is only followed by an emergency stoppage if the alarm recovery sequence is not effective correcting the conditions that called for the alarm recovery sequence in the first place.

[**0072**] In some embodiments a control system is provided with a computer program readable code means that has instructions that mirror the method steps described below. Moreover, those skilled in the art will appreciate that these methods may be modified without departing from the scope of the inventive aspects specifically described herein.

[**0073**] Referring now to **FIG. 5**, illustrated is a flow chart depicting the general steps provided in an emergency stop program according to one embodiment of the invention. Once a safety system concludes that an emergency stoppage is the only way left to deal with violated alarm conditions within an electrolyzer cell module the emergency stop program is started at step **5-1**.

[**0074**] With further reference to **FIGS. 2 and 3**, at step **5-2** the electrolyzer cell stack **11** is disconnected from the power supply **117**. Then at step **5-3**, power supplied to the balance-of-plant elements not related to the circulation pump **23** and the pressure following devices **34** and **34'** is cut-off. That is, the circulation pump **23** and the pressure regulation of the line is maintained until gases dissolved in the water within the electrolyzer cell module (**10***a* or **10***b*) can be flushed from the system, leaving the behind relatively pure water. This process will take some finite amount of time, depending upon the exact configuration of an electrolyzer cell module. Simultaneously, pressure is slowly released by way of the normally open valve **41** and the needle/orifice valve **42** (in **FIG. 2**) or the normally open valve **41'** and the needle/orifice valve **42'**. Normally open valves require power to close the valve, but are normally open when no power is supplied. Accordingly, during an emergency stoppage power does not need to be supplied to the normally open valve **41** or **41'**. However, if the normally open valves were replaced with normally closed valves, power would be required for these valves to remain open during an emergency stoppage.

[**0075**] At step **5-4** it is determined whether or not an emergency timer has expired. The emergency timer provides a count down period that has a duration that is about as long as the finite amount of time it takes to flush out the gases from the electrolyzer cell module. If the emergency timer has not expired (no path, step **54**), then the balance-of-plant elements, such as the circulation pump **23**, required to flush the residual gas from the electrolyzer cell module continue to be powered at step **5-5** while the emergency timer is checked again at step **5-4**, after a short delay. On the other hand, if the emergency timer has expired (yes path, step **54**), then it is assumed that the most of the residual gas left in the electrolyzer cell module has been expelled and the entire electrolyzer cell module is shut down, including elements such as the circulation pump **23** and the pressure following devices **34** and **34'**.

[0076] While the above description provides examples according to aspects of embodiments of the invention, it will be appreciated that the present invention is susceptible to modification and change without departing from the fair meaning and scope of the accompanying claims. Accordingly, what has been described is merely illustrative of the application of some aspects of embodiments of the invention. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

We claim:

1. An electrolyzer cell module comprising:

an electrolyzer cell stack for electrolysing a compound liquid to produce at least one gas;

a plurality of balance-of-plant elements connected to the electrolyzer cell stack, for regulating the operation of the electrolyzer cell stack;

a safety system connected to at least some of the balance-of-plant elements and the electrolyzer cell stack, for monitoring at least one process and operating parameter related to the operation of the electrolyzer cell module and evaluating whether or not at least one alarm threshold has been violated by the at least one process and operating parameter;

a computer usable medium, in communication with the safety system, having computer program readable code means embodied therein for emergency stoppage of the normal operation of the electrolyzer cell module when the at least one alarm threshold has been violated, the computer program readable code means including:

instructions for stopping the electrolysis of the compound liquid within the electrolyzer cell stack, thereby stopping the production of the at least one gas;

instructions for operating the electrolyzer cell module so as to flush out residual amounts of the at least one gas dissolved in the compound liquid over a time period; and

instructions for cutting-off power, at the end of the time period, to all of the elements included in the electrolyzer cell module required for flushing out residual amounts of the at least one gas dissolved in the compound liquid, to shut-down the electrolyzer cell stack.

2. An electrolyzer cell module according to claim 1, wherein the computer program readable code means further comprises:

instructions for cutting-off power to some of the balance-of-plant elements included in the electrolyzer cell module, while continuing to provide power to other balance-of-plant elements required to flush out the residual amounts of the at least on gas dissolved in the compound liquid within the electrolyzer cell module.

3. An electrolyzer cell module according to claim 2, wherein the balance-of-plant elements that continue to receive power during an emergency stoppage include a circulation pump and pressure regulating devices.

4. An electrolyzer cell module according to claim 1 further comprising a pressure release means that is operable to slowly and controllably release the pressure within the electrolyzer cell module as it is being turned off.

5. An electrolyzer cell module according to claim 4, wherein the pressure release means in comprised of a combination of valves.

6. An electrolyzer cell module according to claim 5, wherein the combination of valves is comprised of a need/orifice valve and a second valve connected in series, wherein the second valve is opened when the electrolyzer cell module is shut down.

7. An electrolyzerr cell module according to claim 6, wherein the second valve is one of a normally open valve and a normally closed valve.

8. An electrolyzer cell module according to claim 4 further comprising a hydrogen collection device and an oxygen collection device.

9. An electrolyzer cell module according to claim 8, wherein the pressure release means is connected to one of the hydrogen collection device and the oxygen collection device.

10. An emergency stoppage method of operating an electrolyzer cell module that includes a number of balance-of-plant elements and an electrolyzer cell stack, the method comprising:

stopping electrolysis of a compound liquid, thereby stopping the production of at least one gas dissolved in the compound liquid;

flushing out residual amounts of the at least one gas evolved from the compound liquid by operating some of the balance-of-plant elements included in the electrolyzer cell module and not others; and

cutting-off power, to all of the elements included in the electrolyzer cell module required to flush out the residual amounts of the at least one gas dissolved in the compound liquid, to shut-down the operation of the electrolyzer cell stack.

11. A method according to claim 10 further comprising:

controllably releasing the pressure within the electrolyzer cell module as the residual amounts of the at least one gas are flushed from the electrolyzer cell module.

12. A method according to claim 11 further comprising:

cutting-off power to some of the balance-of-plant elements included in the electrolyzer cell module, while continuing to provide power to other balance-of-plant elements required to flush out the residual amounts of the at least on gas dissolved in the compound liquid within the electrolyzer cell module.

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