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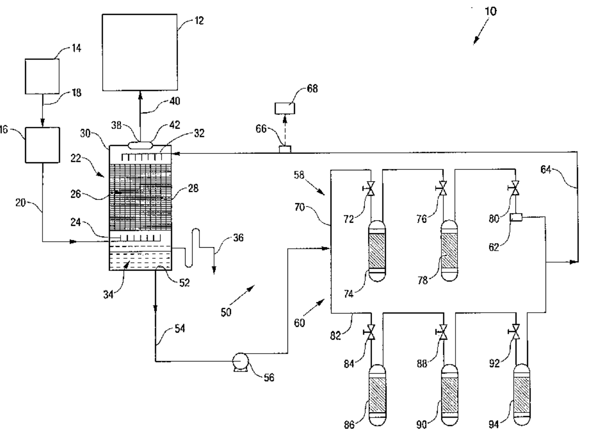
# (54) Title: A SEPARATOR SCRUBBER AND PARALLEL PATH CONTAMINANT ISOLATION LOOP FOR A FUEL REACTANT STREAM OF A FUEL CELL

FIG. 1



(57) **Abstract**: The disclosure includes a separator scrubber (22) for removing ammonia from a fuel reactant stream into a separated contaminant liquid stream that is directed through a parallel path contaminant isolation loop (50) that includes a first path (58) and a second path (60) to decontaminate the stream and direct it back to the scrubber (22). First flow rate and first decontamination capacity operational parameters of the first path (58) may only be the same as either one or none of second flow rate and second decontamination capacity operational parameters of the second path (60) so that the second path (60) decontaminates for a second decontamination duration that is greater than a first decontamination duration of the first path (58) by a predetermined duration of a warning period. Ion exchange decontaminators (74, 78, 86, 90, 92) may be serviced during the warning period.

WO 2010/147569 A1

Description

# A SEPARATOR SCRUBBER AND PARALLEL PATH CONTAMINANT ISOLATION LOOP FOR A FUEL REACTANT STREAM OF A FUEL CELL

## Technical Field

**[0001]** The present disclosure relates to fuel cells that are suited for usage in transportation vehicles, portable power plants, or as stationary power plants, and the disclosure especially relates to a separator scrubber and parallel path contaminant isolation loop for efficiently removing contaminants such as ammonia from a fuel reactant stream passing into a fuel cell.

## Background Art

**[0002]** Fuel cells are well known and are commonly used to produce electrical current from hydrogen containing reducing fluid fuel and oxygen containing oxidant reactant streams to power electrical apparatus such as transportation vehicles. In fuel cells of the prior art, it is well known that fuel is produced by fuel processing system including a reformer and the resulting fuel is referred to as a reformate fuel that flows from the fuel processing system through a fuel reactant stream inlet line into an anode flow field of the fuel cell. As is well known an oxygen rich reactant simultaneously flows through a cathode flow field of the fuel cell to produce electricity.

**[0003]** Unfortunately, such reformate fuels frequently contain contaminants especially ammonia. The presence of ammonia in the reformate fuel stream is detrimental to the performance of the fuel cell. It is understood that ammonia is a common byproduct of the reforming process and although the reforming process is designed to minimize formation of ammonia, it is common that low levels of ammonia are present in the reformate fuel. The ammonia formation results from nitrogen that is present in natural gas that is fed into the reformer as a base fuel to be reformed into the hydrogen rich fuel. Typically nitrogen content is between 2-3 percent but may reach as high as 15 percent in some parts of the world. Known fuel cells, especially those that include phosphoric acid as an electrolyte, cannot achieve a desired 10 year life with greater than 1-2 percent nitrogen within the natural gas. Additionally, in the case of auto thermal or partial oxidation reformers, nitrogen can also be introduced when air is used as the oxygen source for the reforming process.

**[0004]** Many efforts have been undertaken to remove ammonia and other contaminants from fuel reactant streams of fuel cells. For example, U.S. Patent No. 4,801,356 that issued on January 31, 1989, to Grasso disclosed an elaborate system for removal of ammonia from fuel cell power plant water. The system of Grasso includes passing cooling water that had been used to cool the reformate fuel through a first steam stripper and a second steam stripper to remove the ammonia contaminant. Although effective, the system of Grasso requires complex and costly strippers and processing of a large volume of fuel cell coolant water.

**[0005]** More recently U.S. Patent No. 6,376,114, that issued on April 23, 2002 to Bonville, Jr. et al., disclosed another elaborate system for removing ammonia and other contaminants from reformate fuel. The system of Bonville, Jr. et al., includes alternatively a disposable ammonia scrubber, an ammonia scrubbing cool water bed and an ammonia stripping warm water bed, a pair of first and second regenerable scrubbers, or a single regenerable scrubber. While effective the Bonville, Jr. et al. system also includes elaborate and costly components that require a high level of maintenance to operate the system.

**[0006]** An International Patent Application that was published under the Patent Cooperation Treaty on March 27, 2008 with Publication Number WO 2008/036090 A1 by inventors Grasso et al. discloses use of an ammonia separator scrubber that has an isolation loop directing flow of separated contaminants within a liquid stream through the isolation loop and through an ion exchange resin within the loop and then circulating the decontaminated stream back through the separator scrubber. Grasso et al., therefore enhances efficiencies by concentrating the contaminants outside of the separator scrubber. However, scheduling maintenance and/or replacement of the ion exchange resin or ion exchange decontaminator holding the resin presents substantial challenges, especially where a level of ammonia contaminant varies depending upon nitrogen content within a base fuel. A set maintenance schedule is difficult to establish, and in the event the ion exchange resin is exhausted, permanent damage may result in the associated fuel cell. The patents to Grasso and Bonville, Jr. et al., and the published application to Grasso et al. are owned by the owner of all rights in the present disclosure.

**[0007]** Other ammonia and related contaminant removal systems for fuel cells are known in the art. However, none of these provide for efficiently removing ammonia with minimal costs and minimal maintenance requirements. Most known ammonia contaminant removal systems require large components for processing a high volume of fluids, or require high frequency removal and replacement of contaminated filters and/or ion beds, etc.

**[0008]** Consequently, there is a need for a contaminant removal system for a fuel reactant stream for a fuel cell that may be operated efficiently for long periods of time without high frequency maintenance.

## Summary

**[0009]** The disadvantages and limitations of the background art discussed above are overcome by the present disclosure. The disclosure is a separator scrubber and parallel path contaminant isolation loop for a fuel reactant stream of a fuel cell. The separator scrubber and isolation loop are secured in fluid communication between a fuel processing system for processing a base fuel into the fuel reactant stream and a fuel reactant inlet line of at least one fuel cell for receiving the fuel reactant stream. The separator scrubber includes an ammonia dissolving means disposed within a scrubber container of the separator scrubber for dissolving ammonia from the fuel reactant stream into a separated contaminant liquid stream within the separator scrubber. A water discharge is secured adjacent the ammonia dissolving means and is configured to discharge water to flow through the ammonia dissolving means. A fuel reactant discharge is also secured adjacent the ammonia dissolving means and configured to discharge the fuel reactant to flow through the ammonia dissolving means. An accumulator is secured in fluid communication with the ammonia dissolving means. A scrubber fuel outlet is secured within the scrubber container and is configured to direct flow of the decontaminated fuel reactant from the ammonia dissolving means and from the separator scrubber into the fuel reactant inlet line.

**[0010]** The parallel path contaminant isolation loop is secured in fluid communication with the separator scrubber and the loop includes a loop conduit configured to direct the separated contaminant liquid stream out of the accumulator. An isolation loop pump is secured in fluid communication with the loop conduit for pumping the separated contaminant liquid stream from the accumulator through the loop conduit. A first path is secured in fluid communication with the loop conduit downstream from the pump, and the first path defines two operational parameters including a first flow rate and a first decontamination capacity. A second path is secured in fluid communication with the loop conduit downstream from the pump and parallel to the first path. The second path also defines two operational parameters including a second flow rate and a second decontamination capacity. The first path may include a variable flow restrictor to selectively adjust the flow rate through the first path.

**[0011]** The operational parameters of the first path may only be the same as either one or none of the operational parameters of the second path so that the second path decontaminates for a second decontamination duration that is greater than a first decontamination duration of the first path by a predetermined safe-interval. This means that the first path and the second path may have equal flow rates and differing decontamination capacities; differing flow rates and equal decontamination capacities; or, differing flow rates and differing decontamination capacities. The relative operational parameters of the first and second paths are selected so that the second decontamination duration of the second path is greater than the first decontamination duration of the first path by the predetermined safe-interval.

**[0012]** The first and second parallel paths are configured to direct flow of the separated contaminant liquid stream through the two parallel paths and into a loop conduit return line that directs flow of the decontaminated liquid stream from the parallel paths into the water discharge within the separator scrubber. A liquid ion conductivity sensor is secured in communication with the liquid stream passing from the separator scrubber and through the parallel path contaminant isolation loop and back to the scrubber, for sensing a conductivity of the liquid stream.

**[0013]** It has been determined by the inventors of the present disclosure that electrical conductivity through the decontaminated liquid stream is not linear with ammonia concentration. It is believed that an interaction between ammonia, carbon dioxide and varying pH levels causes the non-linear relationship between ammonia concentration and conductivity. Therefore, simply measuring conductivity of a decontaminated liquid stream passing from an ion exchange decontaminator to a separator scrubber is not an accurate measure of a rate of a useful life of an ion exchanger, such as a cation exchange bed within the parallel paths.

[0014] Common practice in water treatment has been to place a conductivity sensor between two ion exchange beds in series. When the first ion exchange bed exhausts its decontamination capacity there will be an increase in conductivity thereby warning the operator that service is required. However, such an application is ineffective in an ammonia removal context primarily because an amount of carbon dioxide dissolved in the water masks any impact ammonia will have on the conductivity of the water. Hence, any ammonia passing through an exhausted bed will not be detected as increased conductivity. Having two parallel paths solves this problem. When the decontamination capacity of the first path is exhausted the additional ammonia slippage through the exhausted first path will cause additional carbon dioxide adsorption into the water when the ammonia is in contact with the fuel passing through the scrubber. This added carbon dioxide adsorption along with the ammonia will be sufficient to cause a substantial increase in conductivity.

[0015] For an exemplary phosphoric acid fuel cell, a nominal conductivity of such a decontaminated liquid stream passing from an effective ion exchange decontaminator has been found to be about 12 micro Siemens per square centimeter("uS/cm"). (For purposes herein, the word "about" is to mean plus or minus twenty percent.) It has also been determined by the present inventors that a conductivity of up to about 100uS/cm indicates that an acceptable, non-harmful amount of ammonia is within the decontaminated stream. Any conductivity beyond about 100uS/cm indicates that the ion exchangers must be serviced immediately to avoid damage to the fuel cell. Therefore, the operational parameters of the first and second paths are selected so that whenever the first decontamination duration is exceeded, the conductivity of the stream will jump from about 12uS/cm to somewhere below 100uS/cm.

**[0016]** The separator scrubber and parallel path contaminant isolation loop provide an apparatus and method for safely and efficiently scheduling replacement and/or maintenance of the ion exchange decontaminators within the parallel paths. Selection and design of the relative flow rates and decontamination capacities of the operational parameters of the first and second paths is also made so that the safe-interval of additional decontamination capacity can provide satisfactory decontamination for a predetermined duration of time referred to herein as a warning period. During operation of the parallel path contaminant isolation loop, after a first or normal operating period, the ion exchange decontaminators of both parallel paths decontaminate all of the contaminated liquid stream to a satisfactory level. Eventually the first decontamination duration of the first path is reached. Whenever that happens, the contaminated liquid stream passing through the first path would no longer be decontaminated. Therefore, there would be a sudden and substantial increase in the conductivity of the liquid stream passing adjacent the liquid ion conductivity sensor. The sensor would then detect such an increase and communicate a maintenance schedule signal to a controller.

**[0017]** The greater second decontamination duration of the second path is therefore selected to maintain the conductivity of the decontaminated stream below a predetermined harmful upper limit so that the fuel cell is not harmed while the safe-interval of the second decontamination duration of the second path is utilized. The operational parameters of the first and second paths may be designed and selected to provide such satisfactory decontamination during the safe-interval of the extended decontamination duration of the second path for the predetermined warning period. For example, based upon an average nitrogen content of a natural gas base fuel, the safe-interval of the second decontamination duration of the second path may be designed and manufactured to provide satisfactory decontamination for a warning period of between four to six weeks, or whatever predetermined warning period provides for efficient maintenance and/or replacement of the ion exchange decontaminators.

**[0018]** Therefore, the present separator scrubber and parallel path contaminant isolation loop provides for enormous flexibility to operate with substantial variations of nitrogen concentrations within the base fuel. The scrubber and loop also provide for a user-adjustable warning period prior to maintenance and/or replacement of the ion exchangers by varying the operational parameters of the parallel paths.

**[0019]** Additionally, because one of the parallel paths may be isolated by valves while the other is continuously decontaminating the contaminated liquid stream, the ion exchangers may be maintained and/or replaced while the fuel cell remains in operation, such as during the warning period.

**[0020]** The disclosure includes a method of operating the separator scrubber and parallel path contaminant isolation loop to enhance efficiencies of maintenance and/or replacement of ion exchange decontaminators

## Brief Description of Drawing

**[0021]** Figure 1 is a simplified schematic representation of a separator scrubber and parallel path contaminant isolation loop for a fuel reactant stream of a fuel cell constructed in accordance with the present disclosure.

## Description of the Preferred Embodiments

**[0022]** Referring to the drawings in detail, a separator scrubber and parallel path contaminant isolation loop for a fuel reactant stream of a fuel cell is shown in FIG. 1, and is generally designated by the reference numeral 10. A fuel cell 12 appropriate for the present disclosure may be a phosphoric acid electrolyte, a proton exchange membrane ("PEM") electrolyte, or any electrolyte known in the art. A fuel supply 14 delivers a hydrogen containing base fuel to a reformer based fuel processing system 16 through a fuel supply line 18. The fuel supply 14 may be a pressurized supply source, or may include pressurizing means for increasing a pressure of the fuel in a manner known in the art. The reformer based fuel processing system 16 may be any system known in the art for reforming hydrogen rich fluids into reformate fuels appropriate for use in fuel cells. The fuel processing system 16 also includes related components necessary for processing the hydrogen rich fuel into a reformate fuel appropriate for a fuel cell, such as de-sulfurizers, shift converters (not shown), etc.

**[0023]** The reformate fuel leaves the fuel processing system 16 through a first section of the fuel reactant inlet line 20. The fuel then is directed into a separator scrubber 22 to be discharged through a fuel reactant discharge 24 within the scrubber 22. The separator scrubber 22 includes an ammonia dissolving means 26 for dissolving ammonia from the reformate fuel into a separated contaminant liquid stream within the separator scrubber 22, such as a packed bed 28 of a high surface area medium disposed within a scrubber container 30. Alternative ammonia dissolving structures 28 that may be utilized include open cell foams, unitary integral ceramic foam, honey-comb materials, corrugated materials, wool, or wire-mesh structures. A water discharge 32 is secured above the packed bed 28 for discharging water from the discharge 32 to pass downward by gravity through the packed bed 28. The fuel discharge 24 is secured below the packed bed 28 so that the fuel discharged through the discharge 32 passes upward through the packed bed as the water is flowing downward through the packed bed 28. As the gaseous fuel passes over and contacts the surface area of the packed bed so that 28 contaminants within the gaseous fuel are dissolved into solution within the water passing over the surface of the medium within the packed bed 28.

**[0024]** Flow through the above described packed bed 28 of the separator scrubber 22 has been described with the flow of the water being downward by force of gravity and the flow of the gaseous fuel being upward, counter to the water flow ("counter-flow"). However, it is to be understood that other configurations of the scrubber 22 within the scope of the disclosure may provide for alternative flow patterns, wherein the water and fuel flow across each other ("cross-flow") and/or in parallel ("co-flow") with each other.

**[0025]** An accumulator 34 is defined in fluid communication with the scrubber container 30 such as below the fuel reactant discharge 24 so that water passing downward through the packed bed 28 is accumulated within the accumulator 34. It is to be understood however, that the accumulator 34 may also be a separate container (not shown) secured in fluid communication with the water within the scrubber container 30. An overflow vent 36 may also be secured to the scrubber container 30 for directing any excess water out of the scrubber 22. A scrubber fuel outlet 38 is secured within the scrubber container 30 and is configured to direct flow of decontaminated fuel reactant stream from the ammonia dissolving means 26 and from the separator scrubber 22 into a fuel reactant inlet line 40 that is secured in fluid communication with the fuel cell 12. The scrubber 22 may also include a mist eliminator 42 adjacent the scrubber fuel outlet 38 for eliminating movement of any water droplets along with the fuel reactant stream. The mist eliminator 42 may be any mist eliminator for achieving such a function, such as steel-wool, etc.

**[0026]** A parallel path contaminant isolation loop 50 is secured in fluid communication with the separator scrubber 28 such as through an accumulator outlet 52 located within the accumulator 34. The loop 50 includes a loop conduit 54 configured to direct the separated contaminant liquid stream out of the accumulator 34. An isolation loop pump 56 is secured in fluid communication with the loop conduit 54 for pumping the separated contaminant liquid stream from the accumulator 34 through the loop conduit 54. A first path 58 is secured in fluid communication with the loop conduit 54 downstream from the pump 56. The first path 58 defines two operational parameters including a first flow rate and a first decontamination capacity. A second path 60 is secured in fluid communication with the loop conduit 54 downstream from the pump 56 and is configured to be parallel to the first path 58. The second path 60 also defines two operational parameters including a second flow rate and a second decontamination capacity. The first path may include a variable flow restrictor 62 to selectively adjust the flow rate through the first path 58. The operational parameters of the first path 58 may only be the same as either one or none of the operational parameters of the second path 60 so that the second path 60 decontaminates for a second decontamination duration that is greater than a first decontamination duration of the first path by a predetermined safe-interval.

**[0027]** The first and second parallel paths 58, 60 are configured to direct flow of the separated contaminant liquid stream through the two parallel paths 58, 60 and into a loop conduit return line 64 that directs flow of the decontaminated liquid stream from the parallel paths 58, 60 into the water discharge 32 within the separator scrubber 22. A liquid ion conductivity sensor 66 is secured in communication with the liquid stream passing from the separator scrubber 22 through the parallel path contaminant isolation loop 50 and back to the scrubber 22 for sensing a conductivity of the liquid stream. The liquid ion conductivity sensor 66 may be in communication with a controller 68 for receiving sensed conductivity information from the sensor 66 and for communicating such sensed information, such as by a maintenance schedule signal.

**[0028]** The first and second paths 58, 60 are configured so that the first path 58 and the second path 60 may have equal flow rates and differing decontamination capacities; differing flow rates and equal decontamination capacities; or, differing flow rates and differing decontamination capacities. The relative operational parameters of the first and second paths 58, 60 are selected so that the second decontamination duration of the second path 60 is greater than the first decontamination duration of the first path 58 by the predetermined safe-interval, or warning period duration.

**[0029]** FIG. 1 shows an exemplary embodiment of the variable configurations of the first and second paths 58, 60 described above. In particular, FIG. 1 shows that the first path 58 may have a lower decontamination capacity than the second path 60, while the variable flow restrictor 62 may be configured to assure that the first and second paths 58, 60 have the same flow rates. In the FIG. 1 embodiment, a first path line 70 directs flow of about one-half of the liquid contaminated stream from the loop conduit 54 through a first first-path valve 72 and then into and through a first first-path ion exchange decontaminator 74, and then through a second first-path valve 76, into and through a second first-path ion exchange decontaminator 78, and then through a third first-path valve 80 and then into and through the variable flow restrictor 62, and then out of the first path 58 and into the loop conduit return line 64.

**[0030]** As shown in the exemplary embodiment of FIG. 1, the second path 60 includes a second path line 82 that directs flow of about one-half of the liquid contaminated stream from the loop conduit 54 through a first second-path valve 84 and then into and through a first second-path ion exchange decontaminator 86, and then through a second second-path valve 88, into and through a second second-path ion exchange decontaminator 90, and then through a third second-path valve 92 and then into and through a third second-path ion exchange decontaminator 94, and then out of the second path 60 and into the loop conduit return line 64.

**[0031]** In operation of the exemplary embodiment as shown in FIG. 1 of the parallel path contaminant isolation loop 50, after a first or normal operating period, the ion exchange decontaminators 74, 78, 86, 90 and 94 of both parallel paths 58, 60 decontaminate all of the contaminated liquid stream to a satisfactory level. Eventually the first decontamination duration of the first path 58 is surpassed. Whenever that happens, the contaminated liquid stream passing through the first path 58 would no longer be decontaminated. Therefore, there would be a sudden and substantial increase in the conductivity of the liquid stream passing adjacent the liquid ion conductivity sensor 66. The sensor would then detect such an increase and communicate a maintenance schedule signal to the controller 68.

**[0032]** The greater second decontamination duration of the second path 60 is therefore configured to maintain the conductivity of the decontaminated stream below a predetermined harmful upper limit so that the fuel cell 12 is not harmed while the safe-interval of the second decontamination duration of the second path 60 is utilized. The operational parameters of the first and second paths 58, 60 may be designed, selected and/or controlled to provide such satisfactory decontamination during the safe-interval of the extended decontamination duration of the second path 60 throughout safe-interval or predetermined warning period.

**[0033]** Instead of having different decontamination capacities of the first and second paths 58, 60, as shown in FIG. 1, the first and second paths 58, 60 in contrast may be configured to have about the same decontamination capacities while the first path 58 has a different flow rate of the liquid contaminated stream through the first path 58 than a flow rate of the stream through the second path 60. This would be shown in FIG. 1 if the third second-path ion exchange decontaminator 94 was eliminated. In this embodiment the variable flow restrictor 62 in the first path 58 could be controlled to slow a rate of flow through the first path 58. This would result in the decontamination duration of the first path 58 being less than the decontamination duration of the second path 60. As described above, whenever the decontamination duration of the first path 58 ends, the conductivity of the liquid decontaminated stream passing through the loop conduit return line 64 would substantially increase, resulting in a maintenance signal during the warning period as the decontamination duration of the second path 60 is utilized.

**[0034]** In a further embodiment similarly shown in FIG. 1 the first path 58 may have a different decontamination capacity and a different flow rate than the second path 60. In this embodiment the variable flow restrictor 62 could be utilized to reduce the flow rate of the liquid stream passing through the first path 58 to thereby increase a difference between the decontamination duration of the first path 58 and the second path 60. This provides for user adjustable controlling of the length of the warning period. For example, if the base fuel within the fuel supply 14 is found to have an unexpected high concentration of nitrogen, so that the warning period preceding a first scheduled maintenance of the decontaminators 74, 78, 86, 90 and 94 is shorter than anticipated, the variable flow restrictor 62 could then be adjusted to slow the flow rate through the first path 58. This would result in a greater difference between the decontamination durations of the first and second paths 58, 60, thereby resulting in a longer warning period.

**[0035]** The same user adjustable control of the duration of the warning period may also be utilized to provide an efficient warning period based upon factors external to the operation of the fuel cell 12. For example, a fuel cell 12 (which would most likely be one of many fuel cells in a cell stack assembly (not shown)) may be operated in a highly populated area where service of the decontaminators 74, 78, 86, 90 and 94 can be efficiently scheduled in a short time span such as one week. In contrast, the fuel cell 12 may be operated in a very remote area where efficient service of the decontaminators 74, 78, 86, 90 and 94 requires more than a four week notice. The present disclosure provides for a user adjustable setting of the warning period to efficiently accommodate such variable circumstances. The same user adjustable control similarly provides for a custom setting of the warning period to efficiently accommodate other unique circumstances, including variability of nitrogen content of the base fuel, desired ammonia levels in the decontaminated fuel, possible necessity of uninterrupted fuel cell 12 operation during service of the decontaminators 74, 78, 86, 90 and 94, etc.

**[0036]** The inventive variability of the operational parameters of the first and second paths 58, 60 that results in satisfactory decontamination during the safe interval and warning period is referred to herein for clarity as follows: The flow rate and decontamination capacity operational parameters of the first path 58 may only be the same as either one or none of the flow rate and decontamination capacity operational parameters of the second path 60 so that the second path 60 decontaminates for a second decontamination duration that is greater than a first decontamination duration of the first path by a predetermined duration of a warning period.

**[0037]** The present disclosure also includes a method of scheduling service of the ion exchange decontaminators 74, 78, 86, 90 and 94 including directing the base fuel from the reformer-based fuel processing system through the separator scrubber 22, removing ammonia from the fuel into the separated contaminant liquid stream, directing flow of the separated contaminant liquid stream through the parallel path contamination isolation loop 50 wherein the flow rate and decontamination capacity operational parameters of the first path 58 may only be the same as either one or none of the flow rate and decontamination capacity operational parameters of the second path 60 so that the second path 60 decontaminates for a second decontamination duration that is greater than a first decontamination duration of the first path by a predetermined duration of a warning period; and servicing the ion exchange decontaminators 74, 78, 86, 90 and 94 during the warning period.

**[0038]** While the present disclosure has been disclosed with respect to the described and illustrated separator scrubber and parallel path contaminant isolation loop for a fuel reactant stream of a fuel cell 10, it is to be understood the disclosure is not to be limited to those alternatives and described embodiments. For example, while a fuel cell 12 having a phosphoric acid electrolyte is known to be detrimentally affected by ammonia contamination and is therefore a likely form of fuel cell 12 to benefit from this disclosure, the disclosure also will be of substantial advantage to and appropriate for fuel cells with other known electrolytes. Accordingly, reference should be made primarily to the following claims rather than the forgoing description to determine the scope of the disclosure.

CLAIMS

What is claimed is:

1. A separator scrubber and parallel path contaminant isolation loop (10) for a fuel reactant stream of a fuel cell (12), comprising:

a. at least one fuel cell (12) for receiving the fuel reactant stream;

b. a fuel processing system (16) for processing a base fuel into the fuel reactant stream;

c. a separator scrubber (22) secured in fluid communication between the fuel processing system (16) and a fuel reactant inlet line (40) of the fuel cell (12) and configured for dissolving ammonia from the fuel reactant stream passing from the fuel processing system (16) through the separator scrubber (22) to the fuel cell (12) and for directing flow of the dissolved ammonia into a separated contaminant liquid stream within an accumulator (34) secured in fluid communication with the separator scrubber (22);

d. a parallel path contaminant isolation loop (50) secured in fluid communication with the accumulator (34) and configured for directing flow of the separated contaminant liquid stream through the loop (50), the parallel path contaminant isolation loop (50) including a loop conduit (54) for directing flow of the separated contaminant liquid stream out of the accumulator (34), an isolation loop pump (56) secured in pumping relationship with the loop conduit (54) for pumping the separated contaminant liquid stream through the isolation loop (50), a first path (58) secured in fluid communication with the loop conduit (54) downstream from the isolation loop pump (56), a second path (60) secured in fluid communication with the loop conduit (54) downstream from the isolation loop pump (56) and configured to be parallel with the first path (58), the first path (58) and second path (60) being configured to direct flow of the separated contaminant liquid stream through the paths (58, 60) and into a loop conduit return line (64) secured in fluid communication between the paths (58, 60) and a water discharge (32) within the separator scrubber (22);

d. wherein first flow rate and first decontamination capacity operational parameters of the first path (58) may only be the same as either one or none of the second flow rate and second decontamination capacity operational parameters of the second path (60) so that the second path (60) decontaminates the separated contaminant liquid stream for a second decontamination duration that is greater than a first decontamination duration of the first path (58) by a predetermined duration of a warning period; and,

e. a liquid ion conductivity sensor (66) secured in communication with a liquid stream passing from the separator scrubber (22) through the parallel path contaminant isolation loop (50) and back to the scrubber (22) for sensing a conductivity of the liquid stream.

2. The separator scrubber and parallel path contaminant isolation loop (10) of claim 1, wherein the first path (58) includes a variable flow restrictor (62) for selectively varying the first flow rate operational parameter of the first path (58).

3. The separator scrubber and parallel path contaminant isolation loop (10) of claim 2, wherein the first decontamination capacity of the first path (58) is different than the second decontamination capacity of the second path (60) and wherein the variable flow restrictor (62) controls the first flow rate of the first path (58) to be about the same as the second flow rate of the second path (60).

4. The separator scrubber and parallel path contaminant isolation loop (10) of claim 1, wherein the first decontamination capacity of the first path (58) is about the same as the second decontamination capacity of the second path (60) and wherein the first flow rate of the first path (58) is different than the second flow rate of the second path (60).

5. The separator scrubber and parallel path contaminant isolation loop (10) of claim 1, wherein the first decontamination capacity of the first path (58) is different than the second decontamination capacity of the second path (60) and wherein the first flow rate of the first path (58) is different than the second flow rate of

the second path (60).

6. The separator scrubber and parallel path contaminant isolation loop (10) of claim 1, further comprising a first path line (70) of the first path (58) directs flow of about one-half of the liquid contaminated stream from the loop conduit (54) through a first first-path valve (72) and then into and through a first first-path ion exchange decontaminator (74), and then through a second first-path valve (76), into and through a second first-path ion exchange decontaminator (78), and then through a third first-path valve (80) and then into and through a variable flow restrictor (62), and then out of the first path (58) and into the loop conduit return line (64), and comprising a second path line (82) of the second path (60) that directs flow of about one-half of the liquid contaminated stream from the loop conduit (54) through a first second-path valve (84) and then into and through a first second-path ion exchange decontaminator (86), and then through a second second-path valve (88), into and through a second second-path ion exchange decontaminator (90), and then through a third second-path valve (92) and then into and through a third second-path ion exchange decontaminator (94), and then out of the second path (60) and into the loop conduit return line (64).

7. A method of scheduling service of a separator scrubber and parallel path contaminant isolation loop (10) for a fuel reactant stream of a fuel cell (12), comprising:

a. directing flow of a base fuel from a fuel processing system (16) through a separator scrubber (22);

b. removing ammonia from the base fuel into a separated contaminant liquid stream;

c. directing flow of the separated contaminant liquid stream through a parallel path contamination isolation loop (50) wherein first flow rate and first decontamination capacity operational parameters of a first path (58) may only be the same as either one or none of second flow rate and second decontamination capacity operational parameters of a second path (60) so that the second path (60) decontaminates the separated contaminant liquid stream for a second decontamination duration that is greater than a first decontamination duration of the first path by a predetermined duration of a warning period; and,

d. servicing the separator scrubber and parallel path isolation loop (50) during the warning period.

8. The method of scheduling service of a separator scrubber and parallel path contaminant isolation loop (10) for a fuel reactant stream of a fuel cell (12) of claim 7, further comprising sensing a conductivity with a liquid ion conductivity sensor (66) of the liquid stream passing from the separator scrubber (22) through the parallel path contaminant isolation loop (50) and back to the scrubber (22); and, then identifying with the sensor (66) a beginning of the warning period whenever the sensor (66) senses increased conductivity of the liquid stream resulting from expiration of the first decontamination duration.

9. The method of scheduling service of a separator scrubber and parallel path contaminant isolation loop (10) for a fuel reactant stream of a fuel cell (12) of claim 8, further comprising directing flow of about half of the contaminated liquid stream through at least one ion exchange decontaminator (74) within the first path (58) and through a variable flow restrictor (62) within the first path (58), and directing flow of about half of the contaminated liquid stream through at least one ion exchange decontaminator (86) within the second path (60).

10. The method of scheduling service of a separator scrubber and parallel path contaminant isolation loop (10) for a fuel reactant stream of a fuel cell (12) of claim 9, further comprising directing flow of the about half of the contaminated liquid stream through an additional second second-path ion exchange decontaminator 90 within the second path (60).

11. The method of scheduling service of a separator scrubber and parallel path contaminant isolation loop (10) for a fuel reactant stream of a fuel cell (12) of claim 7, further comprising decontaminating the contaminated liquid stream throughout the second decontamination duration so that a predetermined acceptable, non-harmful amount of ammonia is within the decontaminated stream resulting in no harm to the fuel cell (12).

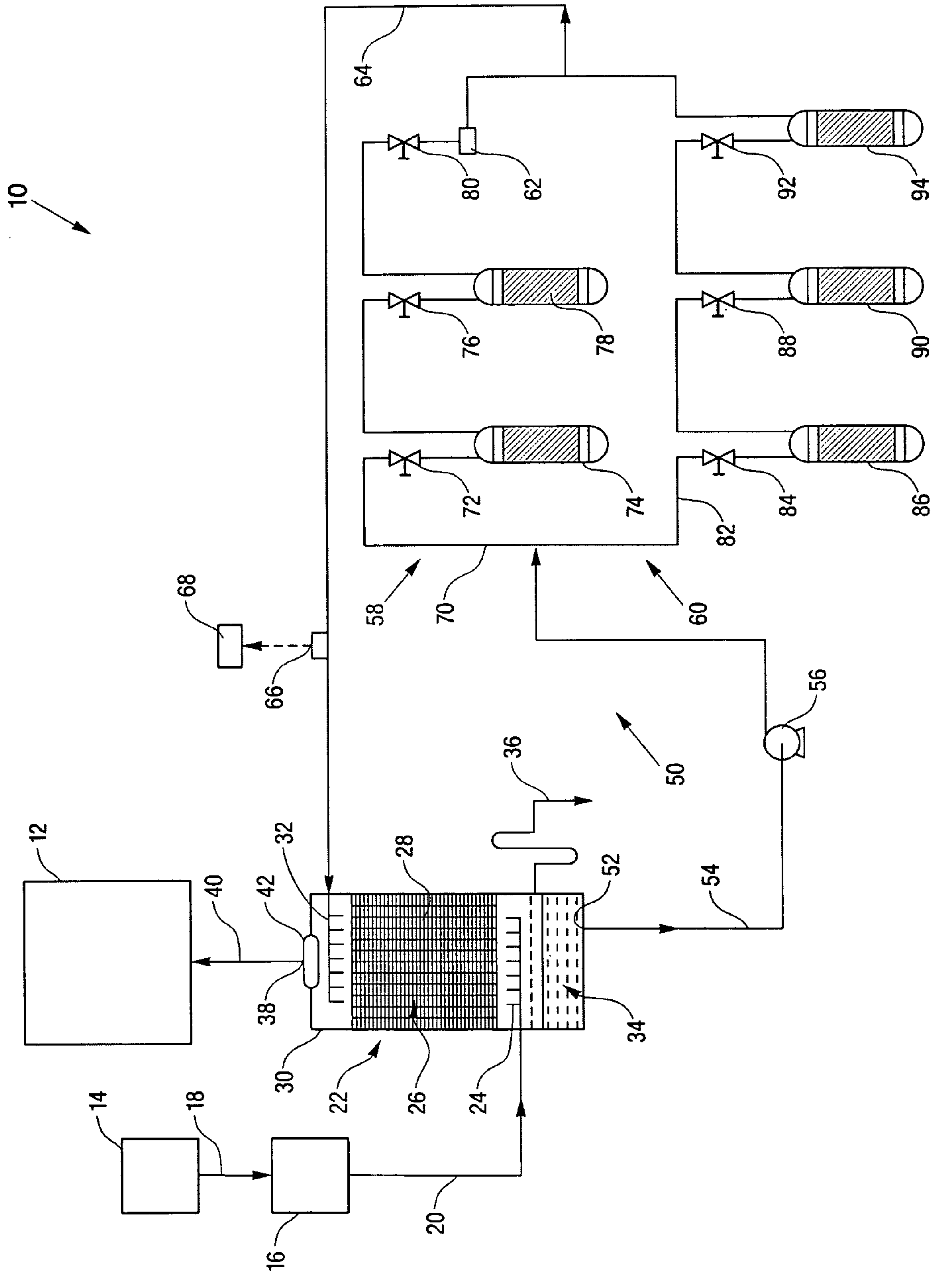

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FIG. 1

**INTERNATIONAL SEARCH REPORT**

International application No.
**PCT/US2009/003684**

**A. CLASSIFICATION OF SUBJECT MATTER**

***H01M 8/04(2006.01)i, H01M 8/02(2006.01)i***

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC : H01M, C10J, C10B, B01J, C02F, B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility Models
Japanese utility models and applications for utility Models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS (KIPO internal) and keywords: "separator scrubber, parallel path, contaminant isolation loop, fuel processing, ammonia, ion exchange decontaminator, ion exchange bed, fuel cell, and similar terms"

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | WO 2008-036090 A1 ( Grasso et al. ) 27 March 2008<br>See abstract, Figure 1, paragraphs [0017], claims 1, 3, 4, 6, 7 | 1-11 |
| A | JP 2005-317392 A ( EBARA BALLARO CORP ) 10 November 2005<br>See abstract, Figure 1, paragraphs [0022], [0030], [0035], [0036], claims 1, 2, 5 | 1-11 |
| A | JP 09-108657 A ( TOSHIBA CORP ) 28 April 1997<br>See abstract, Figure 1, paragraphs [0013], claims 1-4 | 1-11 |
| A | US 4816040 A ( Bonville et al. ) 28 March 1989<br>See abstract, Figure 1, column 3, line 34 to column 4, line 17, claim 1 | 1-11 |

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 19 MARCH 2010 (19.03.2010) | **22 MARCH 2010 (22.03.2010)** |

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| Facsimile No. 82-42-472-7140 | Telephone No. 82-42-481-8173 |

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2009/003684**

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| WO 2008-036090 A1 | 27.03.2008 | None | |
| JP 2005-317392 A | 10.11.2005 | None | |
| JP 09-108657 A | 28.04.1997 | None | |
| US 4816040 A | 28.03.1989 | JP 2685247 B2<br>JP 02-090472 A | 03.12.1997<br>29.03.1990 |