United States Patent Application Publication	20250266476
Kind Code	A1
Publication Date	August 21, 2025
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CONDENSER-BASED ANODE HYDROGEN PRECONDITIONING

Abstract

Disclosed is a hydrogen feed conditioning system for a hydrogen fuel cell in which fresh hydrogen from storage and recycled hydrogen from an anode exhaust of the fuel cell are mixed and fed to an anode feed of the fuel cell. A stream of recycled hydrogen is first passed through a hydrogen/water separator configured to reduce an amount of water vapor in the recycled hydrogen stream. The system includes a condenser for the anode exhaust stream upstream of the hydrogen water separator.

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Family ID: **1000008556779**

Appl. No.: **19/058979**

Filed: **February 20, 2025**

Foreign Application Priority Data

GB	2402476.2	Feb. 21, 2024

Publication Classification

Int. Cl.: **H01M8/04082** (20160101); **H01M8/04007** (20160101); **H01M8/04119** (20160101); **H01M8/04701** (20160101); **H01M8/04828** (20160101)

U.S. Cl.:

CPC **H01M8/04201** (20130101); **H01M8/04074** (20130101); **H01M8/04164** (20130101); **H01M8/04716** (20130101); **H01M8/04843** (20130101);

Background/Summary

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims benefit to UK Application Serial No. 2402476.2, filed Feb. 21, 2024, the contents of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to fuel cell systems and methods for operating same. The disclosure has particular utility in connection with the preconditioning of hydrogen fuel feeds for low temperature proton exchange membrane (LT-PEM) hydrogen (H.sub.2) fuel cells for use in H.sub.2 fuel-cell-powered vehicles, including aircraft, and will be described in connection with such utility, although other utilities are contemplated.

BACKGROUND AND SUMMARY

[0003] This section provides background information which is not necessarily prior art, and is related to the present disclosure. This section provides a general summary of the disclosure and is not a comprehensive disclosure of its full scope or all its features.

[0004] In operation, an H.sub.2 fuel cell requires that the H.sub.2 supplied to the anode of the fuel cell be within defined temperature, humidity, and pressure ranges to ensure efficient operation of the fuel cell. This requires pre-conditioning of the H.sub.2 prior to feeding it to the anode.

[0005] In practice, the H.sub.2 supplied to an H.sub.2 fuel cell is a combination of two streams mixed via a venturi tube [operating by the Venturi effect]: [0006] 1. A fresh H.sub.2 stream from an H.sub.2 fuel tank of the H.sub.2 management system (HMS). This H.sub.2 stream typically is quite cold and has a relative humidity (RH) of 0%; and [0007] 2. An H.sub.2 and water vapor stream that has been recirculated from the anode exhaust. This stream is warm and typically has a RH of 100%.

[0008] A common practice of the prior art is to heat up fresh, relatively cold and dry H.sub.2 from the H.sub.2 fuel tank, (typically −40° C. and 0% relative humidity) prior to mixing it with relatively warm and moist recirculated H.sub.2 from the anode exhaust (typically +80° C. and 100% relative humidity). The purpose of this heat exchange (HEX) is to add sufficient heat and humidity to the fresh H.sub.2 so that, when the fresh H.sub.2 stream and the H.sub.2 recycled stream are mixed, the mixed stream has the desired relative humidity of 30-60% and temperature gradient (from −40° C. to +80° C.). FIG. **1** plots relative humidity at the anode inlet as a function of H.sub.2 temperature supplied from the H.sub.2 tank of a typical prior art HMS. As shown in FIG. **1**, the minimum temperature of the supplied H.sub.2 from the HMS needs to be approximately 45° C. to achieve a relative humidity in the 30-60% range.

[0009] In practice, H.sub.2 fuel cells use coolant-hydrogen heat exchangers (HEXs) with relatively high heat transfer areas in order to achieve the desired relative humidity and temperature of anode fuel when mixing together fresh H.sub.2 and recirculated H.sub.2. These HEXs add cost, complexity, and weight to the coolant system and may result in an additional failure mode in which H.sub.2 may leak into the coolant system and be transported through the coolant pipework to undesirable parts of the powertrain installation where the H.sub.2 could ignite or explode.

[0010] FIG. **2** illustrates a prior art anode hydrogen preconditioning system **8**. In practice, H.sub.2 recycle anode exhaust stream **10** from a fuel cell (not shown) is passed via a conduit **12** to an H.sub.2/water separator **14** in which liquid water is separated and passed via line **16** to exhaust or used to add humidity to cabin air in accordance with the teachings of co-pending U.S. application Ser. No. 18/338,205, filed Jun. 20, 2023, the contents of which are incorporated by reference. And fresh H.sub.2 from an H.sub.2 fuel tank **18** is passed via conduit **20** through a heat exchanger (HEX) **22**, where the H.sub.2 is warmed to a desired operating temperature by heat exchange with coolant circulated through the fuel cell (not shown) via conduit **24**. Due to the high heat loads that need to be transferred from the fuel cell particularly in certain stages of flight, i.e., take-off and climb, HEX **22** is a dedicated high heat transfer area coolant-H.sub.2 HEX. The H.sub.2/water separator **14** removes liquid water from the anode exhaust prior to recirculating the H.sub.2 as feed to the anode. The warmed fresh H.sub.2 exiting HEX **22** via conduit **26** is mixed in venturi tube **28** with recycled H.sub.2 exiting H.sub.2/water separator **14** via conduit **27**, and the mixture is then introduced into the fuel cell via anode inlet line **30**.

[0011] The requirement of a dedicated high heat transfer area coolant-H.sub.2 HEX **22** adds cost, complexity, and weight to the coolant system and results in an additional failure mode in which H.sub.2 may leak into the coolant system and be transported through the coolant pipework to undesirable parts of the powertrain installation where the H.sub.2 could be ignited or explode. This failure mode is a consequence of the HEX requiring a high heat transfer area.

[0012] In accordance with the present disclosure, we add a condenser in the anode exhaust line, upstream of the H.sub.2/water separator.

[0013] More particularly, in accordance with Aspect A we provide an H.sub.2 feed conditioning system for an H.sub.2 fuel cell in which fresh hydrogen from storage and recycled H.sub.2 from an anode exhaust of the fuel cell are mixed and fed to an anode feed of the fuel cell, wherein a stream comprising the recycled H.sub.2 is first passed through an H.sub.2/water separator configured to reduce an amount of water vapor in the recycled H.sub.2 stream, and wherein the system includes a condenser for the anode exhaust stream upstream of the H.sub.2 water separator.

[0014] In one embodiment, the anode exhaust stream is cooled by HEX with the fresh H.sub.2 in the condenser.

[0015] In another embodiment fresh H.sub.2 gas after passing through the condenser and recycled H.sub.2 after passing through the H.sub.2 water separator are mixed prior to being fed to the fuel cell anode.

[0016] In yet another embodiment the fresh H.sub.2 gas and recycled H.sub.2 are mixed in a venturi tube.

[0017] In yet another embodiment the fresh H.sub.2 after passing through the condenser is passed directly to the venturi tube.

[0018] In a further embodiment fresh H.sub.2 after passing through the condenser is passed through a fuel cell HEX prior to passing to the venturi tube.

[0019] In yet another embodiment the mixture of fresh H.sub.2 and recycled H.sub.2 has a relative humidity of 30-60%.

[0020] In still another embodiment the mixture of fresh H.sub.2 and recycled H.sub.2 stream has a temperature of −40° C. to +80° C.

[0021] In a further embodiment the fuel cell HEX comprises an elongated chamber having a cooling tube configured to carry the recycled H.sub.2 through an interior of the elongated chamber for HEX with the fresh H.sub.2.

[0022] According to Aspect B there is provided a method for conditioning H.sub.2 for feeding an H.sub.2 fuel cell, wherein fresh H.sub.2 from storage and recycled H.sub.2 from an anode exhaust from the fuel cell are mixed and fed to an anode feed of the fuel cell, and wherein the recycled H.sub.2 is first passed through an H.sub.2/water separator configured to reduce an amount of water vapor in the recycled H.sub.2 stream, said method comprising the steps of passing the recycled H.sub.2 stream through a condenser upstream of the H.sub.2 water separator before passing the recycled H.sub.2 stream to the H.sub.2/water separator.

[0023] In one embodiment of the method the anode exhaust stream is cooled by HEX with the fresh H.sub.2 in the condenser.

[0024] In another embodiment of the method fresh H.sub.2 gas after passing through the condenser and recycled H.sub.2 after passing through the H.sub.2 water separator are mixed prior to being fed to the fuel cell anode.

[0025] In still another embodiment of the method the fresh H.sub.2 and recycled H.sub.2 are mixed

in a venturi tube.
[0026] In still another embodiment of the method the fresh H.sub.2 after passing through the condenser is passed directly to the venturi tube.
[0027] In a further embodiment of the method fresh H.sub.2 after passing through the condenser is passed through a fuel cell HEX prior to passing to the venturi tube.
[0028] In yet another embodiment of the method the mixture of fresh H.sub.2 and recycled H.sub.2 has a relative humidity of 30-60%.
[0029] In still another embodiment of the method the mixture of fresh H.sub.2 and recycled H.sub.2 stream has a temperature of −40° C. to +80° C.
[0030] In a further embodiment of the method the fuel cell HEX comprises an elongated chamber having cooling tubes configured to carry the recycled H.sub.2 through an interior of the elongated chamber for HEX with the fresh H.sub.2.
[0031] According to Aspect C, the anode feed conditioning system of Aspect A is installed on a vehicle.
[0032] According to another embodiment of Aspect C, the vehicle is an aircraft.
[0033] According to Aspect D of the present invention there is provided a hydrogen feed conditioning system for a hydrogen fuel cell in which fresh hydrogen from storage and recycled hydrogen from an anode exhaust of the fuel cell are mixed and fed to an anode feed of the fuel cell, wherein a stream comprising the recycled hydrogen is first passed through a hydrogen/water separator configured to reduce an amount of water vapor in the recycled hydrogen stream, and wherein the system includes a condenser for the anode exhaust stream, performed by or upstream of the hydrogen water separator.
[0034] Preferably the anode exhaust stream is cooled by heat exchange with the fresh hydrogen in the condenser.
[0035] Preferably fresh hydrogen gas after passing through the condenser and recycled hydrogen after passing through the hydrogen water separator are mixed prior to being fed to the fuel cell anode.
[0036] Preferably the fresh hydrogen gas and recycled hydrogen are mixed in a venturi tube.
[0037] In one alternative the fresh hydrogen after passing through the condenser is passed directly to the venturi tube.
[0038] In another alternative the fresh hydrogen after passing through the condenser is passed through a fuel cell heat exchanger prior to passing to the venturi tube.
[0039] Preferably the mixture of fresh hydrogen and recycled hydrogen has a relative humidity of 30-60%.
[0040] 8 Preferably the mixture of fresh hydrogen and recycled hydrogen stream has a temperature of −40° C. to +80° C.
[0041] Preferably the fuel cell heat exchanger comprises an elongated chamber having a cooling tube configured to carry the recycled hydrogen through an interior of the elongated chamber for heat exchange with the fresh hydrogen.
[0042] According to Aspect E of the present invention there is provided a method for conditioning hydrogen for feeding a hydrogen fuel cell using the hydrogen feed conditioning system according to Aspect D of the present invention wherein fresh hydrogen from storage and recycled hydrogen from an anode exhaust from the fuel cell are mixed and fed to an anode feed of the fuel cell, and wherein the recycled hydrogen is first passed through a hydrogen/water separator configured to reduce an amount of water vapor in the recycled hydrogen stream, said method comprising the steps of passing the recycled hydrogen stream through a condenser upstream of the hydrogen water separator before passing the recycled hydrogen stream to the hydrogen/water separator.
[0043] Preferably the anode exhaust stream is cooled by heat exchange with the fresh hydrogen in the condenser.
[0044] Preferably fresh hydrogen gas after passing through the condenser and recycled hydrogen

after passing through the hydrogen water separator are mixed prior to being fed to the fuel cell anode.
[0045] Preferably the fresh hydrogen and recycled hydrogen are mixed in a venturi tube.
[0046] In one alternative the fresh hydrogen after passing through the condenser is passed directly to the venturi tube.
[0047] In another alternative the fresh hydrogen after passing through the condenser is passed through a fuel cell heat exchanger prior to passing to the venturi tube.
[0048] Preferably the mixture of fresh hydrogen and recycled hydrogen has a relative humidity of 30-60%.
[0049] Preferably the mixture of fresh hydrogen and recycled hydrogen stream has a temperature of −40° C. to +80° C.
[0050] Preferably the fuel cell heat exchanger comprises an elongate chamber having cooling tubes configured to carry the recycled hydrogen through an interior of the elongate chamber for heat exchange with the fresh hydrogen.
[0051] According to Aspect F of the present invention there is provided a method for conditioning hydrogen for feeding a hydrogen fuel cell, wherein fresh hydrogen from storage and recycled hydrogen from an anode exhaust from the fuel cell are mixed and fed to an anode feed of the fuel cell, and wherein the recycled hydrogen is first passed through a hydrogen/water separator configured to reduce an amount of water vapor in the recycled hydrogen stream, said method comprising the steps of passing the recycled hydrogen stream through a condenser upstream of the hydrogen water separator before passing the recycled hydrogen stream to the hydrogen/water separator.
[0052] Preferably the anode exhaust stream is cooled by heat exchange with the fresh hydrogen in the condenser.
[0053] Preferably fresh hydrogen gas after passing through the condenser and recycled hydrogen after passing through the hydrogen water separator are mixed prior to being fed to the fuel cell anode.
[0054] Preferably the fresh hydrogen and recycled hydrogen are mixed in a venturi tube.
[0055] In one alternative the fresh hydrogen after passing through the condenser is passed directly to the venturi tube.
[0056] In another alternative the fresh hydrogen after passing through the condenser is passed through a fuel cell heat exchanger prior to passing to the venturi tube.
[0057] Preferably the mixture of fresh hydrogen and recycled hydrogen has a relative humidity of 30-60%.
[0058] Preferably the mixture of fresh hydrogen and recycled hydrogen stream has a temperature of −40° C. to +80° C.
[0059] Preferably the fuel cell heat exchanger comprises an elongate chamber having cooling tubes configured to carry the recycled hydrogen through an interior of the elongate chamber for heat exchange with the fresh hydrogen.
[0060] According to Aspect G of the present invention there is provided a hydrogen feed conditioning system according to Aspect D of the present invention, installed on a vehicle. Preferably the vehicle is an aircraft.
[0061] Adding a condenser in the anode exhaust line upstream of the H.sub.2/water separate provides several functions and advantages. For one, we reduce the amount of water vapor (and thus relative humidity) that is in the mixed flow when the H.sub.2 exhaust is recirculated and mixed with fresh H.sub.2 from the fuel tank and supplied to the anode inlet.
[0062] Secondly, the need for a high heat transfer surface area coolant-H.sub.2 HEX is reduced. Instead, a small heat transfer area coolant-H.sub.2 HEX may be used, or potentially no coolant-H.sub.2 HEX is needed at all. This reduces the amount of water vapor present in the anode inlet and therefore reduces the required additional heat for achieving sufficiently low relative humidity.

Also, providing a condenser in the anode exhaust line upstream of the H.sub.2 water separator in accordance with the present disclosure, eliminates/or at least significantly reduces a potential of H.sub.2 leaking into the coolant system and being transported through the coolant pipework to undesirable parts of the powertrain where the hydrogen could be ignited or explode. Additionally providing a condenser in the anode exhaust line upstream of the water separator in accordance with the present disclosure, reduces complexity, cost, and weight of the coolant system.
[0063] No known anode preconditioning system employs a condenser in the anode exhaust, upstream of the H.sub.2/water separator, instead of the commonly used high heat transfer surface area coolant-H.sub.2 HEX to provide heat addition to the fresh H.sub.2 and ensure the anode inlet H.sub.2 stream is sufficiently warm and has a target relative humidity for optimized fuel cell performance.
[0064] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0065] Further features and advantages of the disclosure will be seen in the following detailed description, taken in conjunction with the accompanying drawings. The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations and are not intended to limit the scope of the present disclosure.
[0066] In the drawings:
[0067] FIG. **1** is a graph plotting percent relative humidity at a fuel cell anode inlet vs. temperature of H.sub.2 flowing in from the HMS in accordance with the prior art;
[0068] FIG. **2** is a schematic flow diagram of an anode H.sub.2 preconditioning system in accordance with the prior art;
[0069] FIG. **3** is a schematic diagram of an anode H.sub.2 preconditioning system in accordance with a first embodiment of the present disclosure;
[0070] FIG. **4**A is a side elevational view of a simplified HEX for an anode H.sub.2 preconditioning system with a condenser in accordance with the present disclosure;
[0071] FIG. **4**B is a side cross-sectional view of the simplified HEX of FIG. **4**A;
[0072] FIG. **5** is a schematic view of an anode H.sub.2 preconditioning system in accordance with a second embodiment of the present disclosure;
[0073] FIG. **6** is a graph plotting precent relative humidity at the anode inlet vs. temperature at the H.sub.2 flowing in from an HMS in accordance with the present disclosure; and
[0074] FIG. **7** is a schematic depiction of an aircraft incorporating an anode H.sub.2 preconditioning of FIG. **3**.
DETAILED DESCRIPTION
[0075] Example embodiments will now be described more fully with reference to the accompanying drawings. Example embodiments are provided so that this disclosure will be thorough and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms, and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.
[0076] The terminology used herein is for the purpose of describing particular example

embodiments only and is not intended to be limiting. As used herein, the singular forms “a,” “an,” and “the” may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms “comprises,” “comprising,” “including,” and “having” are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, components, and/or groups, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0077] When an element or layer is referred to as being “on,” “engaged to,” “connected to,” or “coupled to” another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being “directly on,” “directly engaged to,” “directly connected to,” or “directly coupled to” another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” etc.). As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0078] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers, and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another element, component, region, layer, or section. Terms such as “first,” “second,” and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer, or section discussed below could be termed a second element, component, region, layer, or section without departing from the teachings of the example embodiments.

[0079] Spatially relative terms, such as “inner,” “outer,” “beneath,” “below,” “lower,” “above,” “upper,” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the example term “below” can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0080] FIG. **3** illustrates a feed conditioning system for a hydrogen fuel cell in accordance with the present disclosure. The hydrogen feed conditioning system **50** comprises a condenser **52** upstream of an H.sub.2/water separator **54**. In other embodiments, the condensing and water separation functions may be carried out by the condenser **52** alone (i.e., separately drawn H.sub.2/water separator **54** is optional). Fresh H.sub.2 is fed from an H.sub.2 fuel tank **56** via conduit **58** in heat exchange with warm moist recycled H.sub.2 from the anode exhaust delivered by conduit **60**.

[0081] The warm recycled H.sub.2 is cooled by contact with the cold fresh H.sub.2, and the cooled recycled H.sub.2 is passed via conduit **62** to water separator **54** where liquid water is separated and passed as exhaust by conduit **64**. Alternatively, a portion of the condensed water may be used to add humidity to cabin air in accordance with the teaching of our co-pending U.S. application Ser. No. 18/338,205, filed Jun. 20, 2023, the contents of which are incorporated herein by reference.

[0082] The fresh H.sub.2 from condenser **52** is then passed via conduit **66** to simplified coolant heat exchanger (HEX) **68** where the fresh H.sub.2 is further warmed by heat exchange with coolant delivered via conduit **70** from the fuel cell (not shown). The coolant is then returned to the fuel cell via conduit **71**.

[0083] Warm fresh H.sub.2 is then passed from coolant HEX **68** via conduit **72** where it is mixed in venturi tube **74** with warm moist recycled H.sub.2 delivered from water separator **54** by conduit **76**. The mixture of fresh H.sub.2 and recycled H.sub.2 stream, which has a temperature of −40° C. to +80° C. and relative humidity of 30-60%, is then passed as feed to the anode inlet **79** via conduit **78**.
[0084] Referring to FIGS. **4**A and **4**B, simplified coolant HEX **68** preferably comprises an elongated vessel with an internal pipe **80** coaxially supported within an external pipe **82**. External pipe **82** is sealed at its ends, and has an external pipe inlet **84** adjacent one end and an external pipe outlet **86** adjacent the other end.
[0085] A helically shaped heat exchanger coil **83** is located within internal pipe **80** and is connected at one end to external pipe inlet **84** and at its other end to external pipe outlet **86**. Internal pipe **80** has an inlet **88** at one end and outlet **90** at the other end.
[0086] In operation, recycled H.sub.2 enters external pipe inlet **84** and exits external pipe outlet **86**, passing in heat exchanger coil **83** with fresh H.sub.2 which enters inlet end **88** of internal pipe **80** and exits internal outlet pipe **90**.
[0087] Depending on performance of the condenser it is possible to eliminate the need for a separate H.sub.2 HEX entirely. According to FIG. **5**, there is provided a high efficiency anode H.sub.2 preconditioning system **100**. Anode H.sub.2 preconditioning system **100** includes a condenser **102** and an H.sub.2/water separator **104**, i.e., similar to the system of FIG. **3**. However, in the FIG. **5** embodiment, the coolant H.sub.2 HEX is eliminated entirely. Thus, in the FIG. **5** embodiment, fresh H.sub.2 from the fuel tank **106** is passed via conduit **108** to condenser **102** where the cold dry H.sub.2 is passed in heat exchanger with warm moist recycled H.sub.2 introduced into condenser **102** via line **110**. The cold (fresh) H.sub.2 is thus warmed to a desired operating temperature by heat exchanger with the warm recycled H.sub.2 while within the condenser **102**. Condenser **102** also includes an outlet for passing cooled recycled H.sub.2 via conduit **112** to water separator **104** where liquid water is separated as before and passed to exhaust via conduit **114**. The cool recycled H.sub.2 is passed via conduit **116** to venturi tube **118** where it is mixed with warm fresh H.sub.2 delivered from condenser **102** via conduit **120** to venturi tube **118**, and the mixture is then supplied as feed to the fuel cell anode inlet **123** via conduit **122**.
[0088] FIG. **6** plots relative humidity at the anode inlet as a function of H.sub.2 temperature supplied from the H.sub.2 tank in a fuel cell aviation system employing an H.sub.2 preconditioning system of FIG. **5**. As can be seen, relative humidity at the anode inlet verses temperature of the H.sub.2 feed from the HMS depends on the stage of flight (i.e. take-off, top of climb, cruise, flight idle) and is significantly more controlled and maintained within a narrow range with the present disclosure.
[0089] FIG. **7** illustrates an aircraft **200** including an integrated fuel-cell-electric system **210** including an H.sub.2 preconditioning system in accordance with the present disclosure.
[0090] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure. Various changes and advantages may be made in the above disclosure without departing from the spirit and scope thereof.

Claims

1. A hydrogen feed conditioning system for a hydrogen fuel cell in which fresh hydrogen from storage and recycled hydrogen from an anode exhaust of the fuel cell are mixed and fed to an anode feed of the fuel cell, wherein a stream comprising the recycled hydrogen is first passed through a hydrogen/water separator configured to reduce an amount of water vapor in the recycled hydrogen stream, and wherein the system includes a condenser for the anode exhaust stream, performed by or upstream of the hydrogen water separator.

2. The system of claim 1, wherein the anode exhaust stream is cooled by heat exchange with the fresh hydrogen in the condenser.

3. The system of claim 1, wherein fresh hydrogen gas after passing through the condenser and recycled hydrogen after passing through the hydrogen water separator are mixed prior to being fed to the fuel cell anode.

4. The system of claim 3, wherein the fresh hydrogen gas and recycled hydrogen are mixed in a venturi tube.

5. The system of claim 4, wherein the fresh hydrogen after passing through the condenser is passed directly to the venturi tube.

6. The system of claim 4, wherein the fresh hydrogen after passing through the condenser is passed through a fuel cell heat exchanger prior to passing to the venturi tube.

7. The system of claim 3, wherein the mixture of fresh hydrogen and recycled hydrogen has a relative humidity of 30-60%.

8. The system of claim 3, wherein the mixture of fresh hydrogen and recycled hydrogen stream has a temperature of −40° C. to +80° C.

9. The system of claim 6, wherein the fuel cell heat exchanger comprises an elongated chamber having a cooling tube configured to carry the recycled hydrogen through an interior of the elongated chamber for heat exchange with the fresh hydrogen.

10. A method for conditioning hydrogen for feeding a hydrogen fuel cell using the hydrogen feed conditioning system of claim 1 wherein fresh hydrogen from storage and recycled hydrogen from an anode exhaust from the fuel cell are mixed and fed to an anode feed of the fuel cell, and wherein the recycled hydrogen is first passed through a hydrogen/water separator configured to reduce an amount of water vapor in the recycled hydrogen stream, said method comprising the steps of passing the recycled hydrogen stream through a condenser upstream of the hydrogen water separator before passing the recycled hydrogen stream to the hydrogen/water separator.

11. A method for conditioning hydrogen for feeding a hydrogen fuel cell, wherein fresh hydrogen from storage and recycled hydrogen from an anode exhaust from the fuel cell are mixed and fed to an anode feed of the fuel cell, and wherein the recycled hydrogen is first passed through a hydrogen/water separator configured to reduce an amount of water vapor in the recycled hydrogen stream, said method comprising the steps of passing the recycled hydrogen stream through a condenser upstream of the hydrogen water separator before passing the recycled hydrogen stream to the hydrogen/water separator.

12. The method of claim 11, wherein the anode exhaust stream is cooled by heat exchange with the fresh hydrogen in the condenser.

13. The method of claim 11, wherein the fresh hydrogen gas after passing through the condenser and recycled hydrogen after passing through the hydrogen water separator are mixed prior to being fed to the fuel cell anode.

14. The method of claim 13, wherein the fresh hydrogen and recycled hydrogen are mixed in a venturi tube.

15. The method of claim 14, wherein the fresh hydrogen after passing through the condenser is passed directly to the venturi tube.

16. The method of claim 14, wherein the fresh hydrogen after passing through the condenser is passed through a fuel cell heat exchanger prior to passing to the venturi tube.

17. The method of claim 11, wherein the mixture of fresh hydrogen and recycled hydrogen has a relative humidity of 30-60%, and/or a temperature of −40° C. to +80° C.

18. The method of claim 16, wherein the fuel cell heat exchanger comprises an elongate chamber having cooling tubes configured to carry the recycled hydrogen through an interior of the elongate chamber for heat exchange with the fresh hydrogen.

19. The hydrogen feed conditioning system of claim 1, installed on a vehicle, preferably an aircraft.