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(54) **LIGHTWEIGHT DIRECT METHANOL FUEL CELL AND SUPPORTING SYSTEMS**

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(52) **U.S. Cl.** **429/38**; 429/30; 429/22; 429/24; 429/32; 429/13; 429/25

(57) **ABSTRACT**

A lightweight direct methanol fuel cell unit (**20**) comprising a fuel cell stack (**24**) enclosed within a housing (**22**). In one embodiment the fuel cell stack includes a plurality of polymer electrolyte membrane electrode assemblies (**52**) stacked alternatingly with a plurality of bipolar plates (**48**). Each bipolar plate includes a cathode flow field (**78**) defined by a porous cathode flow field structure (**56**) and an anode flow field (**62**) defined by an upper plate (**58**) and a lower plate (**60**) separated from one another by a plurality of spacers (**64**). The anode flow fields are manifolded with one another via manifold embossments (**118, 120**) that are hermetically sealed with one another with a gasket (**126**). The fuel cell stack and housing are shaped so as to form four manifold regions (**36**) in the spaces between the fuel cell stack and housing. The fuel cell stack is compressed within the housing by compression members (**94**) located between the fuel cell stack and housing so as to place the sidewall (**30**) of the housing into tension. Supporting systems for the fuel cell unit include a fuel handling system (**502**), an oxidant handling system (**600**), and a liquid inventory control system (**700**).

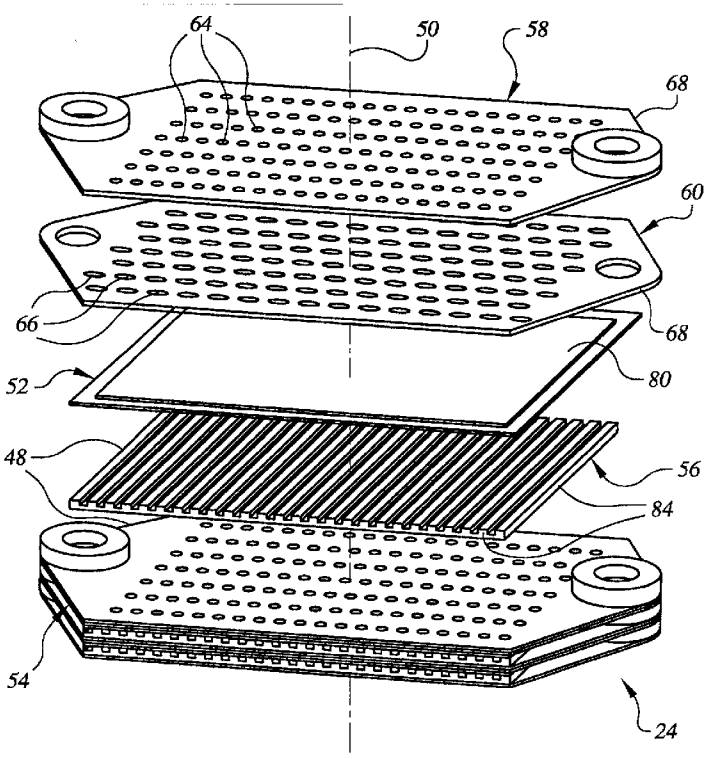


FIG.1

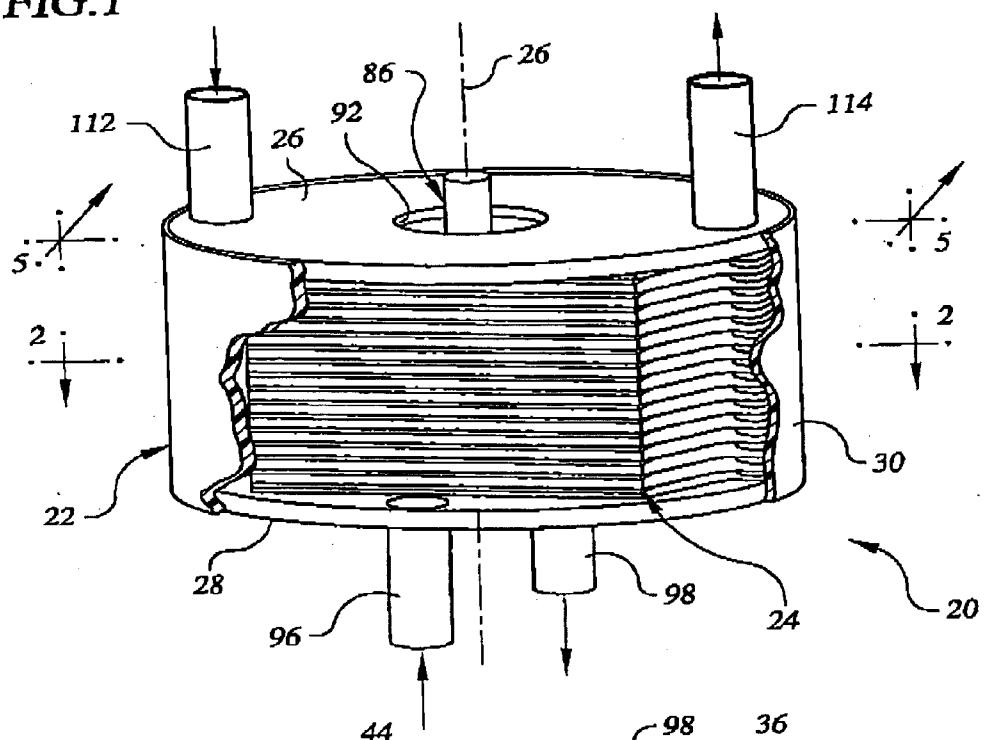

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FIG.2

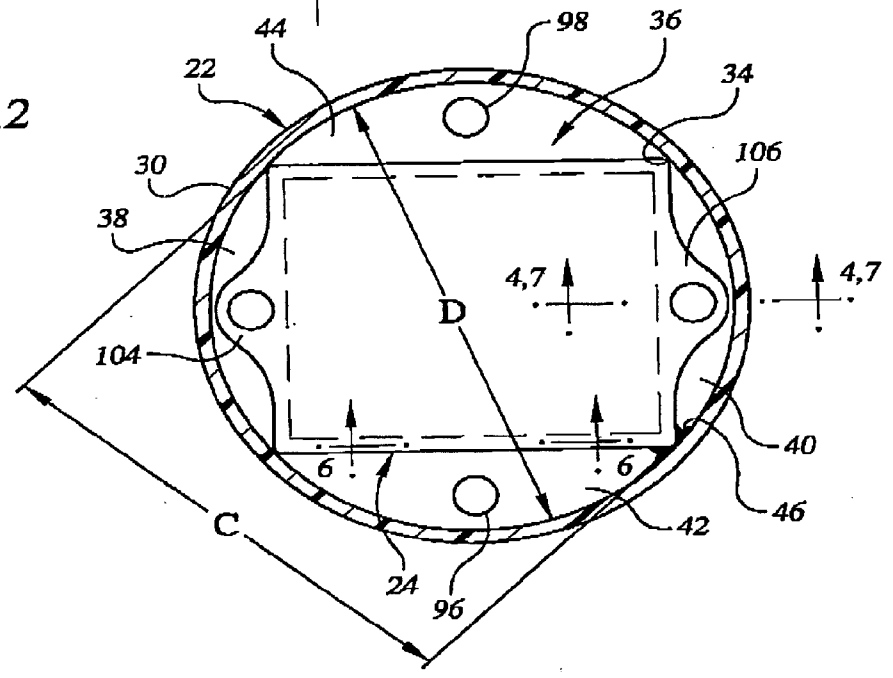

44
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FIG.3

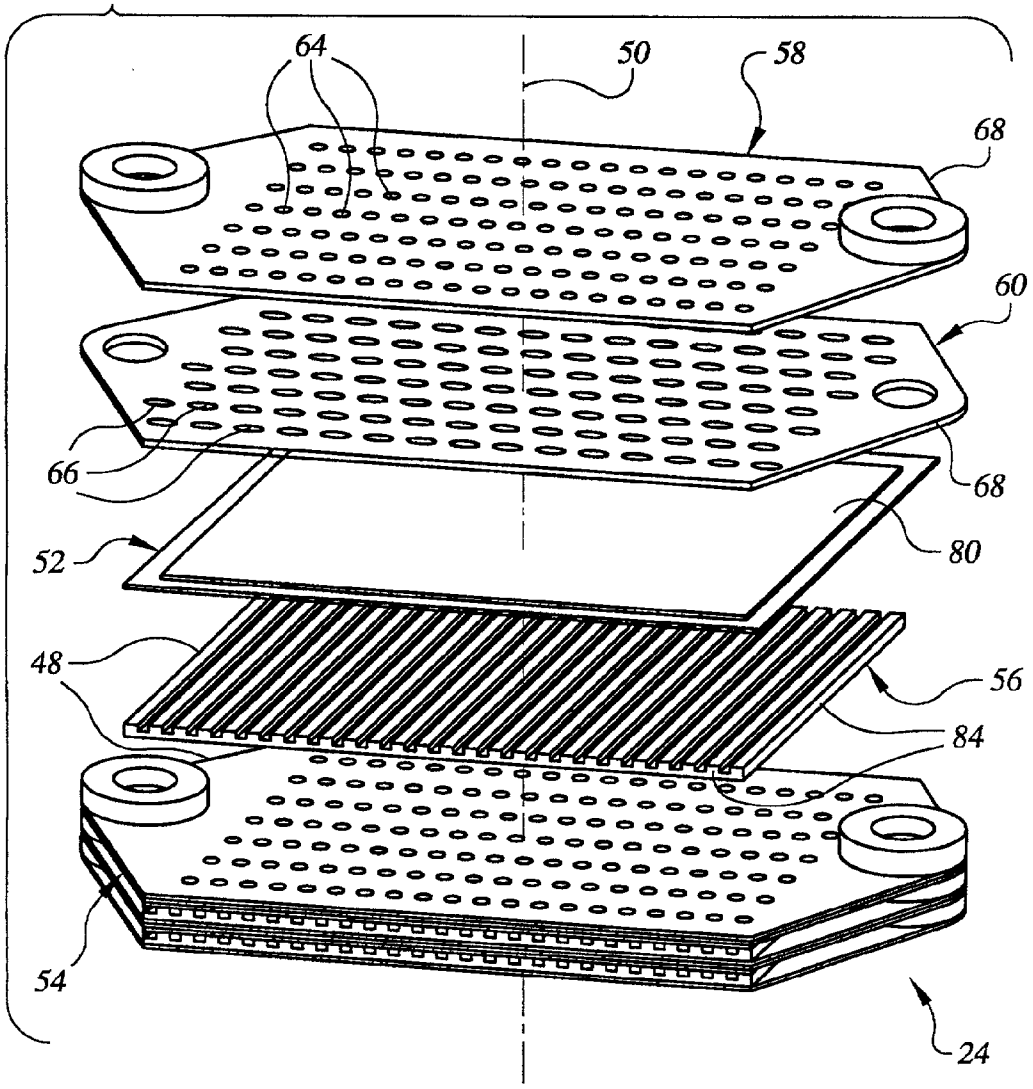

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FIG.5

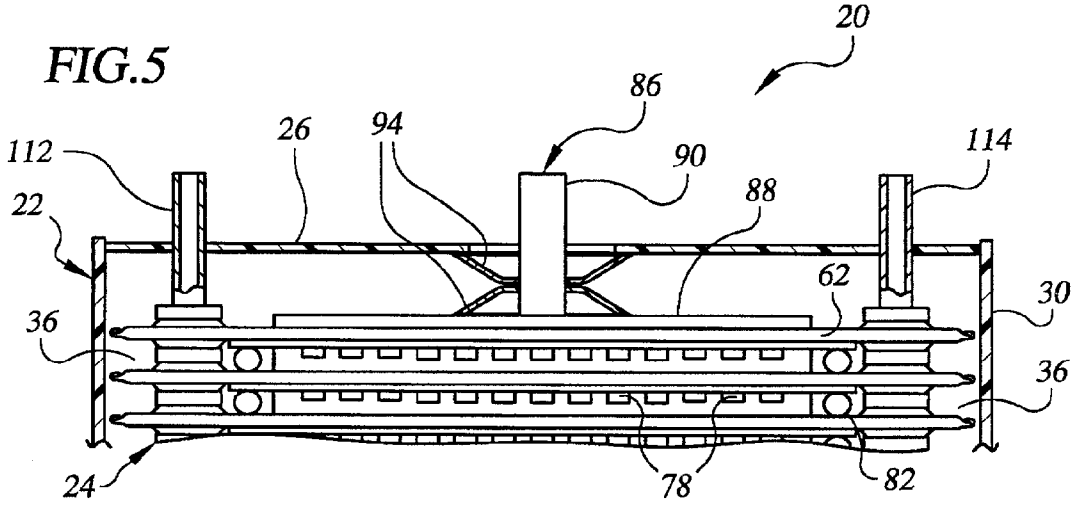

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FIG.4

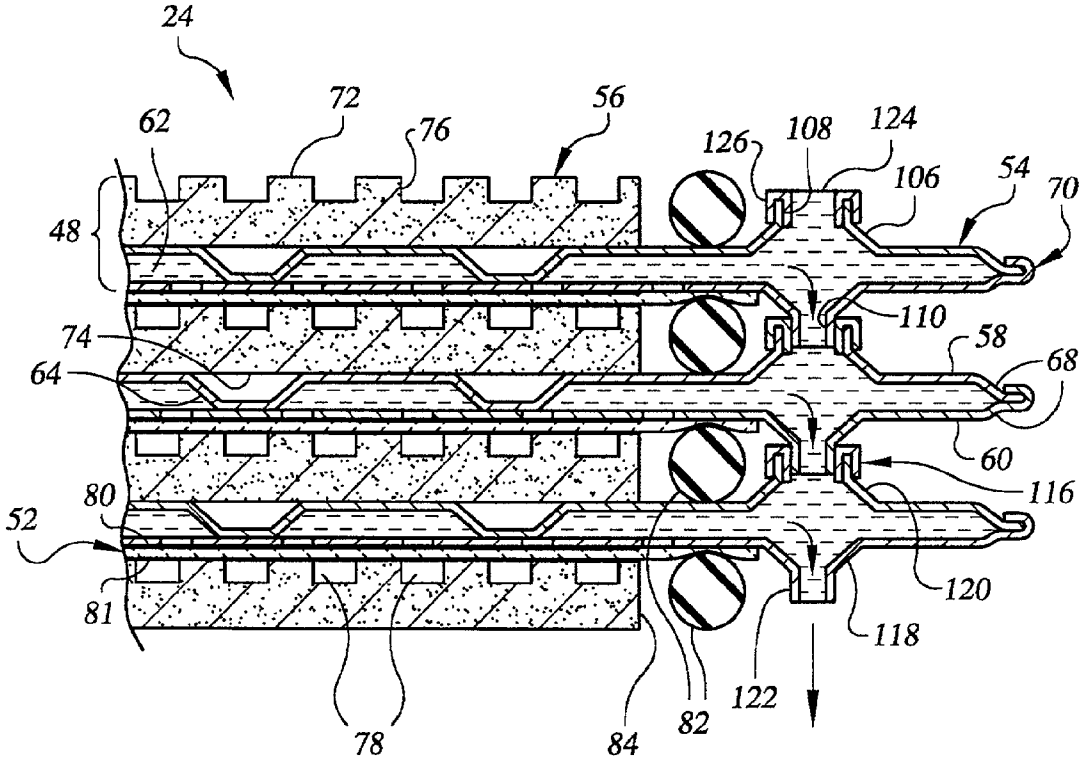

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FIG.6

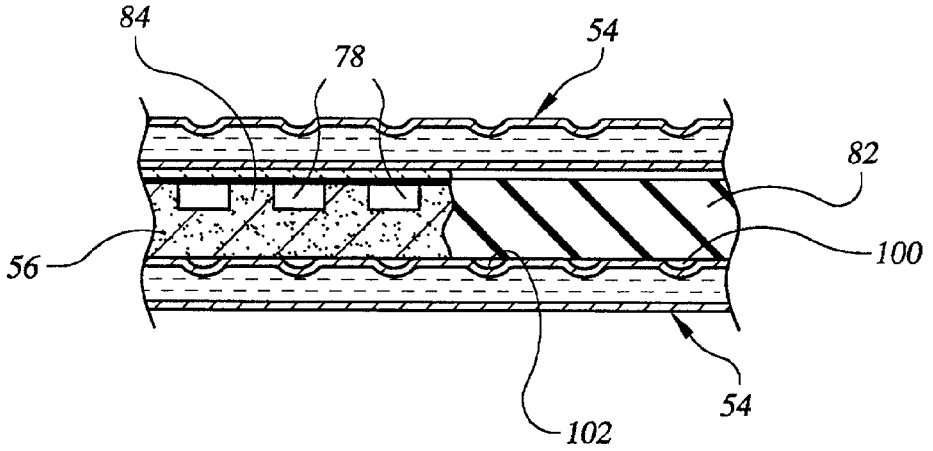

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FIG.7

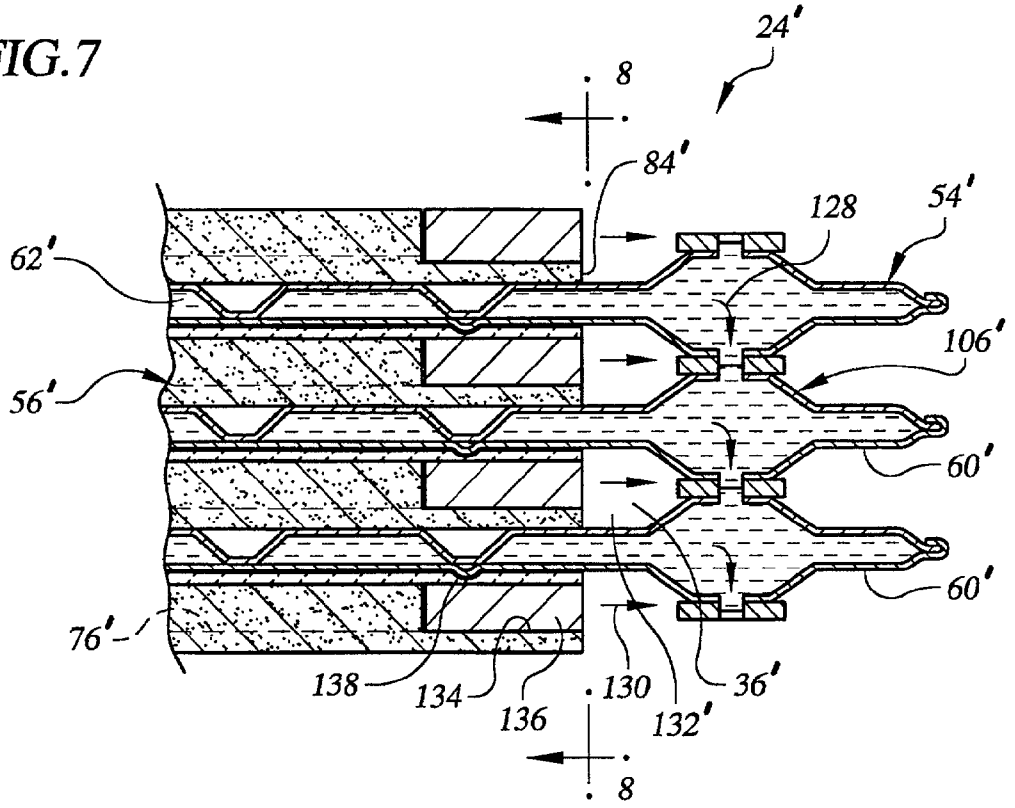


FIG.8

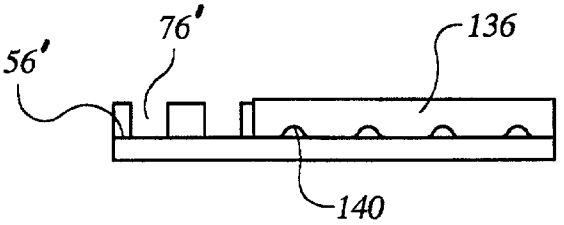


FIG.9

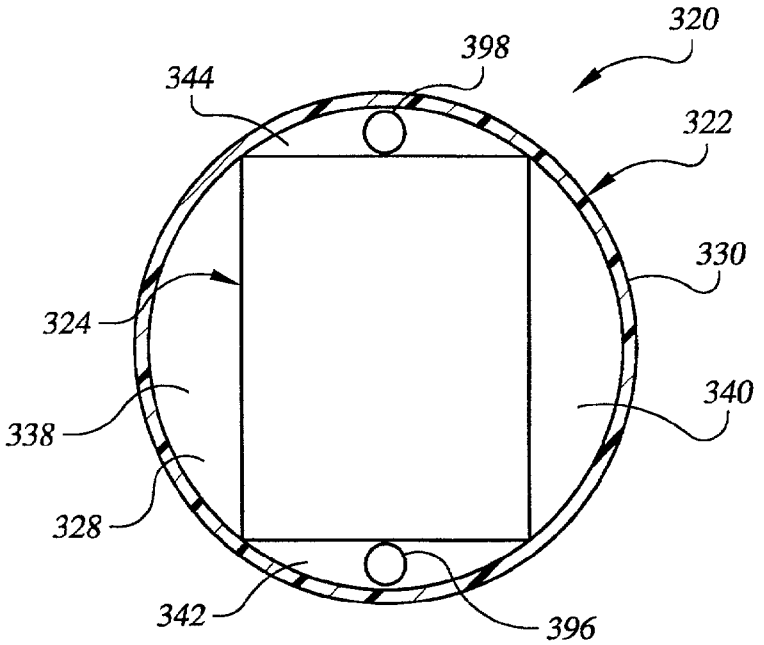


FIG.10

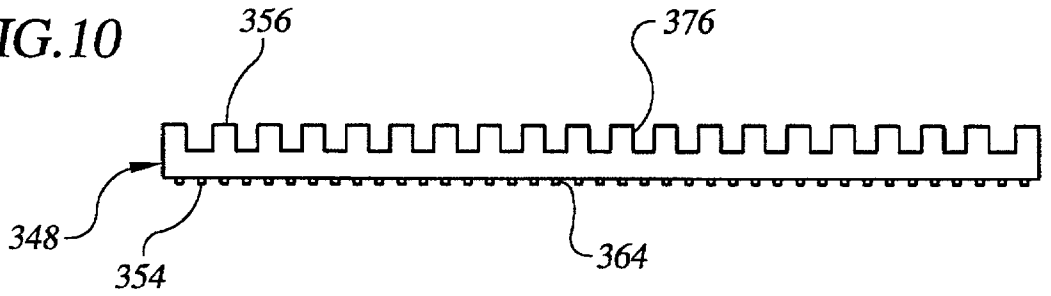


FIG.11

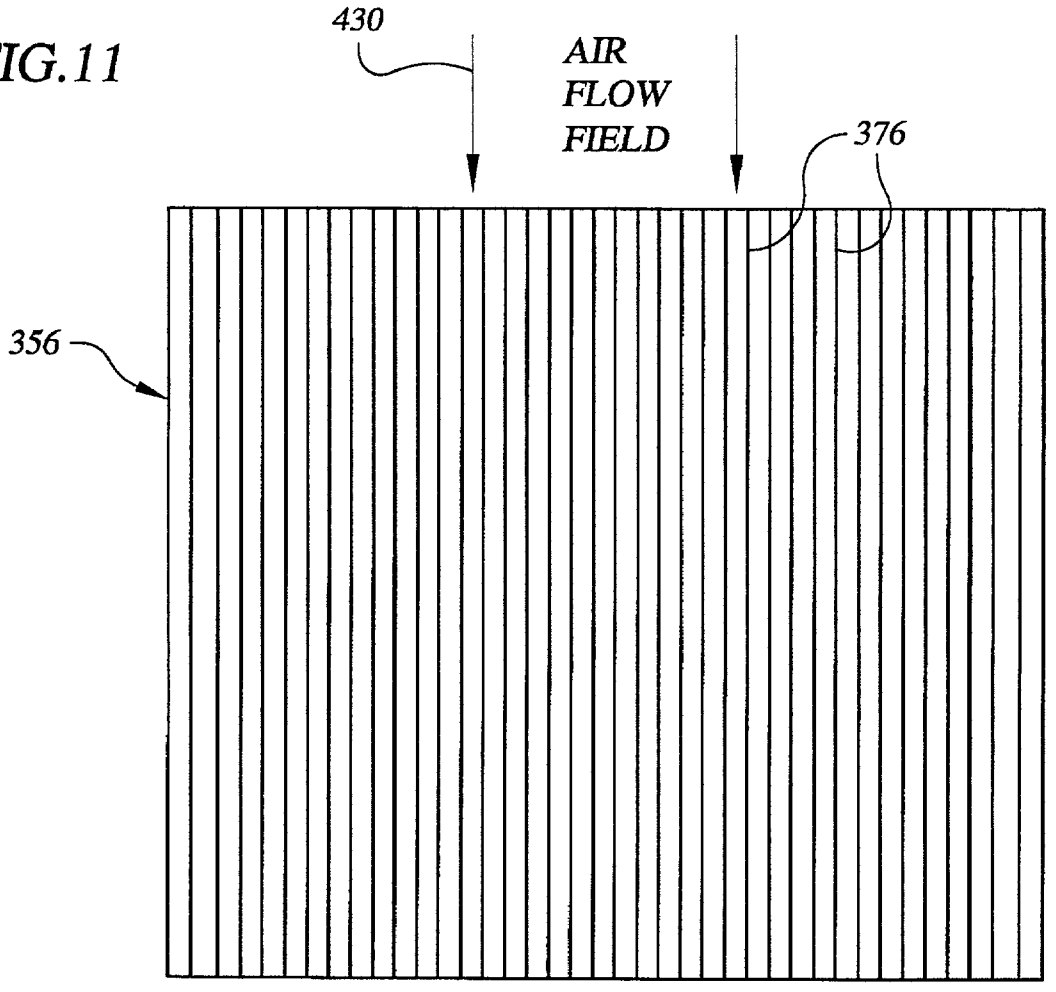


FIG.12

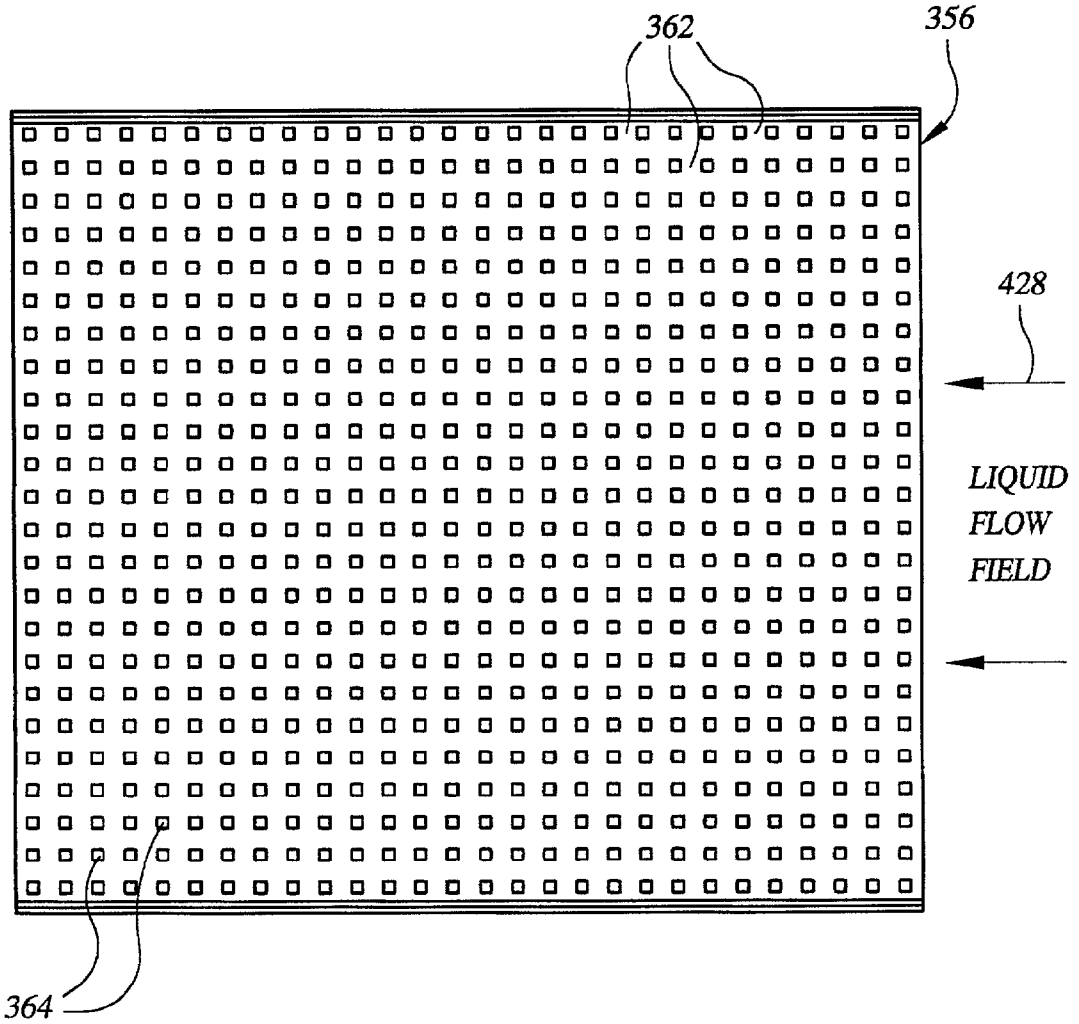


FIG.13

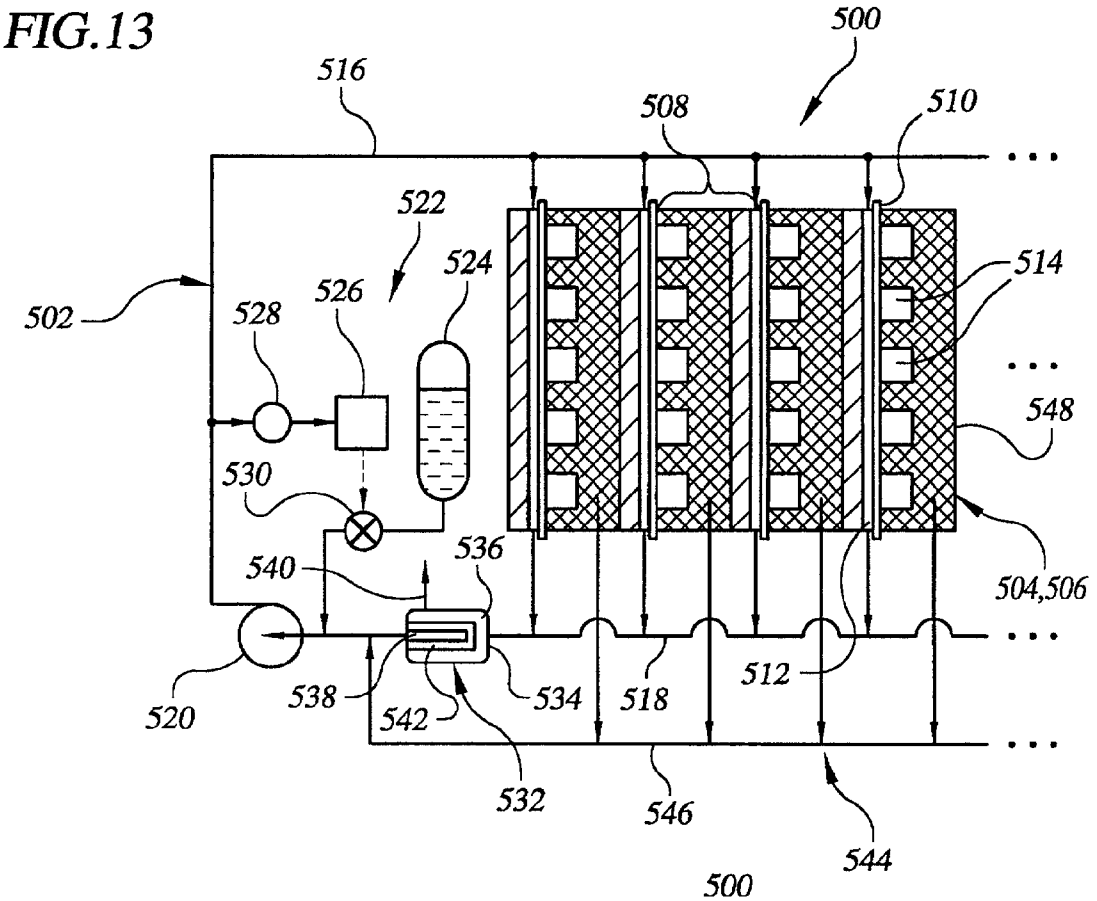

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FIG.14

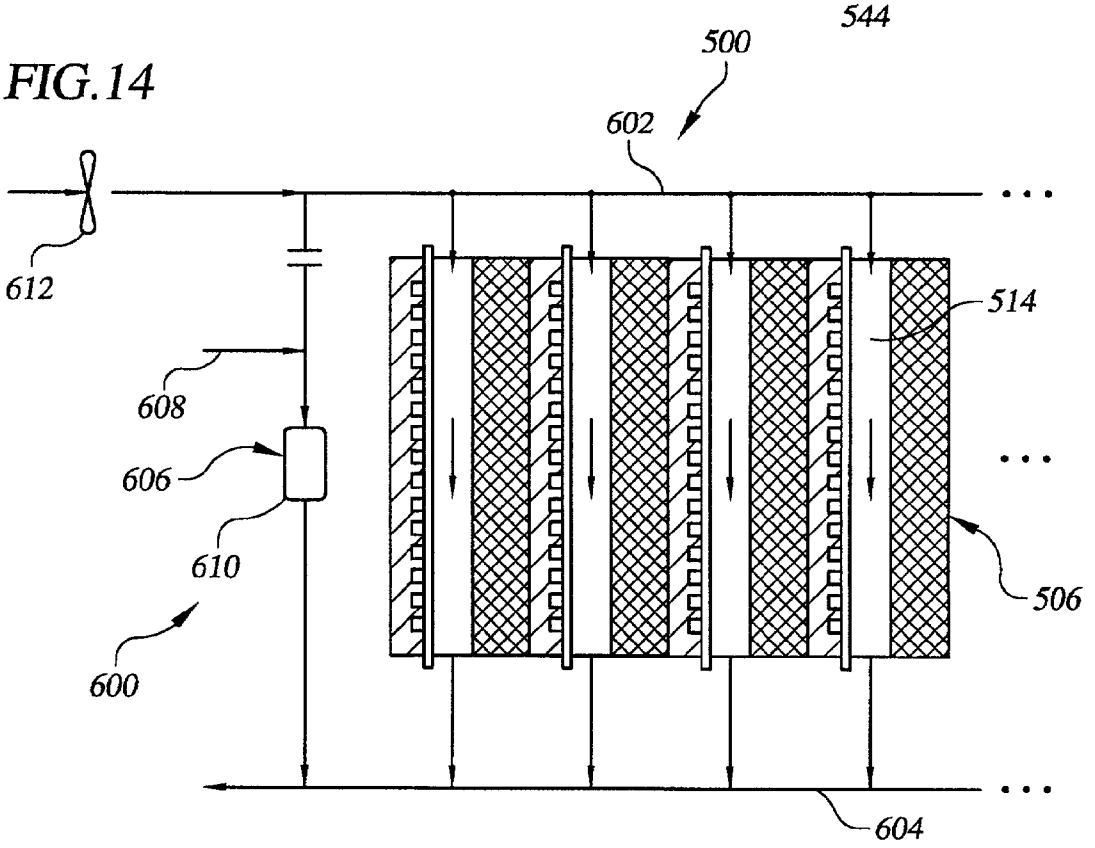
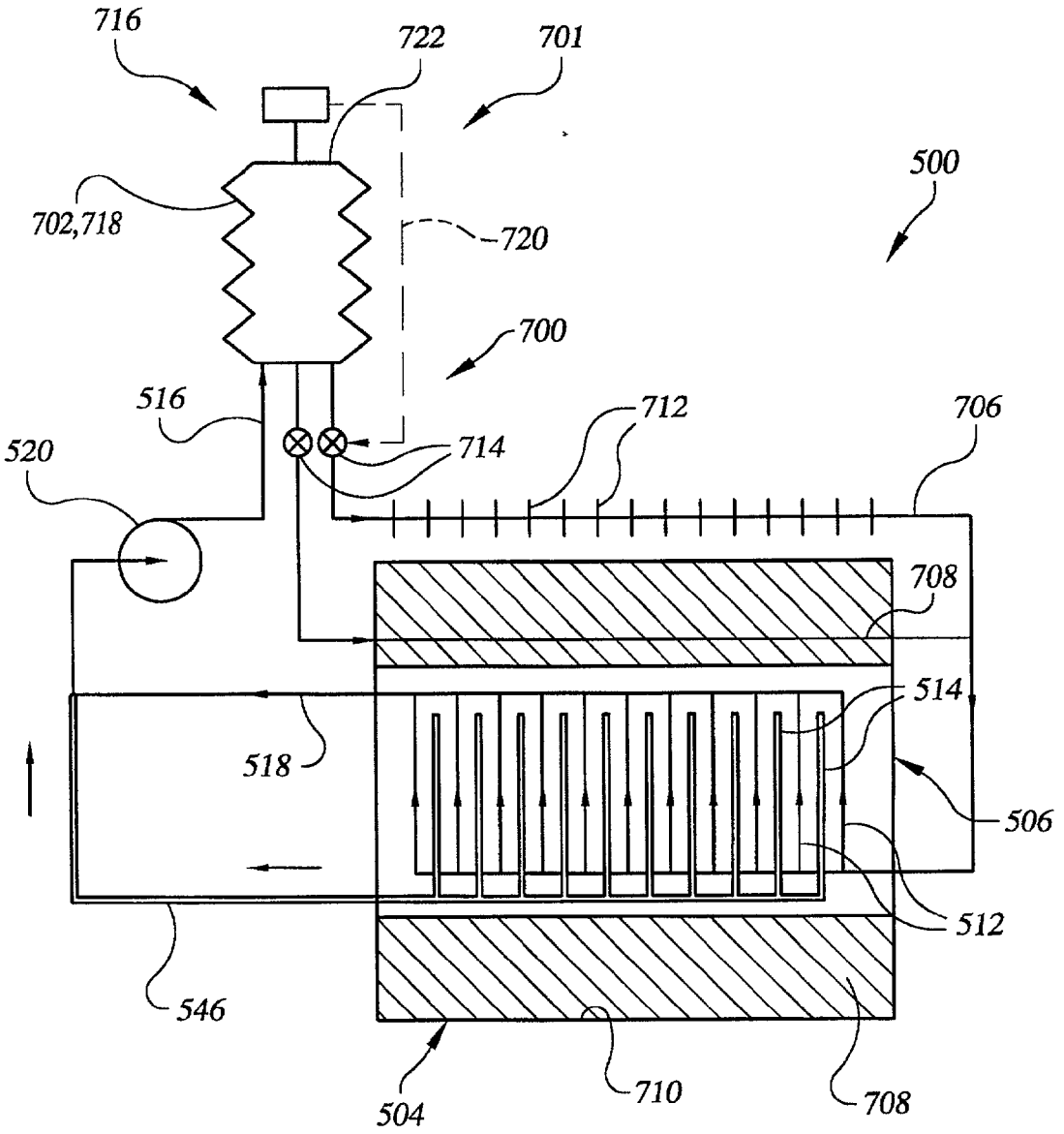

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FIG.15


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LIGHTWEIGHT DIRECT METHANOL FUEL CELL AND SUPPORTING SYSTEMS

RELATED APPLICATION DATA

[0001] This application claims the benefit of priority of U.S. Provisional Patent Application No. 60/276,314, filed Mar. 16, 2001, entitled "Compact, Lightweight Direct Methanol Fuel Cell."

STATEMENT OF GOVERNMENT RIGHTS

[0002] This invention was made with Government support under contract MDA972-01-C-0070 awarded by the Defense Advanced Research Project Agency. The Government has certain rights in the invention.

FIELD OF THE INVENTION

[0003] The present invention is generally related to the field of fuel cells. More particularly, the present invention is directed to a lightweight fuel cell stack and supporting systems therefor.

BACKGROUND OF THE INVENTION

[0004] A fuel cell electrochemically converts a fuel and an oxidant into direct current electricity that may be used to power any of a variety of electrical devices, such as electromechanical equipment, e.g., motors and actuators, digital and analog circuits, e.g., microprocessors and radio transmitters, and other electrical equipment, e.g., heaters and sensors, among others. Fuel cells are generally categorized by the type of fuel, e.g., methanol or hydrogen, and the type of electrolyte, e.g., solid polymer, solid oxide, molten carbonate and phosphoric acid, used to effect the electrochemical process within the fuel cell.

[0005] One type of fuel cell that has emerged as a popular variant is the proton exchange membrane (PEM) (also known as "polymer electrolyte membrane") type fuel cell. The PEM is a thin sheet of polymer that allows hydrogen ions (protons) to pass through it. When used in a fuel cell, the side of the PEM in contact with the fuel is in electrical contact with an anode electrode and the side of the PEM in contact with the oxidant is in electrical contact with a cathode electrode. Hydrogen from the fuel side of the cell ionizes and passes through the PEM to combine with oxygen on the oxidant side of the cell. As each hydrogen ion enters the anode electrode, an electron is split from the hydrogen atom. These freed electrons then become the source of electric current that can power an external load.

[0006] During operation, a hydrogen-rich fuel is provided to the anode side of the PEM as the source of hydrogen atoms that provide the ions and electrons during the electrochemical process that splits the electrons and ions from one another. An oxidant, typically oxygen via air, is provided to the cathode side of the PEM. When the hydrogen ions passing through the PEM reach the cathode side of the PEM, they combine with oxygen to produce water.

[0007] A popular type of PEM fuel cell utilizes methanol as the source of hydrogen atoms for the electrochemical reaction with the PEM. Methanol/PEM fuel cells are desirable due to their relatively low operating temperatures, generally innocuous byproducts, e.g., carbon dioxide and water, and ease of storing the methanol fuel under standard conditions. At standard conditions, i.e., standard temperature and pressure, methanol is liquid. Thus, the methanol fuel is typically stored in conventional liquid-type fuel tanks. In contrast, other types of fuel cells, e.g., hydrogen fuel cells, typically require their fuels to be stored under non-standard conditions. For example, hydrogen fuel may be stored as a cryogenic liquid or a pressurized gas. Liquefying hydrogen at cryogenic temperatures is an expensive process, and storing liquefied hydrogen requires bulky insulated containers that vent and lose hydrogen due to heat leaks. Similarly, compressing and storing hydrogen gas is relatively costly, and storing this highly flammable gas is more problematic than storing liquid methanol.

[0008] Early methanol fuel cell systems included a reformer, e.g., a steam reformer, that stripped from the methanol molecules the hydrogen necessary for the electrochemical reaction with the electrolyte that produced the electricity. The present focus of methanol fuel cells, however, is on direct methanol fuel cells in which the liquid methanol fuel is circulated into direct contact with the anode, rather than just the hydrogen atoms split from the methanol molecules. In lieu of the reformer, a methanol break-down catalyst is typically provided adjacent the PEM to remove the hydrogen atoms from the methanol molecules. Direct methanol fuel cells have the advantages of, among other things, lighter weight, reduced complexity, and lower cost due to the elimination of the reformer.

[0009] In general, to provide a usable amount of electricity all direct methanol fuel cells require a PEM having a relatively large surface area. This is typically accomplished by providing a plurality of PEMs, a plurality of fuel (anode) flow fields, and a plurality of oxidant (cathode) flow fields stacked alternately with one another to form a generally compact fuel cell stack, which is typically enclosed within a housing. The anode and cathode flow fields are typically provided by plates made from various materials and having channels or other flow regions formed therein. Since parallel anode flow fields, and parallel cathode flow fields, are spaced from one another, manifolds must be provided to distribute the fuel and oxidant to all of the corresponding flow fields. Depending upon a particular design of a direct methanol fuel cell system, the fuel cell stack must be supported by a variety of supporting systems, which may include a fuel storage and delivery system, a fuel recirculation system, a carbon dioxide removal system, an oxidant delivery system, a cathode exhaust system, a water circulation system, and/or a cooling system, among others.

[0010] Fuel cell system designers are continually striving to reduce the complexity of fuel cell systems for a number of reasons including lower cost, manufacturing efficiency, and reduced maintenance. In addition, since important applications for fuel cells include, among other things, manned and unmanned spacecraft, terrestrial vehicles, and portable electronic equipment, such as computers and cell phones and similar devices, designers are also continually striving to decrease the weight and size of fuel cell stacks, housings, and supporting systems.

SUMMARY OF INVENTION

[0011] In one aspect, the present invention is directed to a fuel cell unit. The fuel cell unit comprises at least one flow field structure that includes a first plate having a plurality of

apertures. A second plate confronts the first plate so as to form a flow field between the first plate and the second plate. A membrane electrode assembly confronts the first plate.

[0012] In another aspect, the present invention is directed to a fuel cell unit comprising a fuel cell stack. The fuel stack comprises a plurality of first flow field structures each having an outer periphery. A plurality of second flow field structures are located alternatingly with the plurality of first flow field structures. Each of the plurality of second flow field structures defines a cavity for receiving a fluid. Each cavity has first portion extending radially outward of the outer periphery of each immediately adjacent second flow field structure. Each of the first portions fluidly communicating with at least one adjacent first portion radially outward of the outer periphery of each immediately adjacent second flow field structure.

[0013] In a further aspect, the present invention is directed to a fuel cell unit comprising a fuel cell stack that comprises a plurality of first flow field structures each defining a flow field having an outer periphery. A plurality of second flow field structures are located alternatingly with respect to the plurality of first flow field structures. Each of the plurality of second flow field structures has a portion extending beyond the outer periphery of each immediately adjacent first flow field structure. A plurality of sealing members are each located radially outward of the outer periphery of a corresponding one of the plurality of first flow fields structures and confront two of the plurality of second flow field structures.

[0014] In yet another aspect, the present invention is directed to a fuel cell system that has a fluid inventory and utilizes a recirculated fluid having a temperature. The fuel cell system comprises at least one anode flow field for conducting the recirculated fluid and a fluid inventory control system. The fluid inventory control system comprises a sensor for measuring the fluid inventory. The sensor generates a first control signal. A first flowpath extends from the at least one anode flow field to the sensor. At least one second flowpath is in fluid communication with the first flowpath and extends from the sensor to the first anode flow field. A device is operatively coupled to the sensor for controlling the temperature of the recirculated fluid in response to the first signal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] For the purpose of illustrating the invention, the drawings show a form of the invention that is presently preferred. However, it should be understood that the present invention is not limited to the precise arrangements and instrumentalities shown in the drawings, wherein:

[0016] FIG. **1** is a perspective view of a fuel cell stack and housing according to the present invention;

[0017] FIG. **2** is a cross-sectional view of the fuel cell stack and housing as taken along line **2-2** of FIG. **1**;

[0018] FIG. **3** is a partially exploded perspective view of a portion of the fuel cell stack of the fuel cell unit of FIG. **1**;

[0019] FIG. **4** is an enlarged partial cross-sectional view of the fuel cell stack as taken along line **4-4** of FIG. **2** showing a system for sealing anode flow fields and cathode flow fields from one another;

[0020] FIG. **5** is a partial cross-sectional view of the fuel cell unit as taken along line **5-5** of FIG. **1** showing compression members for compressing the fuel cell stack;

[0021] FIG. **6** is an enlarged partial cross-sectional view of the fuel cell stack as taken along line **6-6** of FIG. **2** showing oxidant inlets in conjunction with the sealing system of FIG. **5**;

[0022] FIG. **7** is an enlarged cross-sectional view of the fuel cell stack as taken along line **7-7** of FIG. **2** showing an alternative system for sealing anode flow fields and cathode flow fields from one another;

[0023] FIG. **8** is a partial cross-sectional view of the fuel cell stack as taken along line **8-8** of FIG. **7** showing oxidant inlets in conjunction with the sealing system of FIG. **7**;

[0024] FIG. **9** is a transverse cross-sectional view of an alternative fuel cell unit of the present invention;

[0025] FIG. **10** is an elevational view of one of the bipolar plate assemblies of the fuel cell unit of FIG. **9**;

[0026] FIG. **11** is a plan view of the cathode flow field structure of the bipolar plate assembly of FIG. **10**;

[0027] FIG. **12** is a plan view of the anode flow field structure of the bipolar plate assembly of FIG. **10**;

[0028] FIG. **13** is a schematic diagram of a fuel handling system of the present invention;

[0029] FIG. **14** is a schematic diagram of an oxidant handling system of the present invention; and

[0030] FIG. **15** is a schematic diagram of a liquid inventory control system of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0031] Referring now to the drawings, wherein like numerals indicate like elements, FIG. **1** illustrates in accordance with the present invention a fuel cell unit, which is generally denoted by the numeral **20**. As will become apparent from the accompanying drawings and corresponding description, fuel cell unit **20**, alone and in conjunction with the various supporting systems described below, contains a number of innovative features that can result in reduced size, weight, cost, and complexity of the fuel cell unit and the supporting systems when compared to conventional fuel cell systems having comparable power outputs. Such reductions are important in developing practical fuel cell units and supporting systems. These reductions are a result of a number of factors, including innovative choice of materials for, and design of, the various components of fuel cell **20** unit and supporting systems and innovative approaches to supporting the operation of the fuel cell unit.

[0032] As shown in FIG. **1**, fuel cell unit **20** may comprise a housing **22** and a fuel cell stack **24** contained within the housing. Housing **22** may include an upper wall **26**, a lower wall **28**, and a sidewall **30** extending between the upper wall and lower wall, typically but not necessarily, in a direction parallel to the central axis **32** of fuel cell unit **20**. As used herein, the terms "upper" and "lower" are used for convenience to express the relative position of the corresponding elements as they appear in the appurtenant drawings. Ele-

ments modified by these terms, of course, can be located at orientations other than those shown in the drawings.

[0033] As shown more particularly in FIG. **2**, sidewall **30** of housing **22** may form a cylinder having an inside diameter D. Correspondingly, fuel cell stack **24** may have a rectangular transverse cross-sectional shape generally having four vertices **34** so as to generally define four manifold regions **36**, e.g., an anode inlet manifold region **38**, an anode outlet manifold region **40**, a cathode inlet manifold region **42**, and a cathode outlet manifold region **44**, between fuel cell stack **24** and housing **22**. The distance C between diagonally opposing vertices **34** may be slightly less that inside diameter D of housing **22** so as to form an interference fit between fuel cell stack **24** and sidewall **30** that may aid sealing adjacent manifold regions **36** from one another. To further improve the seals between adjacent manifold regions **36**, a sealing member **46**, such as a formed gasket or caulk bead, may be provided. Sealing member **46** may be made of any suitable material, such as silicone or Viton® rubber (Viton® is a registered trademark of E.I. DuPont de Nemours and Company Corporation, Wilmington, Del.). Those skilled in the art will appreciate that distance C may be equal to or less than inside diameter D and that the sealing detail between vertices **34** of fuel cell stack **24** and housing **22** may need to be modified accordingly.

[0034] Although sidewall **30** is shown as being circular in shape and fuel cell stack **24** is shown as being rectangular in shape so as to form four generally circular-segment manifold regions **36** with housing **22**, the shapes of the sidewall and the fuel cell stack may be any desired. For example, fuel cell stack **24** may be circular and sidewall **30** may be square so as to form generally triangular manifold regions adjacent the vertices of the square sidewall. Other examples include a rectangular fuel cell stack contained in an elliptical sidewall or a quadrilateral fuel cell stack contained in a quadrilateral sidewall, wherein the fuel cell stack is smaller that the housing and is rotated relative to the housing so as to form four triangular manifold regions. Those skilled in the art will appreciate the variety of shape combinations that may be used to form manifold regions **36** between fuel cell stack **24** and housing **22**. In addition, fuel cell stack **24** may be shaped and sized to conformally and snugly fit within housing **22** so as not to form any manifold regions. In such an embodiment, manifolds for fuel cell stack **24** may be provided either external to housing **22** or within the fuel cell stack. However, those skilled in the art will appreciate that creating manifold regions **36** between fuel cell stack **24** and housing **22** may have certain advantages over fuel cell units manifolded external to its housing or within its fuel cell stack.

[0035] Referring to FIGS. **3** and **4**, fuel cell stack **24** may comprise a plurality of bipolar plates **48** stacked with one another along a stacking axis **50** and generally separated from one another by membrane electrode assemblies **52**. Each bipolar plate **48** generally includes an anode flow field structure **54** and a cathode flow field structure **56**. Each anode flow field structure **54** may comprise an upper plate **58** and a lower plate **60** that together define an anode flow field **62** for receiving a fuel. Upper and lower plates **58**, **60** may be made of any conductive material, such as metal or pyrolytic graphite sheets, among others. In the embodiment shown, upper and lower plates **58**, **60** are made of stainless steel coated with a relatively thin layer of gold to improve electrical conductivity and prevent corrosion. Upper and lower plates **58**, **60** may be any thickness desired. However, in the present embodiment, upper and lower plates may have a thickness of about 0.025 mm to about 0.250 mm.

[0036] Upper plate **58** may contain a plurality of spacers **64** that contact lower plate **60** so as to form anode flow field **62** and provide structures for preventing anode flow field structure **54** from deforming significantly when fuel cell stack **24** is compressed with housing **22** (FIG. **1**), as discussed below. Spacers also provide many points of electrical contact between upper plate **58** and lower plate **60**. As those skilled in the art will readily appreciate, spacers **64** may be either formed integrally with upper plate **58** or lower plate **60** or may be formed separate from both the upper and lower plates and secured between the upper and lower plates in any manner known in the art. However, in the present embodiment, spacers **64** are formed integrally with upper plate **58** using a stamping, or embossing, process. Such embossing processes are known in the art and, therefore, need not be described in detail herein. For example, upper and lower plates **58**, **60** may be fabricated using the techniques described in U.S. Pat. No. 6,170,568 to Valenzuela entitled "Radial Flow Heat Exchanger," which is incorporated by reference herein.

[0037] Lower plate **60** may contain a plurality of apertures **66** that allow anode flow field **62** to fluidly communicate with membrane electrode assembly **52**. As those skilled in the art will readily appreciate, apertures **66** may be any shape and size, and arranged in any pattern, desired to suit a particular design. For example, as shown, apertures **66** are elongated slots having a length of about 4 mm and a width of about 2 mm and are arranged in a staggered pattern. The arrangement of spacers **64** and apertures **66** may be coordinated with one another so that the spacers contact the upper surface of lower plate **60** when upper plate **58** and the lower plate are in their proper position with respect to one another.

[0038] Upper plate **58** and lower plate **60** may be secured to one another at their respective peripheral regions **68** to create a fluid seal between anode flow field **62** and regions located radially outward from anode flow field structure **54**. For example, as shown in FIG. **5**, peripheral regions **68** may be secured to one another with a folded and crimped joint **70** similar to the crimped joint between the sidewall and top of a conventional soda can. Crimped joint **70** may be augmented with a sealant (not shown), such as silicone, if needed. Alternatively to crimped joint **70**, peripheral regions **68** may be secured to one another by other means, such as diffusion bonding, sealing with epoxy, or welding, among others.

[0039] Each cathode flow field structure **56** may be a plate having an upper side **72**, a lower side **74** and a plurality of channels **76** formed in at least one of the upper and lower sides to provide a cathode flow field **78**. Cathode flow field structure **56** may be made of a microporous material, such as porous pyrolytic graphite (PPG) or conductive porous metal/ceramic composite materials, among others. As described below, a microporous material, such as PPG, may be desirable from a liquid-management perspective. As shown, cathode flow field structure **56** may contain a plurality of straight channels **76** adjacent to membrane electrode assembly **52** extending from one end of the cathode

flow field structure to an apposing end. Those skilled in the art, however, will appreciate that cathode flow field structure **54** may include any configuration of channel(s) **76**, including a single serpentine channel, required to suit a particular design.

[**0040**] Membrane electrode assembly **52** may comprise any type of electrolyte suitable for the type of fuel cell unit that fuel cell unit **20** is designed to be. In the present embodiment, fuel cell unit **20** may be a direct methanol type fuel cell unit. Accordingly, membrane electrode assembly **52** may comprise a polymer electrolyte membrane (PEM) (also known as a "proton exchange membrane"), such as a Nafion® membrane available from E.I. DuPont de Nemours and Company Corporation, Wilmington, Del. Those skilled in the art will appreciate that the membrane electrode assembly **52** will comprise another material, such as a solid oxide, molten carbonate or phosphoric acid, among others. Membrane electrode assembly **52** also comprises an anode electrode **80** located adjacent anode flow field structure **54** and a cathode electrode **81** located adjacent cathode flow field structure **56**. Depending upon the type of fuel cell, membrane electrode assembly **52** may include catalyst layers (not shown) on one or both of its electrodes **80**, **81** that react with the methanol fuel to free the hydrogen molecules therefrom. For example, in a direct methanol fuel cell utilizing a PEM electrolyte, the PEM may be joined to sheets of carbon paper that make up anode and cathode electrodes **80**, **81**. Anode and cathode electrodes **80**, **81** can be coated with a relatively thin layer of platinum, or other catalyst. Alternatively, a catalyst such as platinum black can be applied directly to the PEM.

[**0041**] Anode flow field **62** and cathode flow field **78** may be fluidly sealed from one another with a sealing member **82** located between adjacent anode flow field structures **54**. Sealing member **82** may be a gasket, e.g., an "O-ring" having a shape corresponding generally to the shape of the outer periphery **84** of cathode flow field structure **56**. Of course, sealing member **82** may be another shape, if desired. Sealing member **82** may be made of a suitable compressible material, such as silicone or Viton® rubber. In the embodiment shown, membrane electrode assembly **52** extends radially beyond sealing member **82** generally to simplify the fluid seal between anode and cathode flow fields **62**, **78**.

[**0042**] Referring again to FIG. **1**, and also to FIG. **5**, fuel cell unit **20** may further include a terminal **86** located at the upper end of fuel cell stack **24**. Terminal **86** may include a plate **88** located within housing **22** and a contact **90** that extends through a corresponding aperture **92** in upper end wall **26** of the housing. A mentioned, it may be desirable to maintain fuel cell stack **24** in compression within housing **22**. This is generally so to maintain good electrical contact throughout stack **24**. Axial compression also increases the effectiveness of sealing members **82** (FIGS. **3** and **4**) to prevent cross-leakage between anode and cathode flow fields **62**, **78** and between the anode and cathode flow fields and manifold regions **36** where appropriate.

[**0043**] Fuel cell stack **24** may be maintained in compression in any of a number of different ways. For example, as shown in FIG. **5**, one or more compression members **94** may be placed between housing **22** and terminal plate **88**. Each compression member **94** may be a Belleville-type disc spring, a leaf spring, a coil spring, a silicone gasket, or any other resilient compressible body. Alternatively, the height along stacking axis of uncompressed fuel cell stack **24** and any relatively rigid bodies stacked therewith, e.g., plate **88** of terminal **86**, may be made somewhat smaller than the distance between upper end wall **26** and lower end wall **28** of housing **22**. Thus, when fuel cell stack **24** is inserted into housing **22** it must be compressed accordingly for the housing to be properly sealed. When fuel cell stack **24** is compressed within housing **22** in either of the above-described manners, sidewall **30** of the housing is placed into tension to counteract the compressive force induced into the fuel cell stack. This allows housing **22** to provide at least two functions, that of a housing and a tensile member, that in conventional fuel cell units are typically provided by separate structures. Accordingly, this consolidation of functions can result in a weight savings with respect to conventional fuel cell units. Those skilled in the art will understand that other means exist for maintaining fuel cell stack in compression, including conventional means, such as tension rods extending through the fuel cell stack, among others.

[**0044**] Referring now to FIGS. **1** and **2**, housing **22** may further include an oxidant inlet **96** and an oxidant outlet **98** in fluid communication with, respectively, cathode inlet and outlet manifold regions **42**, **44**. As described below, oxidant inlet **96** may be in fluid communication with an oxidant handling system and oxidant outlet **98** may be in fluid communication with an exhaust system, a liquid inventory system, and/or a fuel handling system, among other systems. FIG. **6** shows a pair of adjacent anode flow field structures **54** and corresponding intermediate cathode flow field structure **56** and membrane electrode assembly **52** to illustrate a manner in which cathode inlet manifold region **42** (FIG. **2**) may be in fluid communication with cathode flow field **78** via a plurality of passageways **100** to allow an oxidant to flow therebetween.

[**0045**] Passageways **100** may be defined by the space between sealing member **82** and upper plate **58** at each depression **102** in the upper plate located immediately adjacent the sealing member. Each depression **102** may correspond to a spacer, e.g., embossed spacer **64** (FIGS. **3** and **4**), or may be a depression formed particularly for the purpose of creating passageways **100**. Sealing member **82** should be radially spaced from the outer periphery **84** of cathode flow field structure **56** so that passageways **100**, which are located distal from a plane containing membrane electrode assembly **52**, are in fluid communication with channels **76** of the cathode flow field structure located proximate to the plane of the membrane electrode assembly. Depressions **102** may be coated with a material, such as a fluorocarbon, that makes passageways hydrophobic to prevent fluid from blocking the flow of oxidant through the passageways. Those skilled in the art will appreciate that other means may be provided to allow cathode inlet manifold region **42** (FIG. **2**) to fluidly communicate with cathode flow field **78**. For example, in lieu of, or in addition to, depressions **102** in upper plate **58**, sealing member **82** may be provided with transverse grooves and/or apertures (not shown) extending between cathode inlet manifold region **42** and cathode flow field **78**. It is noted that passageways **100** may be provided between cathode flow field **78** and cathode outlet manifold **44** (FIG. **2**) in a similar manner.

[**0046**] Referring again to FIGS. **2** and **4**, each anode flow field structure **54** may contain an inlet manifold region **104**

and an outlet manifold region **106**. In the embodiment shown, the flow direction of the fuel is generally straight through anode flow field **62**. Accordingly, inlet and outlet manifold regions **104**, **106** are located at opposing ends of anode flow field structure **54**. Other configurations of anode flow field **62** having different fuel flow paths may have inlet and outlet manifold regions **104**, **106** at locations other than opposing ends. Each inlet and outlet manifold region **104**, **106** may contain an upper manifold aperture **108** in upper plate **58** and a lower manifold aperture **110** in lower plate **60**. As those skilled in the art will readily appreciate, if sub-manifolding is desired, each inlet and outlet manifold region **104**, **106** may contain more than one each of upper and lower manifold apertures **108**, **110**. As shown in FIGS. **1** and **5**, housing **22** may include a fuel inlet **112** and a fuel outlet **114** in fluid communication with, respectively, inlet and outlet manifold regions **104**, **106** of anode flow field structures **54** of fuel cell stack **24**. Although fuel inlet **112** and fuel outlet **114** are shown entering housing **22** through upper end wall **26**, each may extend through the housing elsewhere, such as through lower end wall **28** or sidewall **30**.

[**0047**] FIG. **4** shows a joint **116** between outlet manifold regions **106** of adjacent anode flow field structures **54** that allows corresponding anode flow fields **62** to fluidly communicate with one another. Inlet manifold regions **104** may be joined in the same, or other, manner. Each lower manifold aperture **110** may be formed in a lower embossment **118** of lower plate **60**, and each upper manifold aperture **108** may be formed in an upper embossment **120** of upper plate **58**. Correspondingly, joint **116** may be comprised of portions of lower and upper embossments **118**, **120** and one or more sealing means, if required. For example, each lower embossment **118** may include a cylindrical portion **122** that extends into corresponding upper manifold aperture **108** defined by a similar cylindrical portion **124**. A gasket **126**, or other sealing means, may be used to seal any space that may be present between the respective cylindrical portions **122**, **124** of lower and upper embossments **118**, **120**.

[**0048**] Gasket **126** shown is generally circular and has a U-shaped cross-sectional shape that allows it to engage cylindrical portion **124** of upper embossment **120**. Gasket **126** may allow cylindrical portion **122** of lower embossment **118** to slide relative to upper embossment **120** to allow for any movement that may occur when fuel cell stack **24** is compressed within housing **22** (FIG. **1**). Gasket **126** should be made of an insulating material to prevent short circuiting of fuel cell unit **20**. Accordingly, gasket **126** may be made of any suitable material, such as silicone or Viton® rubber. Those skilled in the art will appreciate the variety of joints **116** that may be formed between adjacent anode flow structures **54**. For example, in contradistinction to joint of FIG. **5**, cylindrical portion **124** of upper embossment **120** may be smaller in diameter that cylindrical portion **122** of lower embossment **118** so that it fits within the cylindrical portion of the lower embossment. In addition, cylindrical portions **122**, **124** of lower and upper embossments **118**, **120** may have the same diameter so that they generally form a butt joint with one another, with or without an intermediate gasket (not shown) or other seal. Moreover, one or both cylindrical portions **122**, **124** and/or one or both lower and upper embossments **118**, **120** may be eliminated. In this case, a suitable gasket (not shown), such as a compressible toroid-shaped gasket, may surround corresponding adjacent upper and lower manifold apertures **108**, **110** to provide a sealing function, if required.

[**0049**] FIG. **7** shows an alternative means for sealing anode flow field **62'** and cathode flow field **78'** (see FIG. **8**) from one another within fuel cell stack **24'** comprising anode flow field structures **54'** and cathode flow field structures **56'** similar to the corresponding structures of fuel cell unit **20** of FIGS. **1-6**. In this embodiment, however, channels **76'** of cathode flow field structure **56'** are oriented parallel to the primary direction of fuel flow **128** in anode flow field so that oxidant flow **130** is parallel to the fuel flow and, in this embodiment, in the same direction, too. Accordingly, manifold region **36'** may provide at least two functions, that of containing outlet manifold regions **106'** of anode flow field structures **54'** and providing a cathode outlet manifold **132**.

[**0050**] Cathode flow field structure **56'** may be the same as cathode flow field structure **56** of FIG. **3**, except for a rabbet **134** formed therein adjacent and surrounding its outer periphery **84'**. Rabbet **134** may contain a support frame **136** made of a substantially impervious material, e.g., graphite or plastic, among others. Lower plate **60'** of anode flow field structure **54'** may include a sealing member **138** that extends along the length of support frame **136** and effects a fluid seal between anode flow field region **62'** and cathode flow field region **78'** when membrane electrode assembly **52'** is compressed between the sealing member and support frame. Sealing member **138** may be formed integrally with lower plate **60'**, e.g., by stamping, embossing, or otherwise forming the lower plate. Alternatively, sealing member **138** may be formed separately from lower plate **60'**. For example, sealing member **138** may be a gasket, which may or may not be compressible. As shown in FIG. **8**, frame member **136** may contain grooves **140** and/or apertures that allow cathode flow field **78'** to fluidly communicate with manifold region **36'**, i.e., cathode outlet manifold **132**. The sealing detail shown in FIGS. **7** and **8** may be used at the opposing side, i.e., inlet side, of fuel cell stack **24'**. The sides of fuel cell stack **24'** parallel to the direction of flow in anode and cathode flow fields **62'**, **78'** may be completely sealed, e.g., by coating these sides with silicone, or other suitable sealing material. This is so because no fuel or oxidant flow occurs through these sides.

[**0051**] FIGS. **9-12** show an alternative embodiment of a fuel cell unit **320** of the present invention. As shown, housing **322** is substantially similar to housing **22** of FIG. **1**. That is, housing **322** includes a circular sidewall **330** and a lower end wall **328** that includes oxidant inlet **396** and oxidant outlet **398** that fluidly communicate with a corresponding cathode inlet and outlet manifold regions **342**, **344**, which serve as the cathode inlet and outlet manifolds themselves. Housing **322** and fuel cell stack **324** also define anode inlet and outlet manifolds **338**, **340**, which similarly serve as the anode inlet and outlet manifolds. Not shown are a fuel inlet and a fuel outlet that communicate with anode inlet and outlet manifold regions **338**, **340** via an upper end wall, also not shown. Those skilled in the art will appreciate that the fuel inlet **396** and outlet **398** and oxidant inlet and outlet need not be located as indicated, but rather may be located at any suitable locations.

[**0052**] Among the differences between fuel cell unit **320** and fuel cell unit **20** of FIGS. **1-6** is the use of a single plate

for anode flow field structure **354** rather than the substantially sealed two-plate anode flow field structure **54** of FIGS. **1-6**. Depending upon the type of fuel cell unit and the overall design of fuel cell unit **320**, this difference can result in a reduction in the weight of the fuel cell unit. However, if fuel cell unit **320** is of the liquid fuel type, e.g., a direct methanol fuel cell, and the dimensions of fuel cell stacks **324**, **24** and corresponding housings **322**, **22** are substantially the same, the weight savings of single plate anode flow field structures **354** may be more than offset by the weight of additional fuel needed to fill entire anode inlet and outlet manifold regions **338**, **340** rather than the self-contained inlet and outlet manifold regions **104**, **106** of two-plate anode flow field structures **54**.

[**0053**] As shown particularly in FIG. **10**, each bipolar plate **348** generally comprises cathode flow field structure **356** and anode flow field structure **354**. Referring to FIGS. **10** and **11**, cathode flow field structure **356** may be made of a porous material similar to cathode flow field structure **56** described above in connection with FIGS. **1-6**. Cathode flow field structure **356** may include a first side containing a plurality of channels **376** and a second side that is substantially planar. Channels **376** define the predominant direction of oxidant flow **430** through cathode flow field structure **356**. Referring to FIGS. **10** and **12**, anode flow field structure **354** of each bipolar plate **348** may be a plate similar to upper plates **58** of anode flow field structure **54** of the embodiment of FIGS. **1-6**. Similarly, anode flow field structure **354** may contain a plurality of spacers **364** that may be either formed integrally with the anode flow field structure **354** by stamping, embossing, or another process, or formed separately and secured to the anode flow field structure by, e.g., welding, bonding or other means.

[**0054**] Anode flow field structure **354** may confront cathode flow field structure **356** so that spacers **364** extend in a direction away from the cathode flow field structure. To form fuel cell stack **324** using a plurality of bipolar plates **348**, the bipolar plates may be stacked alternatingly with a membrane electrode assembly (not shown) such that channels **376** confront the cathodes in the membrane electrode assemblies and spacers **364** confront the anodes. The membrane electrode assembly may comprise any suitable electrolyte. However, if fuel cell unit is a direct methanol fuel cell unit, the membrane electrode assembly may include a PEM similar to PEM described above in connection with FIGS. **1-6**. Each membrane electrode assembly may optionally be located adjacent to one or more porous layers, e.g., carbon fiber paper, similar to fuel cell stack of FIGS. **1-6**.

[**0055**] Spacers **364** generally define a criss-cross pattern of channels that generally define anode flow field **362**. However, the primary direction of fuel flow **428** through these channels is perpendicular to the longitudinal direction of channels **376** of cathode flow field structure **356**. This is necessarily so due to the particular arrangement of anode and cathode manifold regions **338**, **340**, **342**, **344** present in fuel cell unit **320** of FIG. **9**. Those skilled in the art will recognize that alternative shapes of housing **322** and/or fuel cell stack **324** and/or alternative arrangements of manifold regions **336** may be used and that the flow patterns within anode and cathode flow fields **362**, **378** may change accordingly.

[**0056**] FIG. **13** shows a fuel cell system **500** that includes a fuel handling system **502**. Fuel handling system **502** is particularly described in connection with a direct methanol type fuel cell system that utilizes liquid methanol as the fuel. However, those skilled in the art will understand that fuel handling system **502** may be used with any hydrocarbon fuel that can be used in the form of a water solution. Fuel cell system **500** may include a fuel cell unit **504**, which is represented in FIG. **13** by a partial fuel cell stack **506** comprising several bipolar plates **508** separated from one another by corresponding membrane electrode assemblies **510**. Bipolar plates **508** and membrane electrode assemblies **510** may, but need not, be as described in connection with fuel cell units **20**, **320** described above in connection with FIGS. **1-12**. Each bipolar plate **508** generally includes an anode side having an anode flow field **512** and a cathode side having a cathode flow field **514**. Of course, fuel cell unit **504** may comprise a sole anode flow field **512** and a sole cathode flow field **514** separated from one another by one membrane electrode assembly **510** in lieu of the plurality of bipolar plates **508** shown.

[**0057**] Fuel handling system **502** generally includes a fuel supply conduit **516** for supplying a water/methanol fuel solution to anode flow fields **512** of fuel cell stack **506** and a fuel return conduit **518** for recirculating the water/methanol solution through the fuel handling system. As used herein, and in the claims appended hereto, the term "conduit" includes any piping, tubing, manifolding, or other fluid-carrying structure. Fuel handling system **502** may include at least one recirculating pump **52** for circulating the water/methanol solution through fuel supply conduit **516**, anode flow fields **512**, and fuel return conduit **58**, preferably at a relatively high flow rate. Recirculating pump **520** may generally be located at any point within fuel handling system **502** and may be any suitable pump, such as a centrifugal pump, a lobe pump, a screw pump, or a displacement pump, among others.

[**0058**] Fuel handling system **502** may also include a fuel injection system **522** that includes at least one fuel supply **524** for providing fuel handling system **502** with concentrated methanol in a concentration higher than the methanol concentration in the methanol/water solution supplied to fuel cell stack **506**. Fuel supply **524** may be a tank or other storage reservoir. When fuel cell unit **504** is operating, a portion of the methanol (CH_3OH) in the methanol/water solution within anode flow fields **512** is stripped of its hydrogen atoms, e.g., by a catalyst (not shown) within each bipolar plate **508**. The freed hydrogen atoms are then stripped of their electrons as they pass through each corresponding membrane electrode assembly **510** to create an electrical potential. Some of the remaining carbon and oxygen atoms combine to form carbon dioxide gas (CO_2), which remains in the methanol/water solution. Thus, some of the methanol is depleted from the recirculating methanol/water solution with each pass of the recirculating methanol/water solution through anode flow fields **512**. Since it is desirable to provide fuel cell stack **506** with a predetermined optimal methanol concentration, additional methanol should be provided to the recirculating methanol/water solution to make up for the methanol used in the fuel cell stack.

[**0059**] Accordingly, fuel injection system **522** may include a control system **526** in communication with a methanol concentration sensor **528** and a regulating valve **530** located between fuel supply **524** and fuel supply conduit **516** for controlling the amount of concentrated methanol

provided to the recirculating methanol/water solution. Control system **526** may monitor a signal from methanol concentration sensor **528** and actuate regulating valve **530** to control the flow rate of methanol into the recirculating methanol/water solution. Control system **526** may be any suitable digital or analog control system. Such control systems are well known in the art and, therefore, need not be described in detail. Methanol concentration sensor **528** may be any type of concentration sensor, such as the voltage-type sensor described in U.S. Pat. No. 4,810,597 to Kumagai et al., which is incorporated herein by reference. Regulating valve **530** may be any suitable type of controllable valve, such as a rotary valve or a gate valve, among others.

[**0060**] Fuel handling system **502** may further include a carbon dioxide separator **532**, or gas scrubber, for separating the carbon dioxide from the methanol/water solution exiting fuel cell stack **506**. Carbon dioxide separator **532** may be located upstream of recirculating pump **520** so that the carbon dioxide gas does not interfere with the operation of the pump. Carbon dioxide separator **532** may include a housing **534** having an upstream chamber **536**, a downstream chamber **538**, and a carbon dioxide vent **540** in fluid communication with the upstream chamber. Downstream chamber **538** may be separated from upstream chamber by microporous element **542** having a bubble point greater than the suction head of recirculating pump **520**. Accordingly, as recirulating pump **520** draws the methanol/water solution through microporous element **542**, the carbon dioxide gas is trapped in upstream chamber **536**, where it is vented through carbon dioxide vent **540**. It is noted that the carbon dioxide gas vented via carbon dioxide vent **540** may include methanol vapor. This methanol vapor may be handled as described below in connection with the oxidant handling system of FIG. **14**. Housing **534** may be made of any suitable material, such as Nuryl or polycarbonate, among others. Microporous element **542** may also be any shape, such as tubular, and may be made of any suitable porous material that is wettable by the methanol/water solution. Although fuel handling system **502** is shown with carbon dioxide separator having microporous element **542**, the carbon dioxide separator may be any suitable type known in the art.

[**0061**] In addition, fuel handling system **502** may include water recycling system **544** for recycling water from cathode flow fields **514** produced by the oxidation of the hydrogen ions that pass through membrane electrolyte assemblies **510** and water that crosses the membrane electrolyte assemblies due to electro-osmotic drag. Water recycling system **544** may include a water recycling conduit **546** in fluid communication with cathode flow fields **514** at its upstream end and recirculating pump **520** at its downstream end. Recirculating pump **520** generally provides the suction that draws the water through water recycling system **546**.

[**0062**] FIG. **14** shows fuel cell system **500** in conjunction with an oxidant handling system **600**. Like fuel handling system **502**, oxidant handling system **600** is particularly described in connection with a direct methanol type fuel cell system that utilizes air as the oxidant. However, those skilled in the art will understand that oxidant handling system **600** may be used with other types of oxidants, such as pure oxygen, among others, that may be supplied from a pressurized tank.

[**0063**] Oxidant handling system **600** generally includes an oxidant supply conduit **602** for supplying oxidant gas to cathode flow fields **514** of fuel cell stack **506** and an exhaust gas conduit **604** for exhausting air and gaseous products of the electrochemical process from the cathode flow fields. Oxidant handling system **600** may also include a methanol cleanup system **606** in fluid communication with carbon dioxide vent **540** (FIG. **13**) of fuel handling system **502**. As mentioned above, the carbon dioxide vented from fuel handling system **502** may contain methanol vapor. Accordingly, oxidant handling system **600** may be provided with methanol cleanup system **606** to remove this methanol vapor from fuel cell system **500**. For various reasons, it may be desirable to prevent, or otherwise limit the amount of, methanol vapor exhausted into the environment surrounding fuel cell system. Methanol cleanup system **606** may include a conduit **608** for conducting the carbon dioxide and methanol vapor from carbon dioxide vent **540** (FIG. **13**) and a catalyst **610**, e.g., a precious metal, such as platinum, that causes the methanol vapor to react with oxygen to form carbon dioxide and water, which are then exhausted from oxidant handling system along with the gases from cathode flow fields **514**. Oxidant handling system **600** may further include a blower **612** to force air through cathode flow fields exhaust gas conduit and methanol cleanup system. Blower may be any type of blower such as an inline fan or a centrifugal fan. Of course, if the oxidant is pure oxygen supplied from a pressurized tank, blower **612** may be eliminated.

[**0064**] FIG. **15** shows fuel cell system **500** that includes a liquid inventory system **700** for regulating the balance of water in fuel cell unit. Liquid inventory system **700** can play important role in reducing the overall weight of fuel cell system **500**. This is so because water lost from fuel cell system **500**, e.g., by evaporation and exhaustion from oxidant system **600** (FIG. **14**) would otherwise have to be replaced with water from a relatively massive, carry-along water supply. This approach would be detrimental, particularly for fuel cell systems that must be as lightweight as possible. With respect to a direct methanol fuel cell system, maintaining a constant water inventory is possible, despite inevitable water transport from the fuel cell stack, because one byproduct of the reactions within a direct methanol fuel cell is water. A net two moles of water is produced for every mole of methanol consumed. Achieving a water-balanced operation generally requires a liquid inventory control system **700** to recover water from cathode flow fields **514** of fuel cell stack **506** and carefully controlling the operating conditions, e.g., methanol concentration in the methanol/water solution and temperature, of the fuel cell stack. Importantly, liquid inventory control system **700** should collect water from cathode flow fields **514** that cross membrane electrode assemblies due to electro-osmotic drag.

[**0065**] Referring to FIG. **15**, and also to FIG. **13**, liquid inventory control system **700** may comprise recirculating pump **520**, fuel return conduit **518**, and water recycle conduit **546**. As discussed above, recirculating pump **520** provides the methanol/water solution to the inlet side of anode flow fields **512**, preferably at a relatively high flow rate, and recirculates the methanol/water solution through fuel handling system **502**. Recirculating pump **520** also provides a suction to outlet side of cathode flow fields **514** to prevent backflow of the methanol/water solution into the cathode flow fields. When cathode flow field **514** of each bipolar plate **508** is defined by a cathode flow field structure **548**, made of a porous material, such as PPG discussed

above in connection with FIGS. **1-12**, the suction head of recirculating pump **520** is preferably less than the bubble point of the porous material. In this manner, the porous cathode flow field structures **548** remain wetted and recirculating pump **520** will draw only excess water from cathode flow field **514**. Porous cathode flow field structures **548** should be hydrophilic to allow them to wick water away from membrane electrode assemblies **510** and remain wetted. Thus, a porous cathode flow field structure **548** of this type may be considered a wick. Passageways (not shown) similar to passageways **100** (FIG. **6**) may be used to allow access for wicks around sealing members **82** (FIG. **4**) to contact the porous cathode flow field structure **548**, if such a sealing detail is provided.

[**0066**] Liquid inventory control system **700** may also include a sensor **701** to measure the liquid inventory. Sensor **701** can consist of any mechanical or electronic device that can produce a control signal in response to the amount of liquid, e.g., methanol/water solution, in fuel cell system **500**. Sensor **701** may comprise an accumulator **702** for accumulating excess methanol/water solution in fuel handling system **502**. Accumulator **702** may be located downstream of fuel return conduit **518** and water recycling conduit **546**, e.g., in fuel supply conduit **516** of FIG. **13** downstream of, and in fluid communication with, recirculating pump **520**. It is noted that FIG. **13** shows only a sole line representing fuel supply conduit **516**. However, a portion of fuel supply conduit **516** may include two or more pipes, tubes, or other conduits, such as a warm fuel delivery conduit **704** and a cool fuel conduit **706**, extending between accumulator **702** and inlet side of anode flow fields **512**. In this manner, liquid inventory control system **700** may be used to control not only the balance of water in fuel cell system **500** but also control the temperature of fuel cell stack **506**.

[**0067**] In this connection, fuel cell unit **504** may include thermal insulation **708** surrounding fuel cell stack **506** to create an insulated region **710**. Accordingly, a relatively large portion of warm fuel supply conduit **704** may be located within insulated region **710** to keep the methanol/water solution carried therein relatively warm. In contrast, a relatively large portion of cool fuel supply conduit **706** may be located outside insulated region **710** to allow the methanol/water solution carried therein to become relatively cool. Cool fuel supply conduit **706** may be augmented with one or more cooling devices **712**, such as a radiator or fins, to further effect the cooling of the methanol/water solution carried by the cool fuel supply conduit. The methanol/water solution carried by cool fuel supply conduit **706** may be cooled as much as required for a particular design, down to about the temperature of the ambient environment outside of insulated region **710**.

[**0068**] The temperature of methanol/water solution delivered to anode flow fields **512** may be controlled in a number of ways, such as by controlling one or more control valves **714** located in warm and cool fuel supply conduits **704**, **706** that extend between accumulator **702** and the anode flow fields **512**. Each control valve **714** may be any type of valve, such as the various types described above in connection with valve of fuel injection system.

[**0069**] A control system **716** may be used to actuate one or more of control valves **714** in response to the methanol/water solution inventory needs of fuel cell stack **506**. In one embodiment, wherein accumulator **702** is a variable volume reservoir, e.g., bellows **718**, control system **716** may be the bellows in conjunction with an actuator link **720** extending between the movable end **722** of the bellows and at least one of control valves **714**, e.g., the control valve for cool fuel supply conduit **706**. If the temperature of fuel cell stack **506** is too low, then bellows **718** will begin to accumulate methanol/water solution therein and begin to expand such that movable end moves away from control valves **714**, which remain relatively fixed. In response to the movement of movable end **722** of bellows **718**, actuator link **720**, or other motion sensor, actuates control valve **714** of cool fuel supply conduit **706** so that less methanol/water solution flows through the cool fuel supply conduit **706**. In response, fuel cell stack **506** will warm up so that more water will evaporate and be exhausted from fuel cell system **500**. Likewise, if fuel cell stack **506** is too hot, control system **716** will cause more methanol/water solution to flow through cool fuel supply conduit **706** so that the fuel cell stack **506** cools and evaporates less water. Those skilled in the art will appreciate that control system **716** may actuate control valve **714** of warm fuel supply conduit **704**, alone or in combination with control valve **714** of cool fuel supply conduit **706**, in a similar, albeit opposite, manner to achieve similar results.

[**0070**] In an alterative embodiment, sensor **701** may send via control system **716** a control signal to a cooling fan that blows air across cool fuel supply conduit **706**, or alternatively, sole fuel supply conduit **516** (FIG. **13**), and any cooling devices **712**, such as cooling fins, that may be present on the fuel supply conduit(s). Thus, if the methanol/water solution is accumulating in fuel cell system **500**, then control system **716** would decrease the fan speed. This would allow fuel cell system **500** to warm up and evaporate water at a higher rate.

[**0071**] As mentioned, actuator link **720** may be replaced by a suitable sensor to detect the accumulation of methanol/water solution in accumulator **702**. In conjunction, a separate control valve actuator (not shown) may also be provided. If accumulator **702** is bellows **718**, a suitable sensor may be a motion sensor or displacement sensor, among others. Those skilled in the art will understand the variety of different types of sensors that may be used with different types of accumulators **702**. For example, if accumulator **702** is a fixed reservoir, e.g., a rigid-walled tank, the sensor may be a sensor that detects the relative level of the surface of the methanol/water solution within the reservoir. Depending upon the type of control valve(s) **714**, corresponding control valve actuator(s) may be of the rotary or linear type among others. Although liquid inventory system **700** is shown in conjunction with recirculating a fuel solution through anode flow fields **512**, certain aspects of the fluid inventory control system may be used to cool fuel cell stack **506** by circulating water or other coolant through cathode flow field **514** or a coolant flow field (not shown) in a similar manner to regulate the operating conditions of the stack. Those skilled in the art will appreciate the changes necessary to implement such systems.

[**0072**] As mentioned, the operating conditions of fuel cell stack **506** affect the net gain or loss of water from fuel cell system **500**. The main loss mechanism for water is its evaporation from cathode flow fields **514** and the transport of the resulting water vapor out of fuel cell stack **506** along

with the other gases exhausted from the cathode flow fields (see FIG. **14** and accompanying description). The exhaust gas is typically saturated with water, so that the temperature of fuel cell stack **506** and the flow rate of gas through cathode flow fields **516** are critical parameters for maintaining water-balanced operation. In addition to liquid inventory system described above in connection with FIG. **15**, additional measures may be taken to conserve water, if needed. For example, exhaust gases can be at least partially recirculated through cathode flow fields **514** to maintain a relatively high humidity within the cathode flow fields without a large rate of water vapor loss. In addition, a condenser (not shown) may be installed in exhaust gas conduit **604** (FIG. **14**) to recover water from the exhaust gas. The recovered water could then be returned to the suction side of recirculating pump **520**, e.g., using a wick or other device that prevents gases from entering fuel handling system **502** (FIG. **13**).

[**0073**] While the present invention has been described in connection with a preferred embodiment, it will be understood that it is not so limited. On the contrary, it is intended to cover all alternatives, modifications and equivalents as may be included within the spirit and scope of the invention as defined above and in the claims appended hereto.

1. A fuel cell unit, comprising:

a first flow field structure having a first electrical type that is either an anode-type or a cathode-type;

a membrane electrode assembly located adjacent said first flow field structure, said membrane electrode assembly including first and second diffusion layers and an ion conducting membrane located therebetween;

a flow field wick having a second electrical type that is either said anode-type or said cathode-type, said second electrical type being opposite said first electrical type of said first flow field structure, said flow field wick located adjacent said membrane electrode assembly opposite said first flow field structure and comprising a layer that includes:

a first face located adjacent said membrane electrode assembly;

passageways for wicking a liquid to said membrane electrode assembly during use of the fuel cell unit; and

at least one channel for conducting the liquid in a direction substantially parallel to said first face during use of the fuel cell unit; and

a second flow field structure of said first electrical type, said second flow field structure located adjacent said flow field wick opposite said membrane electrode assembly without an intermediate anode flow field or cathode flow field located therebetween.

2. A fuel cell unit according to claim 1, wherein said first and second flow field structures are of the anode-type.

3. A fuel cell unit according to claim 1, wherein said flow field wick includes a second face spaced from said first face and said at least one channel comprises at least one groove formed in said second face.

4. A fuel cell unit according to claim 3, wherein said first face directly confronts said membrane electrode assembly.

5. A fuel cell unit according to claim 1, wherein said flow field wick comprises porous pyrolytic graphite.

6. A fuel cell unit according to claim 1, wherein each of said first and second flow field structures comprises a stamped metal plate.

7. A fuel cell unit according to claim 1, wherein each of said first and second flow field structures comprises first and second plates that together define a corresponding flow field.

8. A fuel cell unit according to claim 7, wherein said first and second plates are made of metal.

9. A fuel cell unit according to claim 7, wherein said first plate includes a plurality of integrally formed spacers defining a space between said first plate and said second plate for said corresponding flow field.

10. A fuel cell unit according to claim 9, wherein said plurality of spacers comprise embossments formed on said first plate.

11. A fuel cell unit according to claim 7, wherein said second plate contains a plurality of apertures in fluid communication with said membrane electrode assembly.

12. A fuel cell unit according to claim 7, wherein said first plate comprises a plurality of integrally formed spacers defining a space between said first plate and said second plate for said corresponding flow field and said second plate contains a plurality of apertures in fluid communication with said membrane electrode assembly.

13. A fuel cell unit according to claim 7, wherein said first and second plates each includes a peripheral region and said first and second plates are fluidly sealed with one another at said peripheral regions so as to partially define said corresponding flow field.

14. A fuel cell unit according to claim 13, wherein said peripheral region of said first plate and said peripheral region of said second plate are joined to one another and sealed by a crimped joint.

15. A fuel cell unit according to claim 1, wherein the fuel cell unit is a direct methanol fuel cell unit.

16. A fuel cell unit according to claim 15, wherein said flow field wick has an outer periphery and said first and second flow fields structures are manifolded radially outward of said outer periphery.

17-23. (canceled)

24. A fuel cell unit according to claim 7, wherein each of said first plates includes a first manifold aperture and each of said second plates includes a second manifold aperture coaxial with said first manifold aperture.

25. A fuel cell unit according to claim 24, wherein said corresponding flow field is substantially planar and at least one of said first and second manifold apertures is formed in a manifold embossment having a central axis substantially perpendicular to said corresponding flow field.

26. A fuel cell unit according to claim 25, wherein said manifold embossment includes a thin-walled cylindrical portion.

27-29. (canceled)

30. A fuel cell unit according to claim 1, wherein each of said first and second flow field structures includes a first manifold outlet and a second manifold outlet, wherein said first and second flow field structures are in fluid communication with one another via said first and second manifold outlets.

31. A fuel cell unit according to claim 30, further comprising a manifold sealing member located between each of corresponding ones of said first and second manifold outlets of said first and second flow field structures.

32. A fuel cell unit according to claim 30, wherein said corresponding flow field is substantially planar and each of said first and second manifold outlets is formed in a mani-

fold embossment having a central axis substantially perpendicular to said corresponding flow field.

33. A fuel cell unit according to claim 32, wherein each of said manifold embossments includes a thin-walled cylindrical portion.

34. A fuel cell unit according to claim 33, wherein said cylindrical portions of said manifold embossments of said first and second flow field structures engage one another so that one surrounds the other.

35. A fuel cell unit according to claim 34, wherein sealing member is positioned between said corresponding engaged ones of said cylindrical portions.

36-44. (canceled)

45. A fuel cell unit according to claim 1, wherein said flow field wick has an outer periphery and each of said first and second flow field structures has a portion extending beyond said outer periphery of said flow field wick, the fuel cell unit further comprising a sealing member located radially outward of said outer periphery of said flow field wick and confronting said portions of said first and second flow field structures extending beyond said outer periphery of said flow field wick.

46. A fuel cell unit according to claim 45, wherein said sealing member is an O-ring.

47. A fuel cell unit according to claim 45, wherein one of said first and second flow field structures includes a plurality of depressions formed therein to provide a plurality of passageways that circumvent said sealing member.

48. A fuel cell unit according to claim 47, wherein each depression is coated with a hydrophobic coating.

49. A fuel cell unit according to claim 45, wherein said membrane electrode assembly has a portion captured between a corresponding sealing member and one of said first and second flow field structures.

50-82. (canceled)

83. A fuel cell unit, comprising:

a first anode flow field structure;

a membrane electrode assembly located adjacent said first anode flow field structure;

a cathode flow field wick located adjacent said membrane electrode assembly opposite said first anode flow field structure and comprising:

a first face located adjacent said membrane electrode assembly;

at least one channel for conducting an oxidant in a direction substantially parallel to said first face during use of the fuel cell unit; and

passageways for wicking liquid to said membrane electrode assembly from said at least one channel during use of the fuel cell unit; and

a second anode flow field structure located adjacent said cathode flow field wick opposite said membrane electrode assembly without an intermediate cathode flow field located therebetween.

84. A fuel cell unit according to claim 83, wherein said membrane electrode assembly includes first and second diffusion layers and a proton exchange membrane located therebetween.

85. A fuel cell unit according to claim 83, wherein each of said first and second anode flow field structures comprises a pair of plates defining a corresponding anode flow field.

86. A fuel cell unit according to claim 85, wherein said pair of plates are sealed with one another at a peripheral seal.

87. A fuel cell unit according to claim 86, wherein said peripheral seal comprises a crimped seal.

88. A fuel cell unit according to claim 83, wherein said cathode flow field wick includes a second face spaced from said first face and said at least one channel comprises at least one groove formed in said second face.

89. A fuel cell unit according to claim 83, wherein said first anode flow field is located immediately adjacent said membrane electrode assembly.

90. A fuel cell unit according to claim 83, wherein said cathode flow field wick is located immediately adjacent said membrane electrode assembly.

91. A fuel cell unit according to claim 83, wherein said cathode flow field wick comprises a porous pyrolytic graphite layer, said at least one channel formed within said porous pyrolytic graphite layer.

92. A fuel cell unit, comprising:

a first anode flow field structure;

a membrane electrode assembly located adjacent said first flow field structure;

a cathode flow field wick located adjacent said membrane electrode assembly opposite said first anode flow field structure and comprising:

a first face confronting said membrane electrode assembly;

a second face spaced from said first face, said second face containing at least one groove for conducting an oxidant in a direction substantially parallel to said first face during use of the fuel cell unit; and

pores extending from said first face for wicking liquid from said membrane electrode assembly; and

a second anode flow field structure located adjacent said cathode flow field wick opposite said membrane electrode assembly without an intermediate cathode flow field located therebetween.

93. A fuel cell unit according to claim 92, wherein said membrane electrode assembly includes first and second diffusion layers and a proton exchange membrane located therebetween.

94. A fuel cell unit according to claim 92, wherein each of said first and second anode flow field structures comprises a pair of plates defining a corresponding anode flow field.

95. A fuel cell unit according to claim 94, wherein said pair of plates are sealed with one another at a peripheral seal.

96. A fuel cell unit according to claim 95, wherein said peripheral seal comprises a crimped seal.

97. A fuel cell unit according to claim 92, wherein said first anode flow field is located immediately adjacent said membrane electrode assembly.

98. A fuel cell unit according to claim 92, wherein said cathode flow field wick is located immediately adjacent said membrane electrode assembly.

99. A fuel cell unit according to claim 92, wherein said cathode flow field wick comprises a porous pyrolytic graphite layer, said at least one channel formed within said porous pyrolytic graphite layer.

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