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(54) **EVAPORATIVE COOLING OF FUEL CELLS EMPLOYING ANTIFREEZE SOLUTION**

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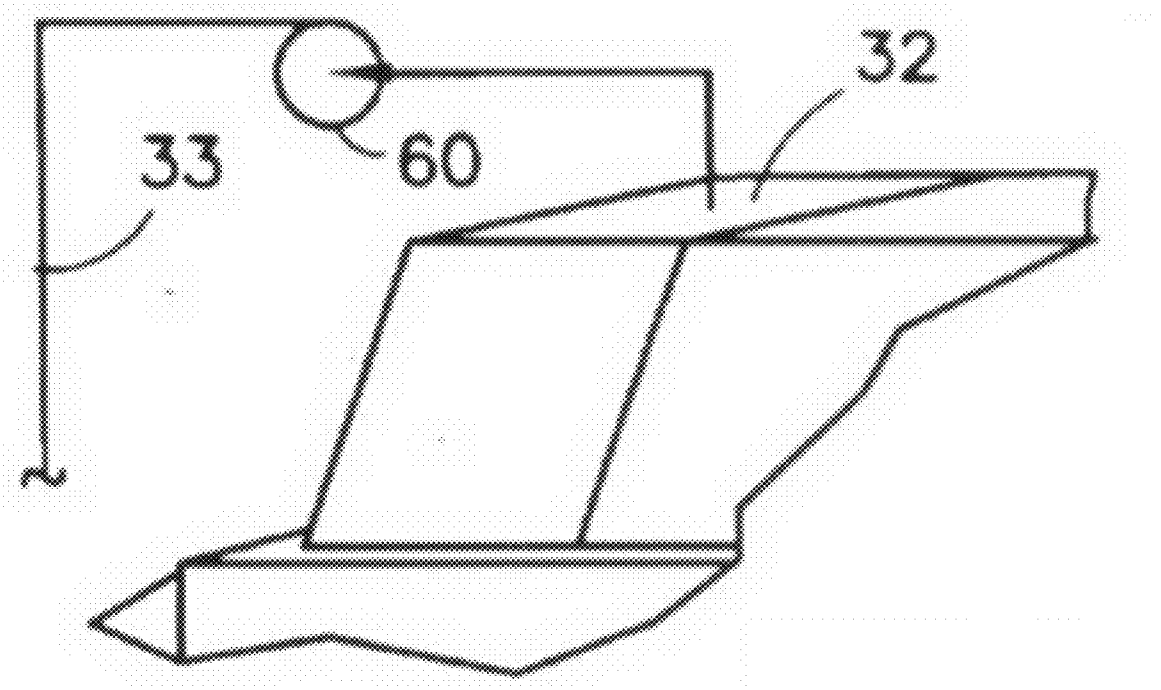
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(57) **ABSTRACT**

A fuel cell power plant (**19**) has a stack of fuel cells (**20**) cooled by a mixture of water with a non-volatile, miscible fluid that sufficiently depresses the freezing point, such as polyethylene glycol (PEG). The water and fluid are mixed in a reservoir (**21**), a small pump (**22**, **60**) flows the mixture through coolant channels (**28**) in or adjacent water transport plates (**29**); heat of the catalytic reaction warms the water transport plates causing water to evaporate therefrom thereby cooling the stack. The PEG is non-volatile at stack operating temperature and does not evaporate; concentrated PEG is returned (**33**) to the reservoir (**21**). Water in the process air flow channels (**41**), including evaporated process water, is recovered in a condensation-rate-controlled (**53**, **54**)) condenser (**46**) in communication (**48**) with the reservoir (**21**) for remixture with the concentrated PEG solution. Hydrophobic gas diffusion layers (**72**) shield the proton exchange membrane (**70**) from the PEG.



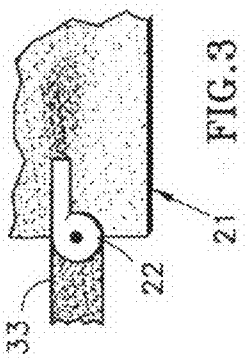

33
22
21

FIG.3

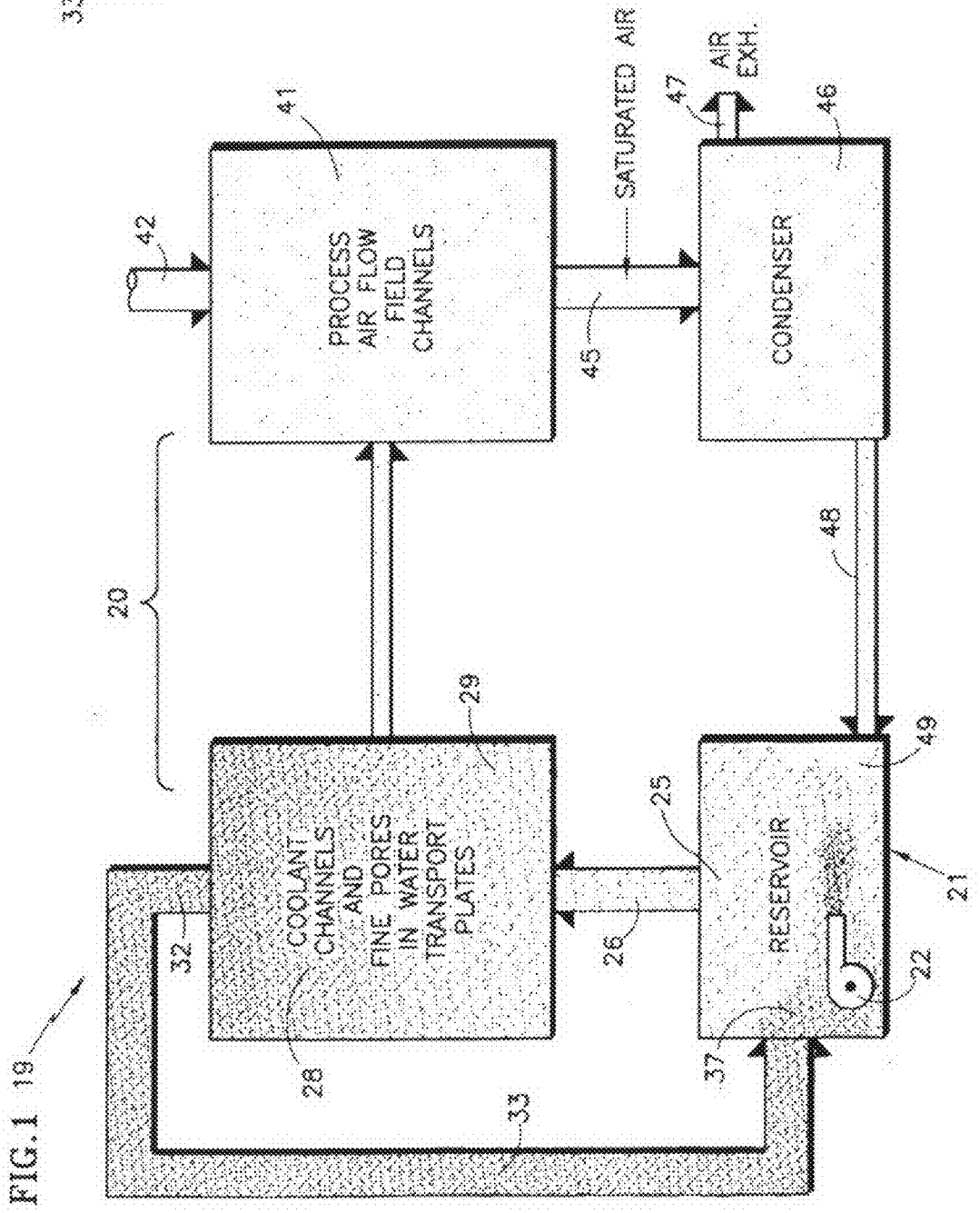

19
20
41
42
PROCESS AIR FLOW FIELD CHANNELS
SATURATED AIR
45
47
AIR EXH.
46
CONDENSER
48
29
COOLANT CHANNELS AND FINE PORES IN WATER TRANSPORT PLATES
32
28
33
25
26
RESERVOIR
49
21
22
37

FIG.1

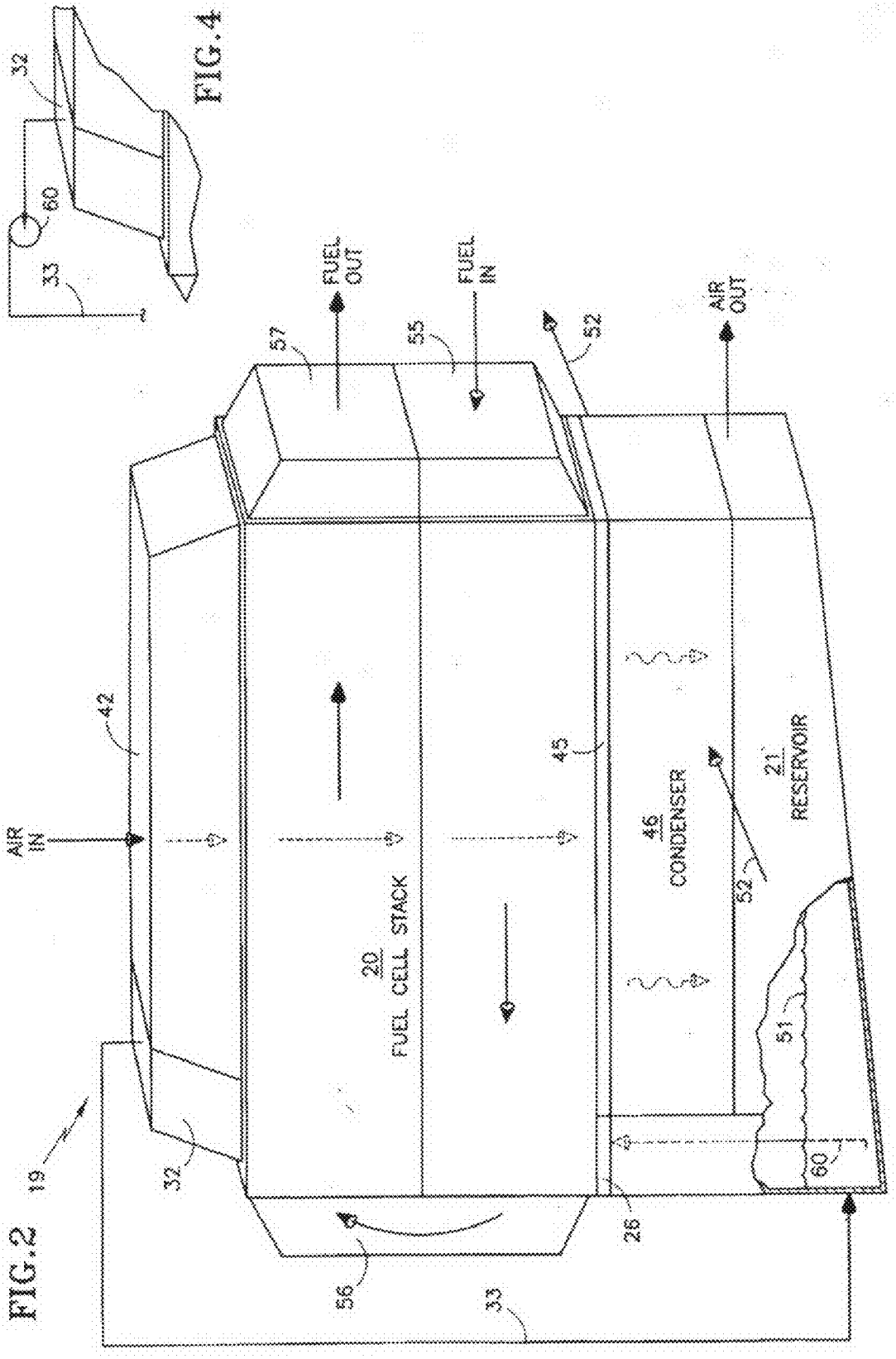
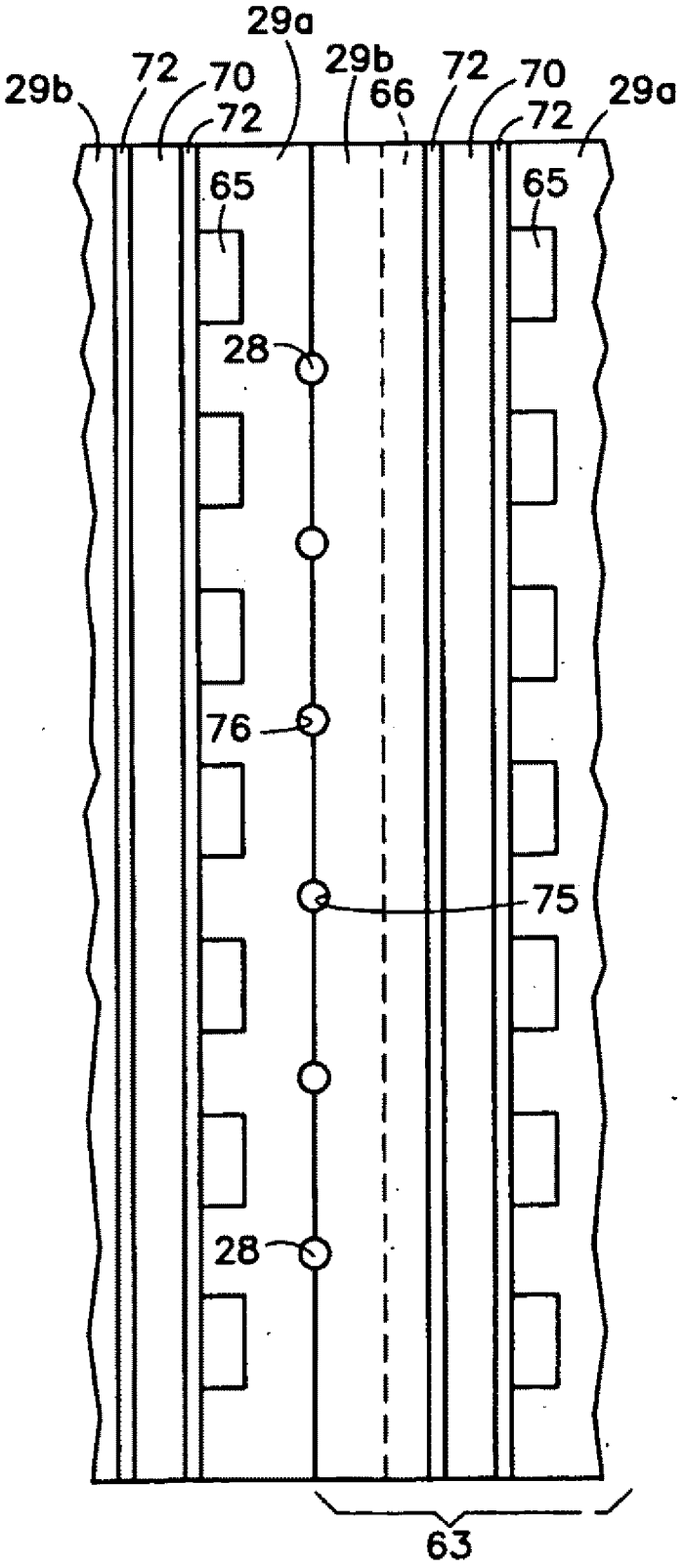

FIG. 4
32
60
33
FIG. 2
FUEL OUT
FUEL IN
AIR OUT
57
55
52
AIR IN
42
45
20
FUEL CELL STACK
46
CONDENSER
21
RESERVOIR
52
51
60
19
32
56
26
33

FIG.5



EVAPORATIVE COOLING OF FUEL CELLS EMPLOYING ANTIFREEZE SOLUTION

TECHNICAL FIELD

[0001] This invention relates to circulating an antifreeze solution from a reservoir through water channels of porous, hydrophilic water transport plates and back to the reservoir; the mixture enters the fine pores of the water transport plates which are warmed by the heat of the fuel cell process, thereby evaporating water which may include product water (but not antifreeze) from the plates into the process oxidant flow channels, cooling the fuel cells. Water is condensed out of the process air oxidant exhaust and returned to re-mix with the concentrated antifreeze.

BACKGROUND ART

[0002] It is known that water produced at the cathodes of fuel cells has to be removed from the cathodes in order to prevent the water from blocking the flow of oxidant gas, such as air, from reaching the electrodes. It is also known that fuel cells, when operating, must be cooled to keep the fuel cells at a proper operating temperature. Some fuel cells are cooled only by conduction of heat into cooler plates which are interspersed between some or all of the fuel cells.

[0003] One known type of fuel cells employ reactant gas flow field plates which are porous and hydrophilic, having fine pores to allow water to pass from the cathode into the oxidant reactant gas flow channels, and to allow water to pass from the fuel reactant gas flow channels toward the membrane. These are typically called water transport plates. Cooling is typically accomplished by sensible heat transfer to water in the water flow channels formed in or adjacent to the water transport plates.

[0004] It has been known to cool fuel cells by evaporation, typically by providing atomized water to the reactant gas streams, which water evaporates, thereby cooling the stack.

[0005] In fuel cells which have employed separate cooler plates, the use of an antifreeze mixture as coolant in place of water is known. The use of separate cooler plates requires a fuel cell stack to occupy a larger volume than it would without cooler plates. Similarly, atomizing water into reactant gas streams for evaporative cooling requires additional equipment, which increases cost and volume and presents difficulty, especially at shut down, for fuel cell power plants operating in freezing environments.

[0006] In any of the cases referred to, even when antifreeze is used in cooler plates, the requirement to eliminate all water from the stack and auxiliary plumbing before freezing, or to otherwise accommodate the likelihood of freezing temperatures during fuel cell power plant shut down poses additional difficulties, requiring apparatus that adds cost and volume, which are most undesirable when a fuel cell is used as a power source for an electric vehicle.

DISCLOSURE OF INVENTION

[0007] Objects of the invention include: reducing the volume of a fuel cell power plant; eliminating or reducing freezable water in a fuel cell power plant system; improving fuel cell power plant for use where freezing temperatures may be encountered when the fuel cell is not operating; avoiding having freezable liquid in contact with moving parts in a fuel cell power plant; shortening fuel cell power plant startup time by reducing cell stack thermal mass; and improved fuel cell power plant.

[0008] According to the invention, fuel cells in a fuel cell power plant are evaporatively cooled by evaporation of at least some of the water in an antifreeze mixture with a freeze depressing substance in the porous, hydrophilic reactant gas flow field plates, which typically have reactant gas flow channels extending from a surface of reactant flow field plates opposite from coolant passageways. The antifreeze coolant mixture circulates through the coolant passageways in or adjacent the reactant gas flow field plates. A more concentrated mixture returns to a coolant reservoir. The evaporation of water from the antifreeze mixture and product water into the reactant streams (primarily the cathode) cools the fuel cell stack. At least some water vapor is condensed out of at least the oxidant reactant gas stream exiting from the stack, the condensed water being returned to the mixture in the accumulator. To avoid diluting the antifreeze mixture, less than all of the water vapor in the air exhaust may be condensed. The rate of condensing may be controlled using a condensate controller to ensure proper water balance, such as a variable flow cooling fan for the condenser, or by cooling the air in the condenser with a controlled circulation of antifreeze.

[0009] A pump is used to pump the antifreeze mixture in a conventional fashion similar to the manner of circulating coolant water in conventional fuel cells. Since only the antifreeze is present in the pump, freezing during shutdown is not a problem.

[0010] Other objects, features and advantages of the present invention will become more apparent in the light of the following detailed description of exemplary embodiments thereof, as illustrated in the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a block illustration of the invention.

[0012] FIG. **2** is a partial perspective view of an embodiment of the invention.

[0013] FIG. **3** is a fragmentary view of a variation of FIG. **1**.

[0014] FIG. **4** is a fragmentary view of an alternative to the embodiment of FIG. **2**.

[0015] FIG. **5** is a sectioned, side elevation view, with sectioning lines omitted for clarity, of portions of fuel cells useful with the invention.

MODE(S) FOR CARRYING OUT THE INVENTION

[0016] Referring to FIG. **1**, a fuel cell power plant **19** has a stack **20** of fuel cells. The concept of the present invention is illustrated by the density of stippling to provide a rough indication of the fraction of fluid in the fuel cell stack coolant that is antifreeze **23**, such as polyethylene glycol (PEG) or other non-volatile, miscible fluid that sufficiently suppresses the freezing point of a mixture with water. In FIG. **1**, PEG and water are mixed in a reservoir **21**, assisted by a pump **22**, so as to achieve the desired freeze point of the mixture. Because the pump is in an antifreeze solution, the pump will not be rendered inoperable due to freezing conditions.

[0017] The desired mixture, such as at the top **25** of the reservoir **21**, is fed through a conventional coolant inlet manifold **26** into coolant channels **28** of the fuel cells (described with respect to FIG. **4**, hereinafter) in the stack **20**, in which the coolant channels are formed within or in fluid communi-

cation with, porous, hydrophilic water transport plates **29**, which have fine pores that contain a water-antifreeze mixture.

[0018] The fuel cell coolant channels **28** are connected to a coolant exit manifold **32** which is interconnected by means of a conduit **33** to the reservoir **21**. At the inlet **37** where the coolant returns to the reservoir, the coolant may be substantially antifreeze **23** (e.g., PEG); that is to say, a very concentrated solution of antifreeze **23**. However, this is remixed in the reservoir **21**, such as by means of the pump **22**, if desired; if the pump **22** is not necessary in any given embodiment of the invention, it may be omitted. Furthermore, other ways of assuring an adequate mixing of the returned antifreeze **23** with the rest of the fluid in the reservoir **21** may be used within the purview of the present invention.

[0019] The water transport plates **29** absorb heat generated in the catalytic reaction of oxygen and hydrogen. Although the antifreeze **23** is non-volatile at the operating temperature of the fuel cell stack, on the order of 60° C.-70° C. (140° F.-158° F.), water evaporates into the oxidant reactant gas stream flow channels **41** that receive oxidant, such as air from an air inlet manifold **42**, cooling the fuel cells by the heat of vaporization. The saturated (or nearly saturated) air exits the fuel cells through an air exit manifold **45** and enters a condenser **46** where at least some water vapor is condensed out of the process air, the dried air flows to exhaust **47**, and the condensate, which is essentially pure water, flows to the reservoir **21** directly or through a conduit **48**. In the area **49** where the condensate enters the reservoir **21**, the mixture is dilute. However, it is remixed with concentrated antifreeze **23** within the reservoir before reentering the fuel cells through the coolant inlet manifold **26**.

[0020] FIG. **2** illustrates a portion of the fuel cell power plant **19** including the fuel cell stack **20**, which employs evaporative cooling. Air is provided to the air inlet manifold **42** and proceeds through the oxidant flow field channels **41** (FIG. **1**) to the air exit manifold **45** and thence into the condenser **46**. The air outflow from the condenser **46** is above the water line **51** of the water reservoir **21**. The cool dried air is expelled to exhaust **47**. The coolant for the condenser **46** may comprise ambient air as illustrated by arrows **52**, the volume of which is controlled by a condenser controller **53** that varies the speed of a flow fan **54** in order to adjust the condensation rate as needed. The condenser **46** may serve as a manifold, and the air exit manifold **45** may then be omitted.

[0021] Fuel provided to a fuel inlet manifold **55** flows to the left, then through a fuel turn manifold **56**, after which fuel flows to the right and out through a fuel exit manifold **57**; the exhausted fuel may be recycled or consumed in a related process.

[0022] Coolant from the reservoir **21** flows through a coolant conduit **60** to the coolant inlet manifold **26**. The coolant passes into the coolant channels (as described with respect to FIG. **1** hereinbefore) to the top of the fuel cell stack **20**, and through the coolant exit manifold **32**. Coolant flowing out of the coolant exit manifold **32** is recirculated over the conduit **33** to the reservoir **21**. The water in the coolant mixture entering through coolant inlet manifold **26** replaces that which is evaporated into the process air channels **41**, as described with respect to FIG. **1** hereinbefore.

[0023] To ensure that adequate water will be present in the fine pores for evaporation, the pump **22** (FIG. **1**) may be disposed at the inlet **37** to draw the coolant into the reservoir **21** from the line **33** as shown in FIG. **3**. Or, a pump **60** (FIG. **4**) may be used in the line **33** or in any other suitable location to ensure adequate coolant circulation. Usually, a pump will be required in order to assure that the flow of antifreeze mixture is sufficient to provide enough water so that evaporation will occur throughout all portions of all of the fuel cells, and to prevent the antifreeze component from partially or completely filling the pores of the water transport plates.

[0024] Because the PEG, or other antifreeze, has a viscosity many times higher than that of pure liquid water, the pressure drop across the coolant channels will be high, or, the coolant channels will have to be larger (deeper) to accommodate the coolant flow rates required to cool the stack. Deeper channels decrease the number of cells per unit of stack length compared to fuel cell stacks employing water transport plates and using evaporative cooling. The channel depth will nonetheless be shallower than in systems employing coolant water or similar systems employing an antifreeze mixture to cool the stack using the fluid sensible heat exchange. Thus, the invention will provide power density which is greater than traditional water or antifreeze cooling systems.

[0025] Detailed descriptions of fuel cells having water transport plates may be found in patent publication US2004/0106034.

[0026] Referring to FIG. **5**, fuel cells **63** which may be used to implement the present invention include anode water transport plates (WTPs) **29***a* having fuel reactant gas flow field channels **65** and cathode water transport plates **29***b* having oxidant reactant gas (air) flow field channels **66**. A membrane electrode assembly (MEA) **70** includes a proton exchange membrane with catalyst on both surfaces. Gas diffusion layers (GDLs) **72** are provided adjacent each surface of the MEAs **70**. In the prior art (such as in the aforementioned patent publication US 2004/0106034) the GDLs are typically constructed from carbon fiber sheet material, and are usually wettable. In some known GDLs, there is an additional wet-proof layer deposited on or joined to the GDL to form a bi-layer. The carbon fiber layer may or may not be wet-proofed whether a bi-layer is used or not used.

[0027] To prevent loss of fuel cell stack performance, the MEAs **70** must be shielded from the non-water component of the antifreeze mixture in the coolant channels **28**. Therefore, the invention preferably employs fuel cells **63** with GDLs **72** which are treated, such as with polytetrafluoroethylene (PTFE) to be wet-proofed, or include an additional wet-proof layer.

[0028] If desired in any utilization of the invention, either the anode WTP **29***a* or the cathode WTP **29***b* may be solid. A solid WTP will block coolant from reaching the MEA on the side it is located. If the cathode WTP **29***b* is solid, water will reach the air (oxidant) flow field channels **66** by migration through the membranes of the MEAs **70** and GDLs **72**. Alternatively, the surfaces of one of the WTPs **29**, adjacent to the GDL **72**, including the reactant gas flow field channels **65**, **66**, may be wet-proofed by treating with a wet-proofing material, such as PTFE, to shield the membrane from the PEG or other antifreeze on that side.

[0029] The coolant channels **28** may be formed by having grooves **75** on the opposite surface of the anode water transport plates **29***a* from the fuel reactant gas flow field channels **65** which match up with grooves **76** on the opposite surface of cathode water transport plates **29***b* from oxidant reactant gas flow field channels **66**. Or, the grooves may be in only one plate **29***a*, **29***b*, the matching surface of the other plate **29***b*, **29***a* being flat.

1. A fuel cell power plant (**19**) comprising:
a stack (**20**) of fuel cells (**63**), each fuel cell including water transport plates (**29**) with coolant channels (**28**) formed therein or adjacent thereto and with fuel reactant gas flow field channels (**65**) and oxidant reactant gas flow field channels (**66**) having inlets and outlets, at least one of said plates being porous and hydrophilic;
a source (**42**) of oxidant reactant gas in fluid communication with inlets of said oxidant reactant gas flow field channels;
a source (**55**) of fuel reactant gas in fluid communication with inlets of said fuel reactant gas flow field channels;
a coolant reservoir (**21**), each of said fuel cell coolant channels being in fluid communication with said coolant reservoir;
a pump (**22**, **60**) for circulating coolant from said reservoir, through said fuel cell coolant channels and back to said reservoir;
characterized by:
said coolant reservoir containing a coolant mixture **23** of water with a miscible, freeze depressing substance; and
a condenser (**46**), connected to the outlet of at least one of said oxidant reactant gas flow field channels of said fuel cells, condensate of said condenser in fluid communication (**48**) with said reservoir, said coolant mixture migrating from said coolant channels into said at least one hydrophilic, porous water transport plate of each fuel cell and at least some water within said coolant mixture along with some process water evaporating into at least said reactant gas flow field channels of said at least one porous and hydrophilic plates of each fuel cell to cool said fuel cells, at least some of the water vapor in at least one of said reactant gas flow field channels being condensed in said condenser and returned to said reservoir where it mixes with coolant in said reservoir.

2. A power plant (**19**) according to claim **1** wherein:
the reactant gas flow field is a fuel channel.

3. A power plant (**19**) according to claim **1** further characterized by:
each fuel cell (**63**) including membrane electrode assembly (MEA) (**70**) having a membrane with catalyst on both surfaces thereof, said MEA configured to provide a wet-proofed barrier between at least one surface of said MEA and said coolant channels.

4. A power plant (**19**) according to claim **3** wherein said wet-proofed barrier comprises:
at least one wet-proofed gas diffusion layer (**72**) adjacent said MEA (**70**) in each of said fuel cells.

5. A power plant (**19**) according to claim **3** wherein said wet-proofed barrier comprises:
at least one bilayer (**70**) adjacent said MEA in each of said fuel cells.

6. A power plant (**19**) according to claim **3** wherein said wet-proofed barrier comprises:
a solid water transport plate (**29**) on at least one side of said MEA (**70**).

7. A power plant (**19**) according to claim **1** further characterized by:
said pump (**22**) being disposed at an inlet of said reservoir (**21**) receiving (**33**) circulating coolant from said coolant channels (**28**).

8. A power plant (**19**) according to claim **1** further characterized by:
said pump (**60**) being disposed in a conduit (**33**) interconnecting said coolant channels (**28**) with an inlet (**37**) of said reservoir (**21**).

9. A power plant (**19**) according to claim **1** further comprising:
a condenser controller (**53**, **54**) for controlling the rate of condensation of water vapor in said condenser (**46**).

10. A power plant (**19**) according to claim **9** wherein:
said condenser (**46**) is cooled by a stream of air (**52**) and said condenser controller is a controller (**53**) that varies the speed of an air fan (**54**).

11. A power plant (**19**) according to claim **9** wherein:
said condenser (**46**) is cooled by a controlled flow of freeze-proof coolant through flow passages in said condenser.

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