(54) Title: PROTON EXCHANGE MEMBRANE FUEL CELL DEVICE WITH WATER TRANSFER SEPARATOR PLATES

(57) Abstract

A proton exchange membrane fuel cell device with an internal water management and transfer system includes a plurality of adjacently arranged proton exchange membrane assemblies including a proton exchange membrane component (21, 21') and a pair or porous anode (23, 23') and a cathode catalyst layers (22, 22') each situated at a different major surface of the proton exchange membrane substantially coextensively with the other, and a porous plate (26) interposed between and in contact with each two adjacent ones of the proton exchange membrane assemblies. Oxidant gas is supplied into oxidant gas supply channels (29, 29') and fuel gas into the fuel gas supply channels (30, 30') of the porous plate for distribution to the anode and cathode catalyst layers, respectively. A water barrier is formed in a water barrier region located within the porous plate. The water barrier region is coextensive with the porous plate and its pores are completely filled with water to keep the oxidant and fuel gases from coming in contact with one another through porous plate.
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Description

Proton Exchange Membrane Fuel Cell Device with Water Transfer Separator Plates

Technical Field

The present invention relates to fuel cells in general, and more particularly to proton exchange membrane fuel cell devices and to water flow management and cooling systems therefor.

Background Art

There are already known various constructions of fuel cells, among them such employing a proton exchange membrane confined between respective porous cathode and anode electrode plates, with respective cathode and anode electrodes being provided at the interfaces between the respective electrode plates and the proton exchange membrane, usually being formed by relatively thin catalyst layers deposited on the respective major surfaces of the proton exchange membrane. The general principles of construction and operation of such fuel cells are so well known that they need not be discussed here in any detail. Suffice it to say that a gaseous fuel and an oxidizing gas are supplied to the anode electrode plate and to the cathode electrode plate, respectively, and distributed as uniformly as possible over the active surfaces of the respective electrode plates (that is, the electrode plate surfaces facing the proton exchange membrane and thus the respective electrodes or catalyst layers), and that an electrochemical reaction takes place at and between such electrodes when the fuel cell device is in operation, with attendant formation of a product of the reaction between the fuel and oxygen (product water when the fuel is hydrogen), release of thermal energy,
creation of an electrical potential difference between
the electrode plates, and travel of electric charge
carriers (hydrogen ions) through the proton exchange
membrane between the electrode plates, with the thus
generated electric power usually constituting the
useful output of the fuel cell.

A fuel cell device of this type usually includes
more than one fuel cell, typically a substantial number
of such cells. The individual fuel cells are arranged,
usually electrically in series, in a stack. The
individual fuel cells are separated from one another by
respective separator plates that are interposed between
the adjacent cells. It is a normal practice to
construct such separator plates as solid, that is,
fluid impermeable, plates to avoid formation of a
potentially explosive mixture as a result of direct
mixing of the fuel gas with the oxidizing gas (oxygen
or air) through the separator plate.

Experience with hydrogen fueled proton exchange
membrane fuel cell devices has shown that, predictably,
product water forms in or at the cathode catalyst
layer. It is also known that, as hydrogen ions travel
through the proton exchange membrane, they entrain
water at the anode side for joint travel therewith to
the cathode side. This brings about two developments
that have to be addressed. For one, unless removed
from the vicinity of the cathode catalyst layer, the
product and entrained water would accumulate in or at
such catalyst layer, thus denying the oxidizing gas
access to the reaction sites thereof. On the other
hand, the removal of the entrained water from the anode
side due to joint travel with the hydrogen ions through
the membrane, would dry out the membrane region facing
the anode side of the fuel cell, unless measures are
taken to replenish such anode side water.
To deal with such problems, it was already proposed to construct one or each of the electrode plates in such a manner as to include a porous backing plate having a relatively substantial thickness and capable of accommodating and conducting fluids in its pores, and a separate relatively thin support plate that is juxtaposed with the associated catalyst layer and that is also porous. The porosity of such backing and support plates is needed to provide not only for supply and substantially uniform distribution of the respective gaseous medium which flows through respective gas channels provided in the backing plate to and over the respective catalyst layer, but also for removal of the reaction product (water) from one of the catalyst layers and/or supply of water to the other of the catalyst layers.

It is also known to make at least the support plate or layer juxtaposed with the cathode catalyst layer at least partially hydrophobic so that the product and entrained water forced through the respective support plate by water pressure buildup at the interface with the membrane beads up at the opposite surface of the support plate, thus avoiding clogging of all pores of the support plate by water.

An example of a fuel cell employing this principle can be found in the U.S. Patent No. 4,729,932 to James F. McElroy which also discloses the expedient of removing the beading up water from the support plate or layer by adsorption into a hydrophilic layer that is spaced from the support layer.

Another area of concern in all types of fuel cells, including those employing proton exchange or solid polymer membranes, is the removal of heat generated during the operation of the fuel cell device from the adjacent fuel cells. To achieve not only the aforementioned product and entrained water removal from
the cathode catalyst layer, but also the supply of replenishment water to the anode catalyst layer and effective cooling of the fuel cell, it was proposed in the U.S. patent No. 4,824,741 to Harold R. Kunz, in addition to using the porous cathode electrode for water removal from the cathode catalyst layer, to supply the needed replenishment water to the anode catalyst layer through the associated electrode plate which includes lands that are in contact with the anode catalyst layer so that the supplied water is able to cross the interface to the catalyst layer on the anode side. This patent also mentions that the evaporation of water from at least one of the electrode plates into the respective gaseous medium in contact therewith provides for sufficient heat removal from the fuel cell.

One disadvantage of the above discussed approaches is that the fuel cell devices invariably employ the aforementioned solid (fluid impermeable) separator plates. The required presence of such solid separator plates not only increases the total number of parts or components in the fuel cell device and thus the cost of manufacture and the space occupied by such a device, but also renders the water flow management system complex and cumbersome.

Accordingly, it is a general object of the present invention to avoid the disadvantages of the prior art.

More particularly, it is an object of the present invention to provide a proton exchange membrane fuel cell device with a water flow management system that does not possess the drawbacks of the known fuel cell devices of this kind.

Still another object of the present invention is to develop the proton exchange membrane fuel cell device of the above kind in such a manner as to be able to dispense with the otherwise existing need for using
solid separator plates between the adjacent fuel cell of the device.

A concomitant object of the present invention is to devise a proton exchange membrane device with a simpler and more efficient cooling system than heretofore used in similar fuel cell devices.

It is yet another object of the present invention to design the cooled fuel cell device of the above type in such a manner as to be relatively simple in construction, inexpensive to manufacture, easy to use, and yet reliable in operation.

Disclosure of the Invention

In keeping with these objects and others which will become apparent hereafter, one feature of the present invention resides in a proton exchange membrane fuel cell device with an internal water management and transfer system that includes a plurality of adjacent proton exchange membrane assemblies. Each of such assemblies includes a proton exchange membrane component having two oppositely facing major surfaces, and a pair or porous anode and a cathode catalyst layers each situated at a different one of the major surfaces of the proton exchange membrane substantially coextensively with the other. A porous plate is interposed between and in contact with each two adjacent ones of the proton exchange membrane assemblies. This porous plate has two major surfaces one of which faces the anode catalyst layer of one of the adjacent proton exchange membrane assemblies and the other of which faces the catalyst layer of the other of the adjacent proton exchange membrane assemblies and including a plurality of oxidant gas supply channels opening onto the one major surface and a plurality of fuel gas supply channel opening onto the other major surface of the porous plate. The device
further includes means for supplying oxidant gas into the oxidant gas supply channels and fuel gas into the fuel gas supply channels for distribution to the anode and cathode catalyst layers, respectively. According to the invention, there is further provided means for forming a water barrier in a water barrier region located within the porous plate between the major surfaces thereof. This water barrier region being coextensive with the major surfaces of the porous plate and its pores being completely filled with water to keep the oxidant and fuel gases from coming in contact with one another through porous plate.

Brief Description of the Drawing

The present invention will be described in more detail below with reference to the accompanying drawing, in which:

Figure 1 is a partially cross sectioned and partially front elevational view of a proton exchange membrane fuel cell device embodying the present invention, taken generally on line 1-1 of Figure 3;

Figure 2 is a somewhat simplified, partially broken away, front generally elevational view of the device of Fig. 1, taken on line 2-2 of Figure 3; and

Figure 3 is a cross sectional view through a fragment of the fuel cell of Figures 1 and 2 but showing only the region of the fuel cell proper at a somewhat enlarged different scale, as indicated by section line 3-3 in Figure 1.

Best Mode for Carrying Out the Invention

Referring now to the drawing in detail, and first to Figure 1 thereof, it may be seen that the reference numeral 10 has been used therein to identify a proton exchange fuel cell device embodying the present invention in an example of embodiment thereof. The
same reference numerals, possibly supplemented with primes where appropriate, are being used throughout the drawings and description to denote corresponding parts.

The fuel cell device 10 as illustrated in the drawing includes a proton exchange fuel cell assembly 11, an oxidizing gas (oxygen or air) inlet manifold 12, an associated spent oxidizing gas outlet manifold 13, a fuel gas (hydrogen) inlet manifold 14, and an associated spent fuel outlet manifold 15. However, under certain circumstances, it may be more advantageous for the positions of the manifolds 14 and 15 to be reversed, that is, for the fuel inlet manifold to be arranged at the bottom, and the fuel outlet manifold 15 on the top, of the fuel cell device 10. In the illustrated construction and orientation, the fuel outlet manifold 15 also serves as a water sump for collecting water that may drip or flow downwardly from the fuel cell assembly 11. The manifolds 12 to 15 open in a sealed manner on respective peripheral portions or surfaces of the fuel cell assembly 11. Figure 1 also shows that a cathode catalyst layer 22 is deposited or otherwise arranged on a major surface of a proton exchange membrane 21. As shown, the catalyst layer terminates short of the periphery of the membrane 21.

Further details of the assembly 11 can be derived from observation of Figure 3 of the drawing which shows portions of two adjacent fuel cells 20 and 20' of the assembly 11. It may be seen there that, in addition to the cathode catalyst layer 22, the membrane 21 of the fuel cell 20 is similarly provided, at its other major surface, with an anode catalyst layer 23. Respective support plates 24 and 25 are arranged next to and are in area contact with the respective associated catalyst layers 22 and 23, respectively. The support plates 24 and 25 are porous to permit flow of the various gaseous media and water through the support plates 24 and 25.
It should be apparent that, in accordance with the present invention, the fuel cell assembly 11 does not include any solid (water and gas impervious) separator plates between the adjacent cells 20 and 20'. Rather, a porous hydrophilic plate 26 is situated at that location. This plate 26, which is shown to be constituted by two separate partial plates 27 and 28 that are substantially identical in composition and structure and are preferably joined by lamination to give the plate 26 a unitary construction, performs several functions. For one, it serves to distribute the respective gaseous medium that is supplied from the respective manifold 12 or 14 (shown only in Figure 1) in a known manner into respective oxidant and fuel gas channels 29 and 29', or 30 and 30', to and over the associated support plates 24 and 24' or 25 and 25' and through the pores of the same ultimately to and over the respective catalyst layers 22 and 22' or 23 and 23'. It is to be noted that, for ease of illustration, the orientations of the hydrogen channels 30 and 30' have been changed in Figure 3 relative to the situation illustrated in Figure 1 by turning them through 90° about a horizontal axis located in the plane of Figure 3 of the drawing.

Moreover, the plate 26 also must prevent the occurrence of direct contact and mixture of the reactant (oxidant and fuel) gases with one another through the plate 26. This gas separation function is achieved by making sure that seepage or flow of such reactants through the plate 26 is blocked by a barrier constituted by water contained in and completely filling the pores of the plate 26 at least at and all over the region of the parting plane between the partial plates 27 and 28. To this end, at least that region of at least one of the partial plates 27 and 28 that is coextensive with the aforementioned parting
plane not only is hydrophilic but also has a fine pore structure such that capillary forces cause water to completely fill such fine pores and thus block passage of gasses through this region.

As shown in Figure 3 and also in Figure 2 of the drawing, water is supplied to this region, in an amount sufficient to keep its pores filled all over the area of the parting plane, through a horizontally extending distribution channel 32 and a multitude of vertically extending secondary channels 31. As indicated in Figure 1, the water to be used for this purpose is withdrawn from the water sump located at the bottom of the fuel exhaust manifold via a conduit 33 having a pump 34 interposed therein. This water that is pumped by the pump 34 is discharged into a conduit 36 which leads to and communicates with a water inlet port 35 indicated in Figure 2 that, in turn, communicates with the distribution channel 32. The distribution channel 32 distributes such water to all of the secondary distribution channels 31. As such water flows down through such channels 31, it penetrates into the fine pores of the aforementioned region and replenishes the water that may have been expelled or may have evaporated therefrom, thus continuously maintaining and restoring the integrity of the water barrier. This replenishment takes place continuously or frequently enough to prevent formation of any gas-conducting paths across such region and thus through the water barrier. Any excess water contained in the plate 26 eventually reaches the bottom of such plate 26, for instance, through the channels 31, and drips into or otherwise joins the water contained in the sump. Of course, provisions may be made to discharge superfluous water from, or to add additional water, to this water circulation circuit, depending on the requirements. For mobile applications using the ambient air as the
oxidizing gas, it is preferred to operate the fuel cell
device 10 in such a manner that the amount of product
water generated in the assembly 11 slightly exceeds
that removed from the fuel cell device 10 with the
discharged oxygen-depleted air, because it is much
easier to discard any excess water present in the water
circulation circuit than it would be to provide for the
presence of a sufficient amount of water aboard for
addition to the water circulation circuit.

It will be appreciated that the constitution of
the unitary plate 26 by the originally separate but
eventually joined parts 27 and 28 facilitates the
fabrication of the water channels 31 and 32 in one or
complementarily in both of the plate parts 27 and 28.

Furthermore, the plate 26 serves other purposes as
well, namely that of removing water from the cathode
support plate, such as 24' (and thus from the cathode
catalyst layer 22') and wetting the region of the
proton exchange membrane, such as 21, that faces the
anode catalyst layer 23. To achieve this, steps are
taken to assure that the pressure of the oxidant gas
slightly exceeds that prevailing at the region of the
water barrier and thus in the water distribution
channels 32 and 31. This is accomplished in any manner
that is so well known that it need not be explained in
detail here. Suffice it to say that it may involve the
use of pressure-controllable pumps or controllable
pressure regulators or valves arranged in the
respective oxidant and water supply and/or discharge
conduits or pipes. When this measure is taken, the
pressure differential existing between the cathode side
of the respective fuel cell and the water barrier
region propels the product and entrained water that has
entered the pores of the plate 26 through the support
plate 24' and that would otherwise tend to remain and
accumulate there, toward the aforementioned parting
plane. On the other hand, the water present at the other side of the parting plane (i.e. either the recirculated water or a mixture thereof with the product and entrained water) is caused to move away from the parting plane and toward and ultimately to the anode region of the membrane 21 by capillary forces encountered in the fine pores of the component 28 or 28', thus preventing such membrane region from drying out. It is currently preferred for the pressure in the water channels 31 and 32 to be somewhat lower than fuel gas pressure to achieve the aforementioned through-plate water transfer at a rate commensurate with the demand for supplying replenishment water to the anode side of the membrane 21 or 21' due to the competition between the capillary forces and the pressure differential. This condition can once more be easily satisfied by again resorting to conventional measures such as those mentioned above.

It is proposed in accordance with another aspect of the present invention to circulate the water through the water distribution channels 32 and 31 at a volumetric rate that is high enough to keep the temperature of the assembly 11 within the desired range. The circulating water is then cooled in a non-illustrated water/ambient air heat exchanger to reduce its temperature before entering the distribution channel 32.

The structure, composition and operation of the various components of the fuel cell assembly 11 are so well known as not to need any elaboration. Suffice it to say that graphite is the material favored for the plates 26 and 26', particularly for its good electrical conductivity, rather high electrochemical stability, light weight, and relatively low cost.

To be effective, it is advantageous for the stack or fuel cell assembly 11 to be operated or used in the
orientation depicted in the drawing, that is, with the cells 20 and 20' arranged in a vertical orientation. However, by taking appropriate well-known measures, it would be possible to use the assembly 11 in other spatial orientations as well. It is also advantageous, albeit possibly not critical, that the fuel gas be externally manifolded and preferably pressurizable.

As shown, the bottom ends of the secondary water distribution channels 31 open into the manifold 15. An alternative to this approach, which is also contemplated herein, is to form another horizontal channel at the bottom of the plate 26 and to collect the water reaching the same at the bottom corner(s). At that point it could exit the assembly 11 stack directly into the manifold 15 or be directed to an external sump.

While the present invention has been illustrated and described as embodied in a particular construction of a proton exchange membrane fuel cell device, it will be appreciated that the present invention is not limited to this particular example; rather, the scope of protection of the present invention is to be determined solely from the attached claims.
Claims

1. A proton exchange membrane fuel cell device with an internal water management and transfer system, comprising

   a plurality of adjacently arranged proton exchange membrane assemblies each including
   a proton exchange membrane component having two oppositely facing major surfaces, and
   a pair or porous anode and a cathode catalyst layers each situated at a different one of said
   major surfaces of said proton exchange membrane substantially coextensively with the other;
   a porous plate interposed between and in contact with each two adjacent ones of said proton exchange
   membrane assemblies, said porous plate having two major surfaces one of which faces said anode catalyst layer
   of one of said adjacent proton exchange membrane assemblies and the other of which faces said catalyst
   layer of the other of said adjacent proton exchange membrane assemblies and including a plurality of
   oxidant gas supply channels opening onto said one major surface and a plurality of fuel gas supply channel
   opening onto said other major surface of said porous plate;

   means for supplying oxidant gas into said oxidant gas supply channels and fuel gas into said fuel gas
   supply channels for distribution to said anode and cathode catalyst layers, respectively; and

   means for forming a water barrier in a water barrier region located within said porous plate between
   said major surfaces thereof, said water barrier region being coextensive with said major surfaces of said
   porous plate and its pores being completely filled with water to keep said oxidant and fuel gases from coming
   in contact with one another through porous plate.
2. The device as defined in claim 1, wherein said forming means includes a plurality of interconnected water distribution channels permeating said water barrier region of said porous plate, means for supplying water into at least one of said water distribution channels, and means for discharging excess water from the remaining ones of said water distribution channels at locations remote from said one water distribution channel.

3. The device as defined in claim 2, wherein said remaining water distribution channels extend through said water barrier region of said porous plate substantially perpendicularly to said one water distribution channel.

4. The device as defined in claim 3, wherein said proton exchange membrane assemblies and said porous plate have substantially vertical spatial orientations; wherein said one water distribution channel extends substantially horizontally through a top portion of said porous plate, and wherein said remaining water distribution channels extend substantially vertically downwardly from said one water distribution channel.

5. The device as defined in claim 4, wherein said discharging means includes respective open lower ends of said remaining water distribution channels.

6. The device as defined in claim 1, wherein each of said proton exchange membrane assemblies further includes a pair of porous support plates each located between and being in contact with one of said anode and cathode layers and the associated one of said major surfaces of the respective adjacent porous plate.
7. The device as defined in claim 1, wherein said forming means further includes means for maintaining the pressure of said fuel gas at a level above that prevailing at said water barrier region of said porous plate to cause water entering said porous plate from said cathode catalyst layer to migrate toward and into said water barrier region.
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<td>PROCEEDINGS OF THE EUROPEAN SPACE POWER CONFERENCE 2-6 OCTOBER 1989 MADRID; SPAIN pages 227 - 231 ANDREI LEONIDA 'HYDROGEN/OXYGEN SPE ELECTROCHEMICAL DEVICES FOR ZERO-G APPLICATIONS' see page 229, left column, last paragraph - right column, line 12; figure 5</td>
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<td>PROCEEDINGS OF THE 26TH INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE VOLUME 3 4-9 AUGUST 1991 MASSACHUSETTS pages 630 - 635 K. STRASSER ET AL 'PEM FUEL CELLS FOR ENERGY STORAGE SYSTEMS' see page 631, right column, paragraph 2; figure 2</td>
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