

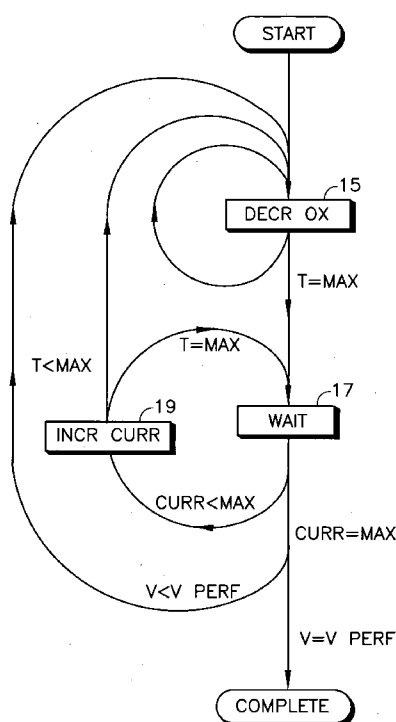


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[Continued on next page]

(54) **Title:** PROCESS FOR STABILIZING NEW FUEL CELL STACK OR RECOVERING FROM LOST FUEL CELL STACK PERFORMANCE

FIG. 1



(57) **Abstract:** A method to increase performance of a fuel cell stack (137), starting at a mediate load (21), adequate fuel (23) and air at nominal utilization for the load (24), including three major steps: (i) decrementing air (15), (ii) waiting and then restoring air to normal for the load (17), and (iii) increasing load (19). Step (i) is first; step (iii) follows step (ii) until max load is reached (47); after either step (i) or step (iii), if stack temperature is below max (29, 53), step (i) is performed, but if temperature equals max (32, 36; 55, 61), step (ii) is performed. The procedure may repeat with max load until suitable voltage is reached (63). An optional step may reduce air to where voltage is barely stable, and then repeat the whole procedure if max load is not reached after air is restored.



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— *of inventorship (Rule 4.17(iv))*

Published:

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— *with amended claims (Art. 19(1))*

Declarations under Rule 4.17:

Process for Stabilizing New Fuel Cell Stack or Recovering From Lost Fuel Cell Stack Performance

Technical Field

[0001] A procedure which can be used to reach peak performance during the initial operation of a newly assembled fuel cell stack, whether or not the stack initially holds adequate current density, or that can be used to rejuvenate a fuel cell stack after performance loss, includes (1) incrementally decreasing O_2 until temperature is max for present load, (2) waiting and adjusting O_2 to normal for present temperature, and then (3) increasing load; after either decreasing O_2 or increasing load, if temperature is less than max, return to (1); if temperature is equal to max, return to (2); until maximum current is reached at voltage of stack's performance curve.

Background Art

[0002] Newly fabricated proton exchange membrane fuel cell stacks have been found to operate at less than maximum performance for the first 50 to 100 hours. To accommodate this, a process, sometimes referred to as "peaking", operates the fuel cell stack for 50 to 100 hours so as to break it in before it is subjected to acceptance testing. During the peaking process, the average cell voltage is monitored while the stack is providing a near-maximum load, which may vary between 800 milliamps per square centimeter (ma/cm²) and 1,500 ma/cm², and the peaking process is deemed complete when the stack's average voltage level is at or near the voltage level expected from the stack's performance curve, such as from around 0.68 volts at low current densities to around 0.50 volts at high current density, and remains substantially stable over some short period of time.

[0003] In addition to the time required for the peaking process (50-100 hours), the process cannot be used on stacks which will not initially hold a current density of a suitable magnitude. Before the peaking process can be performed in such a case, the stack must be "rejuvenated", such as by a hydrogen pumping process, in which the electrochemical process is

reversed by applying a positive voltage to the cathode with its return to the anode, causing hydrogen to migrate to the cathode.

[0004] Hydrogen pumping, as well as numerous other processes, have been utilized and proposed to rejuvenate fuel cell stacks when performance has deteriorated over time, and particularly as a consequence of cold starting. However, hydrogen pumping can take as long as 10 or 12 hours and requires reconfiguring the fuel cell power plant, a process which cannot be done, reasonably, in the field. It is therefore not appropriate for vehicles such as personal passenger cars and light trucks.

Summary

[0005] A procedure which may be used to peak the performance of newly assembled fuel cell stacks, whether or not the stack initially holds adequate current density, and which may be used to rejuvenate fuel cell stacks suffering performance decay after being in use for some time, comprises increasing load to highest load stack will achieve, but not over some mediate load, then three major steps, repetitively, until maximum load is reached, first incrementally decreasing air to reach maximum temperature, second waiting and then adjusting air for normal utilization at present temperature, and third, incrementally increasing load; after each step of decrementing air or incrementing load, if stack temperature is below maximum, air is again decremented to reach maximum temperature, but if stack temperature is maximum, the procedure returns to waiting and then adjusting air for normal utilization at present temperature, repetitively, until maximum load is reached.

[0006] A further step includes repeating the above after maximum load is achieved, starting with decreasing air, until voltage is at least that indicated on performance curve for maximum load.

[0007] An optional additional step includes, once a high target load is reached, reducing the oxidant flow to the lowest point which will sustain stable operation, and operating the stack at that low flow for an initial time period, which may be on the order of a few minutes or some other determinable time period.

[0008] Even a new stack which will initially only support a small fraction of its design maximum current density will be thoroughly broken in and reach its peak performance in less than two hours with the foregoing procedure.

[0009] The foregoing procedure (with or without the optional final step) may also be utilized to rejuvenate fuel cell stacks which have undergone deterioration of performance (that is, reduced voltage as a function of current density). In such a case, the initial current density which may be reached by increasing the load may be fairly high, perhaps close to maximum design current density, but the procedure will begin at a mediate current density, such as around half max. The procedure will rejuvenate the stack in less than two hours.

[0010] Even though performance decay causes a reduction in average cell voltage at any current density, higher current densities may still be attained. A new stack may have adequate current density. The procedure is begun in each of these two situations by purposefully starting with a mediate current density, followed by interspersed steps of decreasing oxidant, waiting and restoring oxidant, and then increasing load, to achieve peak performance.

[0011] The optional step of operating for a small time period (minutes) with the minimum flow of oxidant at which operation is stable, may be used preferentially; however, the optional step may be omitted in given circumstances, if desired, while still taking advantage of the remaining steps of the procedure.

[0012] Other variations will become more apparent in the light of the following detailed description of exemplary embodiments, as illustrated in the accompanying drawings.

Brief Description of the Drawings

[0013] Fig. 1 is a simplified chart of the procedure to initially peak or restore performance of fuel cell stacks.

[0014] Fig. 2 is a simplified functional flow chart of steps which may be performed while testing fuel cell stack parameters, in the performance of the above recited procedure.

[0015] Fig. 3 is a fragmentary view of an optional procedure portion.

[0016] Fig. 4 is a simplified perspective view of an exemplary, evaporatively cooled fuel cell power plant known to the art, which may be subjected to the procedure herein for restoration of performance or initial peaking of performance.

Mode(s) of Implementation

[0017] The present procedure may be practiced, such as with newly assembled fuel cell stacks, on test rigs that can provide controlled amount of reactants, measure average cell voltage and current density, and allow control over the oxidant flow rates and the load on the cell. The procedure may be practiced manually by an operator, or the functions may be computerized by causing the fuel cell stack conditions to be monitored by transducers and fed through a computer, with a program running in such a fashion as to control reactants and load, in response to the current densities, temperature and oxidant flow.

[0018] On the other hand, the procedure may be practiced wholly by the fuel cell controller 139 (Fig. 4), in its working site, such as for rejuvenation of a fuel cell used to power the motor of an electric vehicle.

[0019] As used herein, for simplicity, maximum current density (max) is defined as a high current density which may be at or near the maximum design current density, for the fuel cell stack undergoing steps of the procedure; however, the maximum current density can be some other amount as determined to be desirable in any given implementation of the procedure. Although cell performance is usually related to current density, the terms load and current are also used herein, interchangeably, for simplicity, it being assumed that active area of cells will not change during the procedure.

[0020] Referring to Fig. 1, the procedure comprises successively performing three steps: the first step 15 is reducing the flow of oxidant (typically air) until the temperature of substantially the hottest part of the stack (T_H) reaches the highest permissible temperature for the present current density ($T_{MAX(C.D.)}$). The second step 17 is to wait about five minutes (between about 2 minutes and about 10 minutes, or more), and

then restore air to the normal utilization for the present temperature. The third step 19 is to increase the load on the stack by some predetermined increment, and if the temperature is less than T_{MAX} (C.D.), returning to the first step 15, but when the temperature equals T_{MAX} (C.D.), returning to wait 17. These steps are repeated until maximum load is reached, and may be repeated until stack voltage is at least as high as is indicated on the performance curve of the stack, at max current density.

[0021] Referring to Fig. 2, the procedure starts at a point 20 and the stack is loaded for about half of maximum current density (or any other mediate current density) in a step 21, if that can be achieved. If not, the stack is loaded for as high a current density as it can achieve. Steps 23 and 24 indicate fuel is to be set at a normal utilization for fuel (U_F) and air flow is to be set for nominal air utilization. The first of three principal steps is a step 27 where air is decremented by an increment. A test 29 determines if stack temperature, which should be the hottest part of the stack, T_H , is equal or greater than the maximum temperature for the present load, or current density (T_{MAX} (C.D.)). If the temperature is not equal or greater than max, then it must be less than max, so a negative result of test 29 returns to step 27 to once again decrement air.

[0022] This continues until the maximum temperature is reached or exceeded, which causes an affirmative result of test 29 to reach a test 32 to determine if the temperature is greater than max. If it is greater than max, a step 34 increments air which will reduce the temperature, and a test 36 determines if temperature is equal to or less than max. Having been greater than max in test 32, if it is now equal to or slightly less than max 36, it is deemed to be equal to max. Thus, either a negative result of test 32 or an affirmative result of test 36 will reach the second principal step 17 of the procedure.

[0023] This principal step 17 includes a step 41 which will initiate a timer, which may be anywhere from one or a few minutes to ten or more minutes, but typically may be about five minutes. This can vary in dependence upon the stack with which the present procedure is being utilized. A test 43 determines when the timer has timed out, reaching a step 46 which restores air flow to a nominal utilization.

[0024] Then, unless maximum current density has been reached, a negative result of a test 47 will reach the third principal step 19, to increase the load (current density). Step 48 starts with a pair of steps 49, 50 in which current density (that is, the load) is increased by an increment, and the air is restored to normal utilization of oxygen at the present temperature of the stack, $U_O(T_H)$. After current density is increased, if the temperature is less than the maximum temperature for the present current density, a negative result of a test 53 returns the procedure to the first principal step 27 where air is once again decremented. On the other hand, if the temperature is equal to or greater than max, a test 55 determines if it is greater than max. If so, current density is decreased in a step 57 and the air is adjusted for normal utilization at the present temperature of the stack in a step 58. A test 61 causes the program to revert through the steps 57, 58 until the stack temperature is less than or equal to the maximum temperature for the present current density. Thus, either a negative result of test 55 or an affirmative result of test 61, indicating that the present temperature is equal to the maximum temperature, will cause the program to revert to the second principal step 17, at the step 41.

[0025] Thus following either the first principal step 15 or the second principal step 17, if the temperature is less than max, the procedure reverts to the first principal step 15. But if the temperature is equal to max, then the procedure reverts to the second principal step 17.

[0026] This routing through the principal steps will continue until the test 47 is affirmative, indicating that maximum current density has been reached. Then, a test 63 determines if the average voltage of the stack is the voltage indicated on the performance curve (V_{PERF}). If the voltage is less than it should be, a negative result of test 63 causes the routine to begin all over again at the first principal step 15. The procedure will continue through the first principal step, the second principal step and the third principal step, returning to the first principal step 15 whenever a temperature is less than maximum temperature, and returning to the second principal step 17 whenever the temperature is equal to maximum.

[0027] When the test 63 indicates that the average voltage is adequate, the procedure is complete, at a point 65.

[0028] An optional final step may be performed as indicated generally in Fig. 3. Therein, once an affirmative result of test 63 indicates that the average voltage has reached or exceeded the voltage indicated on the performance curve for the stack, a step 66 may decrease the air by an increment and a test 67 determine if the stack voltage is stable after the air is decreased. This is easily observed by the operator (steady voltage); if automated, the controller will record the voltage, and then compare present voltage, from time to time to see if voltage stays within a short range.

[0029] If voltage is still stable, an affirmative result of test 67 reverts to step 66 to cause the air to be decreased by another increment. Eventually, the stack voltage will become unstable and a negative result of test 67 will reach a step 70 to increase the air by an increment. A test 72 determines if the stack voltage is stable. If it is not, then air is again increased by an increment. After air is increased by one or several increments, the stack voltage will again be stable so an affirmative result of test 72 can reach a step 75 to initiate a timer (not the same as the timer in Fig. 2) and a test 77 determines if the timer has timed out. Until it has, a negative result of test 77 causes the procedure to loop around the test 77.

[0030] When the timer times out, air is restored to the correct utilization in a step 79. A test determines if current density has reached max. If not, the whole procedure is repeated by reverting to step 27 in Fig. 2. When, eventually, the current density is again restored to max, a negative result of test 81 causes the optional part of the procedure to be complete at a point 79.

[0031] The optional part of the procedure shown in Fig. 3 may, of course, be performed by hand by the operator decreasing air as the voltage of the stack is monitored. When the stack voltage begins to decline, the operator can increase the air slightly so as to restore a stable voltage. Then the operator can note the time and wait the required time, which may be on the order of between 5 and 20 minutes. Once the test 77 indicates that the time period is complete, a step 79 restores air to the normal utilization for maximum current density, and a test 81 determines if current density equals or exceeds maximum. If not, the entire procedure

can be repeated including the portions on Fig. 2 and on Fig. 3. When test 81 indicates a current density is equal or greater than max, the optional procedure is complete at point 83. This optional part is used to test the stack's ability to withstand less than a stoichiometric amount of air and restore performance when adequate air is provided thereafter.

[0032] An exemplary fuel cell power plant 136 having a stack 137 for which the present procedure may provide a benefit, either for peaking performance when new or restoring performance after hours of use, is illustrated in Fig. 4. Referring to Fig. 4, an evaporatively cooled fuel cell power plant 136, as more fully described in patent publication US 2006/0141330 A1, includes a stack 137 of fuel cells 138 which are shown disposed vertically, although they may be disposed horizontally.

[0033] In this example, in response to a controller, fuel from a source 141 is provided to a fuel inlet 142 and flows to the right in a first fuel pass, as indicated by the bold arrow 143, to a fuel turn manifold 144. The fuel gas then flows downwardly and into a second fuel pass of the fuel flow fields, wherein the fuel gas flows to the left as indicated by the bold arrow 145. From a fuel outlet 147, the fuel may flow through a recycle pump 148 (perhaps with valves not shown), which may alternatively be an ejector, back to the fuel inlet 142, and may be periodically purged to ambient through a valve 149, all as is known in the art. Single pass, triple pass or other fuel flow configurations may be used.

[0034] In the example of Fig. 4, air is provided by a pump 152 to an air inlet 153, and the air flows upwardly through the oxidant reactant gas flow channels of the fuel cells 138, as indicated by the hollow arrow 154. From an air outlet 157, the air flows over a conduit 158 to a condenser 159, which in a vehicle may be a conventional radiator. The exit air is passed through an exhaust 162. The condensate from the condenser 159 may be accumulated in a reservoir 164, which is connected by a water return conduit 165 to a water inlet 166.

[0035] The water then flows through minute passageways 167 into each of the fuel cells 138; the passageways 167 may terminate in a vent manifold 168, from which removal of gas from the passageways is provided through a vent, such as a porous plug vent 169. Although there

is a water inlet 166, there is no water outlet, the water is simply present in each fuel cell.

[0036] The procedure may also be used with total water management (TWM) fuel cell stacks, which rely on sensible heat cooling, with full flow of water through coolant channels and an external, temperature-regulating heat exchanger. However, the results may be less noteworthy due to lower operating temperatures (60°C-65°C; 140°F-149°F) of TWM stacks compared with evaporatively cooled or low flow stacks (75°C-85°C; 167°F-185°F).

Claims

1. A method comprising:
establishing operation of a fuel cell stack at a mediate load with
adequate fuel utilization and normal oxygen utilization for said load,
characterized by:
5 said method including three major steps of (i) incrementally decreasing
oxygen provided to said stack, (ii) incrementally increasing load on said
stack to a higher load, and (iii) waiting for a short period of time and
thereafter restoring oxygen to normal utilization for the present stack
temperature; and
10 step (i) is performed first;
after each occurrence of either of said steps (i) or (iii), if stack
temperature is less than maximum temperature for the present load,
performing step (i), and if stack temperature is equal to maximum
temperature for the present load, performing step (ii);
15 step (iii) is performed after step (ii) until the load on the stack is a
maximum load for the stack.
2. Rejuvenating a fuel cell stack so as to restore a previous
performance capability using a process including the method of claim 1.
3. Peaking the performance of a newly manufactured fuel cell
stack using a process including the method of claim 1.
4. A fuel cell stack manufactured by a process including the
method of claim 1.
5. A fuel cell power plant including a fuel cell stack according to
claim 4.
6. A method according to claim 1 further comprising:

after the stack load is maximum, performing the three major steps in the aforementioned manner until the stack voltage satisfies a performance curve for said stack, starting with step (i).

7. Rejuvenating a fuel cell stack so as to restore a previous performance capability using a process including the method of claim 6.

8. Peaking the performance of a newly manufactured fuel cell stack using a process including the method of claim 6.

9. A fuel cell stack manufactured by a process including the method of claim 6.

10. A fuel cell power plant including a fuel cell stack according to claim 9.

11. A method according to claim 6 further characterized by:
operating said stack at said maximum load and at the lowest oxidant flow at which voltage of said stack is stable, for a period of time of about one minute or more.

12. Rejuvenating a fuel cell stack so as to restore a previous performance capability using a process including the method of claim 11.

13. Peaking the performance of a newly manufactured fuel cell stack using a process including the method of claim 11.

14. A fuel cell stack manufactured by a process including the method of claim 11.

15. A fuel cell power plant including a fuel cell stack according to claim 14.

AMENDED CLAIMS**[received by the International Bureau on 17 March 2009 (17.03.2009)]**

1. A method comprising:

establishing operation of a fuel cell stack (137) at a mediate load (21) with adequate fuel utilization (23) and normal oxygen utilization (24) for said load, characterized by:

5 said method including three major steps of, first (15), repetitively, incrementally decreasing oxygen provided to said stack, second (17) waiting for a short period of time and thereafter restoring oxygen to normal utilization for the present stack temperature and, third (19), incrementally increasing load on said stack to a higher load; and

10 said first step is performed first;

after each occurrence of either of said first step or said third step, if stack temperature is less than maximum temperature for the present load, performing said first step, and if stack temperature is equal to maximum temperature for the present load, performing said second step;

15 said second step is performed after said third step until the load on the stack is a maximum load for the stack.

2. Rejuvenating a fuel cell stack (137) so as to restore a previous performance capability using a process including the method of claim 1.

3. Peaking the performance of a newly manufactured fuel cell stack (137) using a process including the method of claim 1.

4. A fuel cell stack (137) manufactured by a process including the method of claim 1.

5. A fuel cell power plant (136) including a fuel cell stack (137) according to claim 4.

6. A method according to claim 1 further comprising:

after the stack (137) load is maximum, performing the three major steps (15, 17, 19) in the aforementioned manner until the stack voltage satisfies a performance curve for said stack, starting with said first step.

7. Rejuvenating a fuel cell stack (137) so as to restore a previous performance capability using a process including the method of claim 6.

8. Peaking the performance of a newly manufactured fuel cell stack (137) using a process including the method of claim 6.

9. A fuel cell stack (137) manufactured by a process including the method of claim 6.

10. A fuel cell power plant (136) including a fuel cell stack (137) according to claim 9.

11. A method according to claim 6 further characterized by:
after the stack (137) voltage satisfies said performance curve for said stack, operating said stack at said maximum load (63) and at the lowest oxidant flow (66) at which voltage of said stack is stable (67), for a period
5 of time of about one minute or more (75, 77).

12. Rejuvenating a fuel cell stack so as to restore a previous performance capability using a process including the method of claim 11.

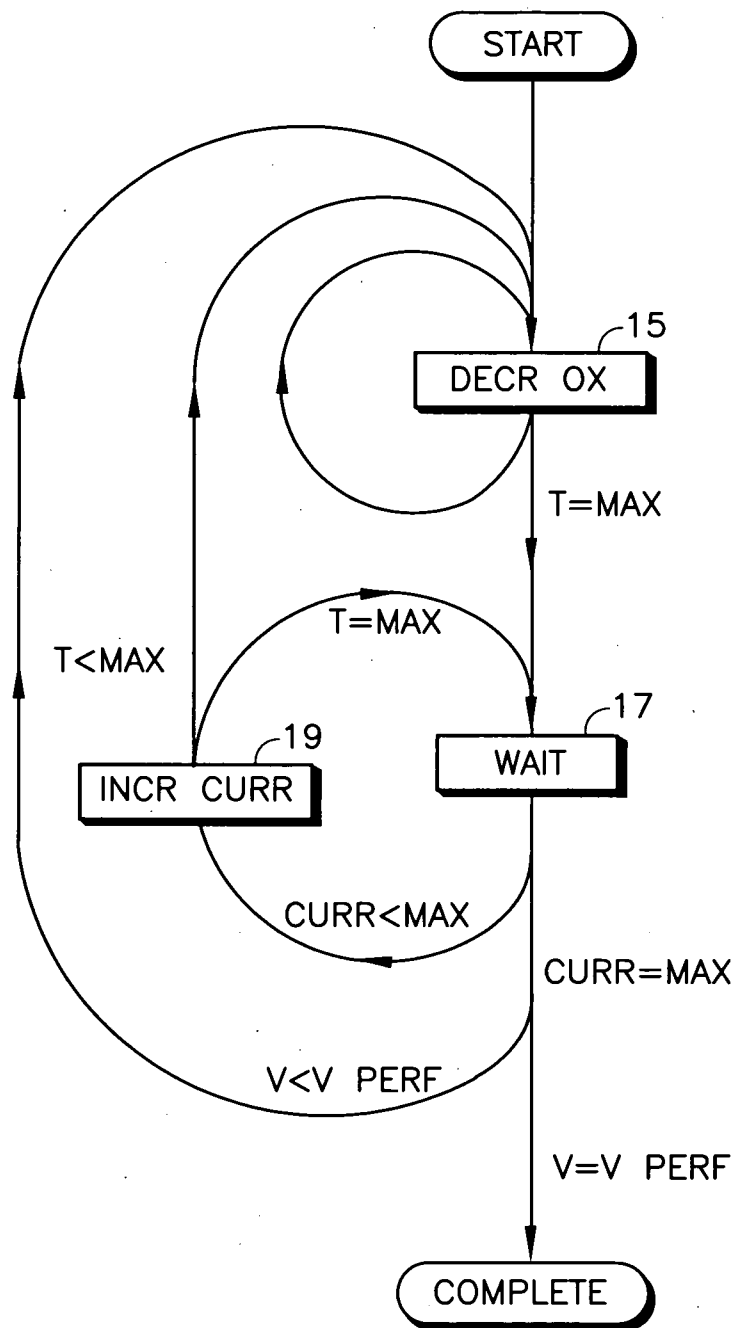
13. Peaking the performance of a newly manufactured fuel cell stack using a process including the method of claim 11.

14. A fuel cell stack manufactured by a process including the method of claim 11.

15. A fuel cell power plant including a fuel cell stack according to claim 14.

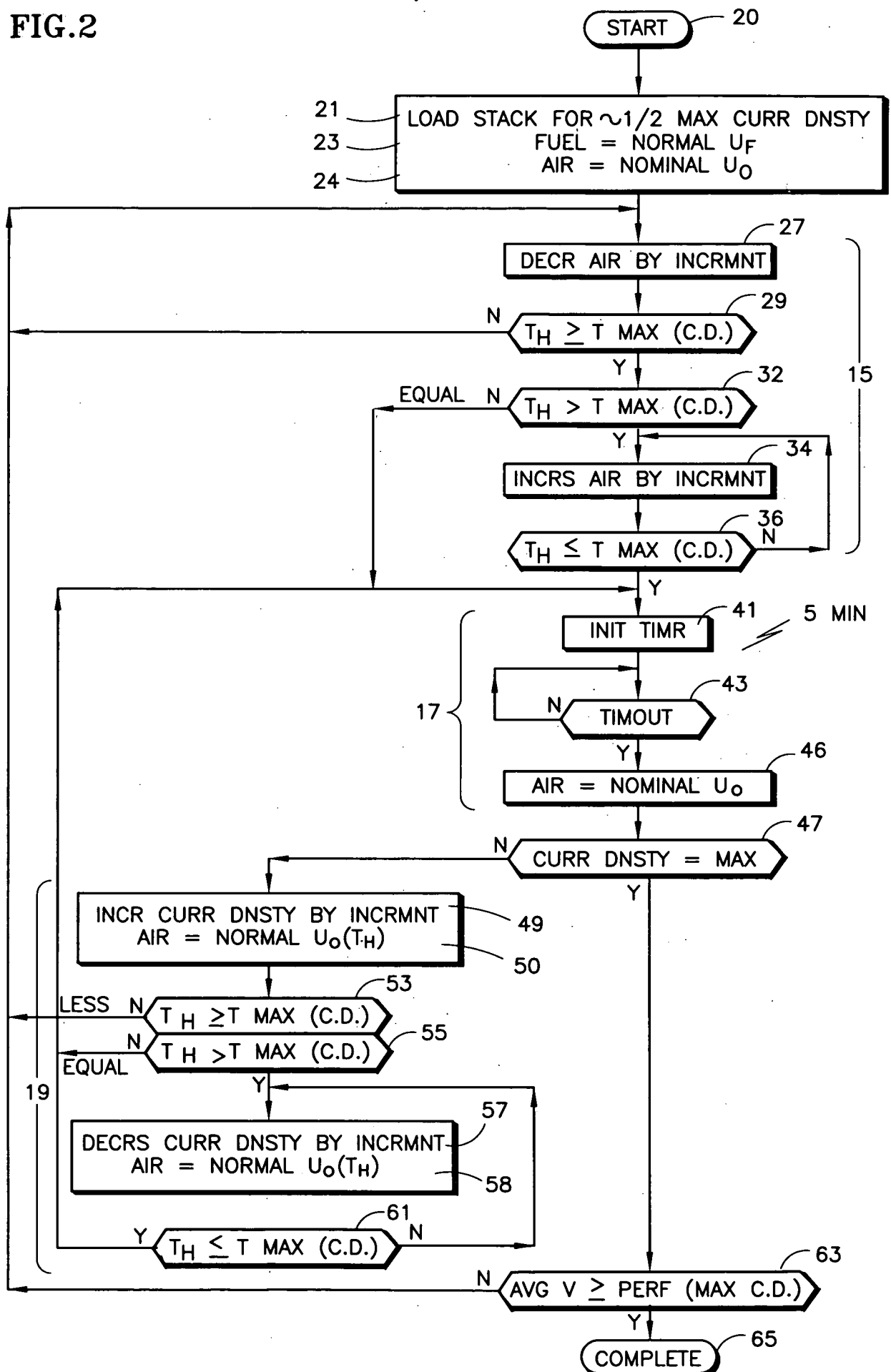
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FIG. 1



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FIG. 2



3/4

FIG.3

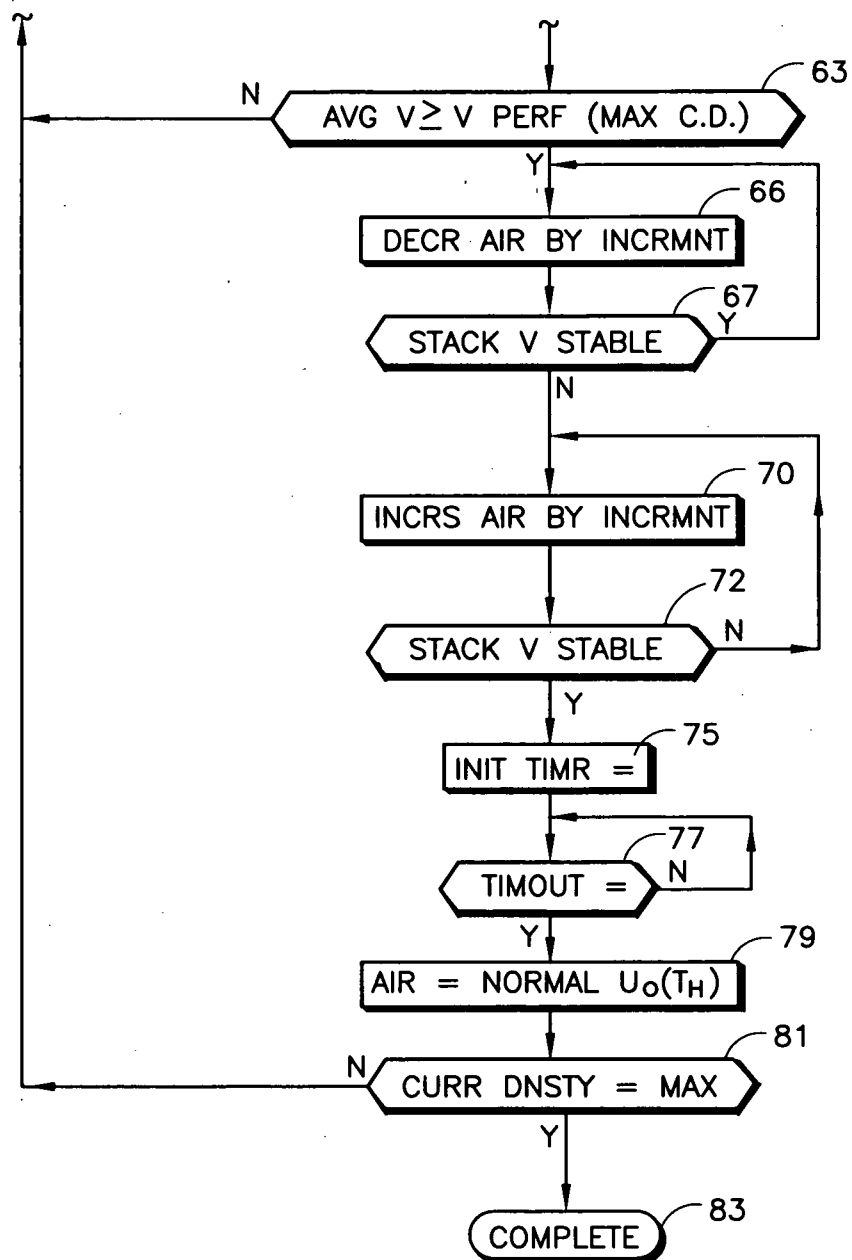
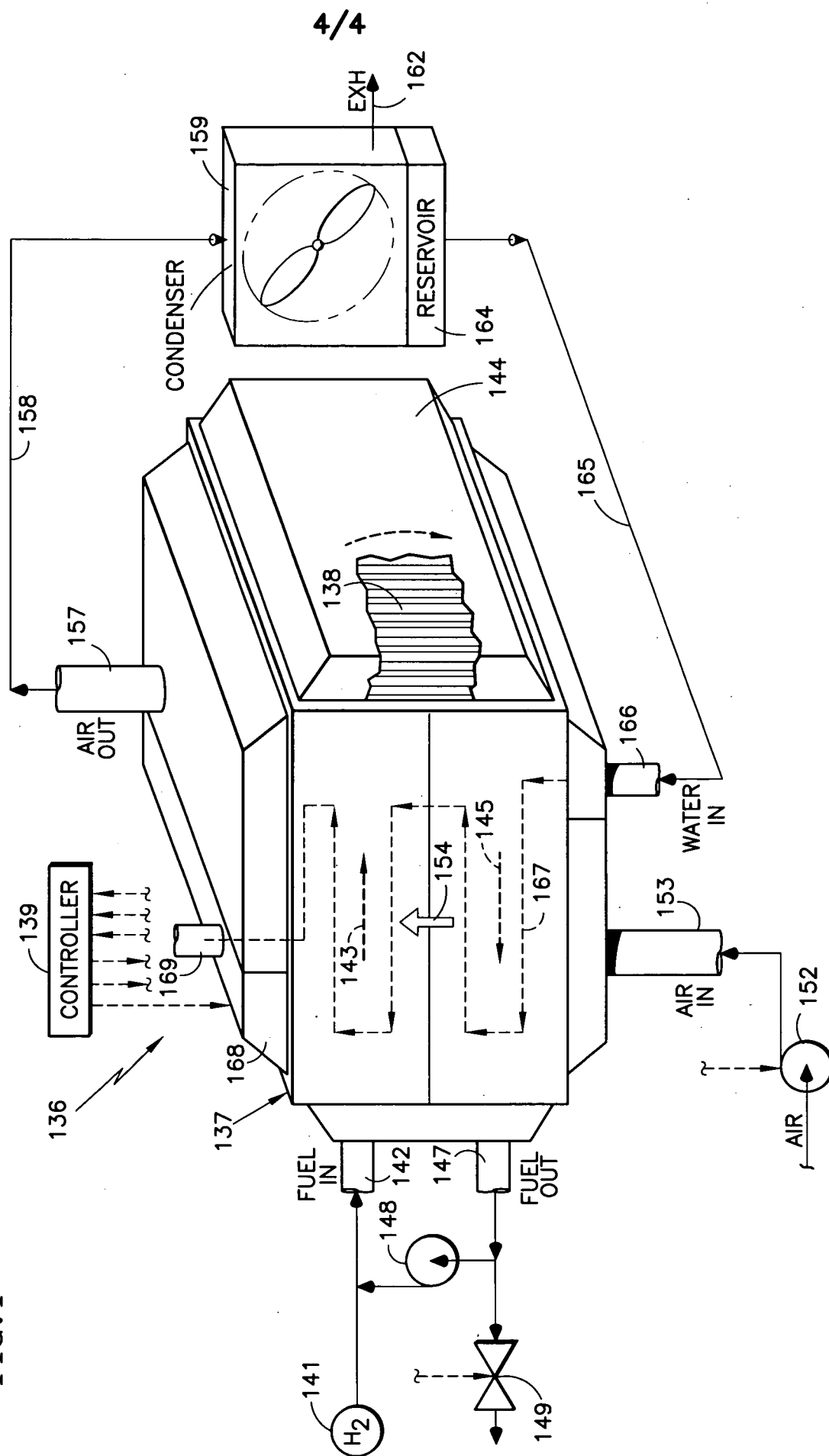


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2008/009651

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01M4/88 H01M8/04

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004/234845 A1 (ROBERTS JOY [CA] ET AL) 25 November 2004 (2004-11-25) paragraphs [0002], [0011], [0015], [0044], [0046], [0047] paragraph [0023]; figures 3A,3B paragraphs [0024], [0052]; figures 4B,4C	1-15
A	XU ET AL: "Combined activation methods for proton-exchange membrane fuel cells" JOURNAL OF POWER SOURCES, ELSEVIER, AMSTERDAM, NL, vol. 156, no. 2, 1 June 2006 (2006-06-01), pages 315-320, XP005459217 ISSN: 0378-7753 page 317, right-hand column, line 24 - line 31 ----- -/-	1-15

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

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- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *&* document member of the same patent family

Date of the actual completion of the international search

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Date of mailing of the international search report

02/02/2009

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2008/009651

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 805 983 B1 (QI ZHIGANG [US] ET AL) 19 October 2004 (2004-10-19) column 4, line 49 - column 5, line 6 -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2008/009651

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004234845	A1	25-11-2004	NONE
US 6805983	B1	19-10-2004	NONE