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Design of External Electric Field Membrane less hydrogen Fuel cell

Merghani T. Mohamed [1 *], Othman O. Khalifa [2], Aisha Hassan A. Hashim [3]
[1,3] Electrical and Computer Engineering, International Islamic University Malaysia
[2] Libyan Center for Engineering Research and Information Technology, Bani Walid, Libya

تصميم خلية وقود هيدروجينية بدون غشاء باستخدام مجال كهربائي خارجي

مرغني تاج السـر محمد [*1]، عثمان عمـران خليفة [2]، عائشة حسن عبد الله هاشم [3]
[3 ,1] قسم الهندسة الكهربائية والحاسوب، الجامعة الإسلامية العالمية، ماليزيا
[2] المركز الليبي للبحوث الهندسية وتقنية المعلومات، بني وليد، ليبيا

[*]Corresponding author: merghanijoudabi@gmail.com

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Abstract:
Sustainable and renewable energy sources are essential to reaching carbon neutrality on a global scale soon. In addition to their potential for producing green energy, hydrogen fuel cells have drawn a lot of interest for their ability to lower CO2 and SO2 emissions, which makes them perfect for usage in homes where people value cleanliness above all else. Hydrogen fuel cells have been around for more than a century, but their general implementation is limited by several technical issues and high costs, especially when it comes to membranes and electrodes. Traditional designs, such as PEM hydrogen fuel cells, microfluidic membrane-less fuel cells, and solid oxide fuel cells, have attempted to overcome these concerns by chemical, mechanical, and material advancements. This paper presents a novel approach that uses an external electric field to improve the efficiency and functionality of hydrogen fuel cells, resulting in the invention of the External Electric Field Membrane-less Hydrogen Fuel Cell (EEFMLHFC). The proposed idea uses the notion of oriented external electrical field electrochemical catalysis to accelerate and steer the ionic reactants—hydrogen and oxygen—towards one other, resulting in a smoother and more efficient reaction. This design eliminates the requirement for a typical membrane while also addressing common difficulties including water flooding, membrane breakdown, and material expansion caused by different heat coefficients. The EEFMLHFC achieves excellent reactant adsorption and cell power production by using porous platinum electrodes that are augmented by an external electric field and a water-cooling system. The design also allows for operation under high pressure, which boosts reactant adsorption and cell current density.

Keywords: Renewable energies, sustainable energy, hydrogen fuel cells, membrane less fuel cells, external electric field.

الملخص
تُعد مصادر الطاقة المستدامة والمتجددة ضرورية للوصول إلى الحياد الكربوني على نطاق عالمي في المستقبل القريب. بالإضافة إلى إمكانياتها في إنتاج الطاقة الخضراء، حظيت خلايا وقود الهيدروجين باهتمام كبير لقدرتها على تقليل انبعاثات ثاني أكسيد الكربون (CO_2) وثاني أكسيد الكبريت(SO_2) ، مما يجعلها مثالية للاستخدام في توفير الطاقة النظيفة. ورغم أن خلايا وقود الهيدروجين موجودة منذ أكثر من قرن، إلا أن تطبيقها العام محدود بسبب عدة مشكلات تقنية وتكاليف مرتفعة، خاصة عندما يتعلق الأمر بالأغشية والأقطاب الكهربائية. حاول الباحثون استخدام التصاميم التقليدية، مثل خلايا الوقود

الهيدروجيني ذات الغشاءPEM ، وخلايا الوقود الدقيقة عديمة الغشاء، وخلايا الوقود بأكسيد صلب، التغلب على هذه التحديات من خلال التطويرات الكيميائية والميكانيكية، ولكن دون الوصول الي نتائج مرضية. في هذا البحث نقدم نهجًا جديدًا يستخدم مجالًا كهربائيًا خارجيًا لتحسين كفاءة ووظائف خلايا وقود الهيدروجين، مما سيؤدى إلى ابتكار خلية وقود هيدروجينية عديمة الغشاء باستخدام مجال كهربائي خارجي (EEFMLHFC) .تعتمد الفكرة المقترحة على مبدأ التحفيز الكهربائي الكهروكيميائية باستخدام مجال كهربائي خارجي موجه لتسريع وتوجيه المتفاعلات الأيونية (الهيدروجين والأكسجين) نحو بعضها البعض، مما يؤدي إلى تفاعل أكثر سلاسة وكفاءة. يلغي هذا التصميم الحاجة إلى غشاء تقليدي ويعالج مشكلات شائعة مثل غمر الخلية بالماء، وانهيار الغشاء، وتمدد المواد الناجم عن تباين معاملات الحرارة. تحقق خلية الوقود EEFMLHFC امتزازًا ممتازًا للمتفاعلات وإنتاجًا عاليًا للطاقة باستخدام أقطاب من البلاتين المسامي مدعمة بمجال كهربائي خارجي ونظام تبريد مائي. كما يسمح التصميم بالعمل تحت ضغط عالٍ، مما يعزز امتزاز المتفاعلات وكثافة التيار في الخلية.

الكلمات المفتاحية: الطاقات المتجددة، الطاقة المستدامة، خلايا وقود الهيدروجين، خلايا الوقود عديمة الغشاء، المجال الكهربائي الخارجي.

Introduction

Renewable sustainable clear energy generation, storage and conversation is most available techniques to fulfil globalized zero co2 emission in recent future. The Hydrogen fuel cell given considerable attention to lead green hydrogen energy utilization and keeps healthy environment, as it has indispensable contribution in co2 and so2 emission reduction, it most likely to be used in residential area where clean environment is highly acquired. Since its discovery more than hundreds of years ago still it associated with some technical problems besides the high cost of its parts like membrane and electrodes. All these said problems besides other factors seize it uses in wide utilization to cover all aspect of life starting from national grid tie in during peak time, emergency backup to vehicle drive. Although its reaction is very simple, hydrogen reacts with oxygen generates electricity, heat and produce water, different types of Hydrogen fuel cell design were founded, the technical problems are still existing, some of these designs are PEM Hydrogen Fuel cell, microfluidic membrane less fuel cell [5] and solid oxide fuel cell [6]. All the invented solutions had played around chemical, mechanical or material design solutions. This paper introduces another alternative solution based on electrical concept by applying external electrical field to the reactant's hydrogen and oxygen by which the name External Electric Field Membrane less hydrogen Fuel cell is formed (EEFMLHFC).

Literature Review

The hydrogen fuel cell initially named hydrogen battery discovered by "Grove's 1839 described placing glass tubes partially filled, one with hydrogen, one with oxygen, in a tank of acid, with two platinum foil electrodes sitting in each tube [3]. When a voltage was applied, hydrogen and oxygen streamed off the electrodes. But if the platinum foil was pushed up out of the liquid to contact the gas, a voltage appeared. The idea that a gas could replace a metal to generate electricity was mind-bending." [3]. This idea developed from static process to dynamic process where continuous flow of reactants with synchronized continuous product extraction to maintain a sustainable power generation. As it as a process, it is necessary to add much equipment to support its work, like air compressors, water extraction pump and cooling system since there is heat generated. It sounds simple, in literature surveying, shows many problems associated with current designs like water flooding, membrane deterioration, materials of different heat expansion coefficients, or lower power generation like microfluidic cell [4]. The EEFMLHFC design is based on the idea of Orient External Electrical filed electrochemical catalysis [6]. This technique is used to accelerate and guide the ionic reactants towards each other to react smoothly in an efficient way, the electric field affects the reactions ions. Water is a dipolar compound affected by electric field; hydrogen ions react with water to form hydronium cations [7]. Oxygen ions react with water to form hydroxide ions [8].

$$H2O + H+ = H3O+$$

$$H2O + O-2 = 2OH-$$

Theoretical Framework

A normal battery "is a device that stores chemical energy and converts it to electrical energy. The chemical reactions in a battery involve the flow of electrons from one material (electrode) to another, through an external circuit. The flow of electrons provides an electric current that can be used to do work. To balance the flow of electrons, charged ions also flow through an electrolyte solution that is in contact with both electrodes. Different

electrodes and electrolytes produce different chemical reactions that affect how the battery works, how much energy it can store and its voltage" [5].

In the normal battery cell anode and cathode are consumed by redox reaction. Likewise, a hydrogen fuel cell uses gaseous electrodes placed on the surface of the heterogeneous catalyst with electrolyte between them. The difference between cell battery and hydrogen fuel cell is in the former it consumes solid electrodes while in the latter it consumes gases. The reaction is like that of any cell reaction, oxidation and reduction reaction. It is easy to substitute gas consumption rather than solid electrodes. The PEM Hydrogen Fuel cell in figure 1 is a brief description to show how cell works [3], the Proton Exchange Membrane sandwiched between electrodes. The hydrogen enters through the gas diffusion layer, passing catalyst electrode(anode) layer where it oxidizes releasing its electron that passes through external circuit, the hydrogen ions travel to the cathode through PEM. The oxygen enters the gas diffusion layer to the cathode where it reduces by the catalyst (cathode), accepts two electrons becomes negative ion then it combines with two hydrogen ions forming water. If the circuit is closed the electrons go to the cathodes to substitute for the electrons taken by oxygen. The cell continues to generate electric current if the reactants flow in the cell and the circuit is closed.

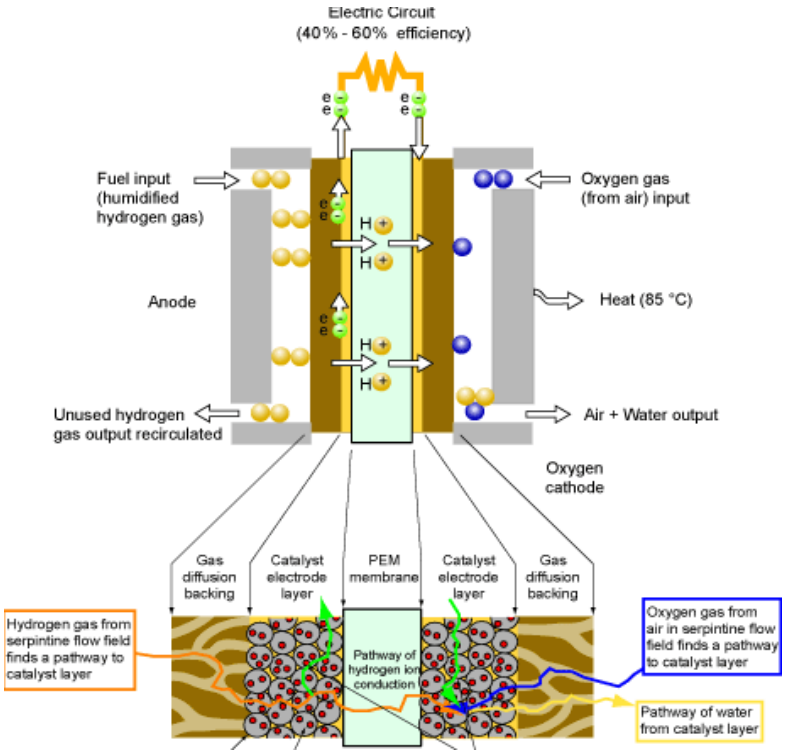


Figure 1: Many cells are attached together to form cell stack to increase cell potential.

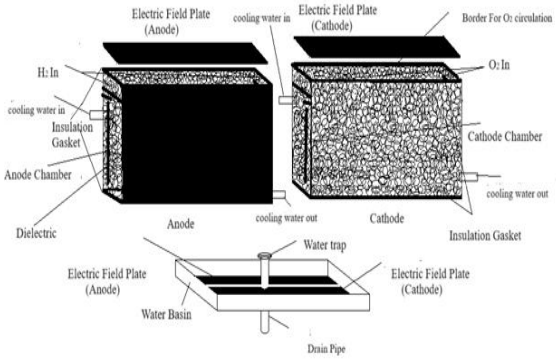
Design and Methodology

The EEFMLHFC design is shown in figure 1, it consists of two porous platinum electrodes(anode and cathode) of rectangular base with water cooling channels passing through. The electrodes joined together separated by a dielectric material. Each electrode is enhanced by external uniformed electric field source (Parallel plates electric field) considering polarity direction of both. Their lower (electrodes) ends with a water basin filled with water, a drainage water trap pipe, fixed inside the basin in a way to maintain water level in the basin and seals the reactants inside the electrodes. The electric field does not cover all the electrodes area specifically at the cell far sides left and right as shown in figure 2, this area in the anode and cathode is internally isolated in such a way to form chambers to accumulate unionized reactants in the anode and in the cathode notably the reactants at the bottoms of the electrodes near to the basin water surface. The unionized reactants are lighter since no force acts on it.

How it works

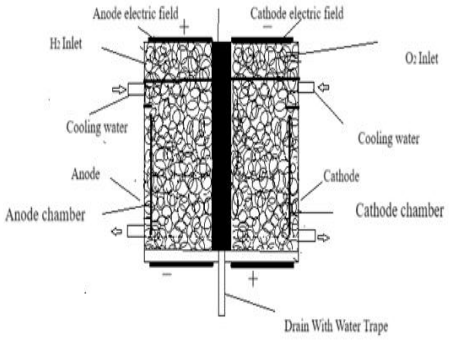
The reactants enter the electrodes at their top sides as shown in figure 2. Hydrogen at the anode and oxygen at the cathode, when the hydrogen passes through the porous anode it oxidizes and releases its electron and becomes positive hydrogen ions ,for the oxygen in the cathode gains electrons and becomes negative oxygen ions ,due to

the presence of the vertical electric fields the ions (hydrogen and oxygen) accelerate downwards and deposit on the water and react producing water .The drainage pipe releases the produced water to maintain water level in the basin to be in contact with electrodes, The cooling water cools the electrodes for better reactants adsorption to maintain cell power output. The electrons released from hydrogen pass through external circuits to the cathode. The unionized reactants in anode and the cathode enter the chambers at the bottom, bushed by the ionized charges rise since it lighter and keep rise and fall from the chamber's top and circulate between chambers and the electrodes till it become ionized. The function of the chamber to empty the reaction area off unreacted hydrogen or oxygen, this will increase reaction rate. The cell generates power or maintains open circuit potential difference as long as the reactants flow into the electrodes. The Cell has no reactants exhaust outlet because the reactants move by electric field, this gives cell features to operate at high pressure that has effect on increasing reactants adsorption [9] which increase cell current density. The electrodes are designed to work efficiently with pure reactants.



External Electric Field Membrane Less Hydrogen Fuel Cell (EEFMLHFC)

Figure 2: Designed by authors



EEFMLHFC Assembly

Figure 3: Designed by authors.

Model Development

Membrane-less hydrogen fuel cells (ML-HFCs) are a possible alternative to classic proton exchange membrane fuel cells (PEMFCs) because of their simpler design and potential cost savings. ML-HFCs separate reactants by careful regulation of fluid dynamics rather than a physical barrier. This strategy can cut material costs while increasing fuel cell durability. An external electric field can improve the performance of ML-HFCs by affecting the behavior of charged species as well as the distribution of reactants and products inside the cell. Modeling these impacts is critical for improving fuel cell design and performance.

In an ML-HFC, the primary processes are hydrogen oxidation at the anode and oxygen reduction at the cathode: Anode reaction:

$$H_2 \rightarrow 2\,H^+ + 2\,e^- e$$

Cathode reaction:

$$\frac{1}{2}O_2 + 2\,H^+ + 2e^- \rightarrow H_2O$$

These reactions generate protons (H^-) and electrons (e^-), which need to be efficiently transported to the respective electrodes. The application of an external electric field can influence this process by enhancing the migration of ions and the alignment of the reactants, potentially improving the overall efficiency of the fuel cell.

The equation (1) below highlighted, is the fundamental equation to be used, to determine HFC design and operation parameters

$$Charges = 4xFxn \qquad (1)$$

where n moles of O_2 Divide by time $t\ charges\backslash t = 4xFx\ n/\ t\ ,\ I = 4xFxM$

Where M flow rate in mole per second, I=current, F= faraday's constant =96,485 C/mol

$Current = PC / VC$

Where PC is cell power, VC is cell voltage PC / VC =4xFxM, so Pc =4xFx Vc x M

O_2 Usage in mole/S M =PC/(4xFx Vc)

O_2 Usage in KG/S =32 X 103 Pc /(4xFx Vc) = 8.29 x 103 x Pc /Vc Kg per Second (2)

Note that if Vc not given can take as 0.65v as good approximation.

The electric field strength between two charged parallel plates is given by the equation:

$$E = V/d$$

E field strength V voltage between the plates d distance between the plates

F of electrons, protons, and other particles. In these cases, we can use the principle of the conservation of energy – electric potential energy is transformed into kinetic energy. The force on a charge in uniform electric field is given by $F = E\ X\ Q$ Also $F = M.a$, where M the mass of the ion and a acceleration of the ion. The charge in oxygen is twice the charge of hydrogen ion of opposite sign. The hydrogen volume consumed cell is twice the volume of oxygen, so the hydrogen should accelerate faster than oxygen to make reactants mass balance for the hydrogen oxygen reaction. This means aH (acceleration of hydrogen) is twice the aO (acceleration of oxygen)

So aH =2 x aO

FH = MH x aH

F=EH x QH,

The charge in oxygen ion is 2 x charge on hydrogen ion.

FO= MO x aO FO=EO x QO,

The mass of oxygen is 16 times hydrogen

FH /FO =MH . aH /(MO x aO) =MH x 2x aO/ (16xMHxaO) =2/16=1/8

FH/ FO = EH x QH /(EO x 2 X QH) =EH/(2 x EO)=1/8

$E_h = 2 \text{ x } \frac{E_o x1}{8} = 1/4xE_o$ (3)

For reactants mass balance the electric field of anode should be quarter of the electric field in the cathode.

To fabricate electrodes with said specifications will take times normal porous electrodes were used with some temporary modification to give approximate results. Although the difficulties in the design of the cell over voltage approximately about 0.57 volt, we still preparing for other parameters to test cell\performance, we will update with any new results within the coming months.

However, Modeling the effects of an external electric field in membrane-less hydrogen fuel cells requires a complicated interaction of electrochemical, fluid dynamic, and transport processes. By creating and solving thorough models, researchers may acquire vital insights into the best design and functioning of these potential energy conversion devices.

By varying the strength and orientation of the external electric field, as well as the flow rates and geometries, the model can identify optimal conditions for maximizing the efficiency of the ML-HFC. Key performance metrics include the cell voltage, power density, and fuel utilization efficiency.

Discussion and Conclusion

The cell uses the electric field to eliminate the presence of the membrane, gas diffusion layers and reactants exhaust outlet. The electric field pushes the reactants to water basin to react, water act likes membrane. The porous electrodes act as electrodes and diffusion layers. In the membrane cell the ions move due to Kinetic energy this process needs exhaust to let the ions move, in electric field the ions move electrically no need for exhaust. The electrodes are designed for pure reactants (hydrogen and oxygen), for oxygen from air need residual outlets. As a conclusion, the cell works properly and can have a promising future in coming years for upgrading and uses. More attention is needed to determine the best electric field strength required for more efficient operation.

Applications and Implications

The cell's use suits all applications of small size to large size power utilization, besides that it suitable to be used in hazardous area since it has no spark when in operation. It can be used in national grid tie in, emergency supply, car and vehicle. If it compares to membrane less fuel cell like one its design based on Laminar flow its power is higher.

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