Review of the Electrodes Layer for Unitized Regenerative Proton Exchange Membrane Fuel Cells

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Abstract: Regenerative Fuel Cell can be used to store energy from renewable resources as solar and wind energy. Such systems consist of electrolyzer and fuel cell. In Unitized Regenerative of Proton Exchange Membrane Fuel Cells both functions are combined at same stack to allowing a cost and volume reduction and enhancement performance. Unitized Regenerative PEM Fuel Cells operating on hydrogen and oxygen are being considered as high efficiency and power generators for stationary and transportation applications. However to penetrate these markets the cost of the fuel cells must be decresed. In this paper review the recent details made on the progress of reduction in the stack cost by lower platinum loadings in the latest URFC stack design. Although such advances are still a need for further reductions in the stack cost through development in the design and performance of the electrodes assembly of URFC. Therefore, the paper is focused on review the preparation of electrodes as design and material with low platinum loading and characterization by using scanning electron microscopy. Also survey the latest literature of electrodes and electrocatalysts to identify major components and materials of URFC stack.

Key-Words: Unitized Regenerative Fuel Cells, Proton Exchange Membrane, Platinum, Electrodes.

1 Introduction

Presently Fuel cells have emerged as a vital alternative energy solution to reduce societal dependence on internal combustion engines and lead acid batteries [1,2]. The conventional batteries have been used for these purposes, but the low energy density (< 200W h kg^{-1}) cannot meet the practical demands. Unitized regenerative fuel cell (URFC) is believed to be a promising alternative. It works both as H_2/O_2 fuel cell and water electrolyzer with a single operation unit.

The practical energy density of URFC can achieve 400-1000W h kg^{-1} [3]. URFC is a reversible electrochemical device which can operate either as an electrolyser for the production of hydrogen and oxygen (water electrolysis mode WE) or as a H_2/O_2 fuel cell for the production of electricity and heat (fuel cell mode FC). In particular, First attempts to built URFCs using proton-exchange membrane technology were made in the 1960s [3]. At that time, systems suffered from inacceptable low electrochemical performances. This was due to problems with membrane and electrocatalysts. More promising results have been obtained in 1970s by General Electric Co. [4]. Later, in the 1990s a prototype URFC stack having a specific power density 450W/h kg^{-1} has been developed and tested at the Lawrence Livermore National Laboratory (LLNL). In 1998 Proton Energy Systems has developed a commer -cial product (Unigen reversible module) consuming 15 kW in electrolysis mode and producing up to 5 kW of electric power in fuel cell mode [3-5]. URFC electrodes are the sites where electrical energy conversion occurs and it is considered as the heart of the proton exchange membrane fuel cell which is transport the protons from the anode to the cathode. Most of the electrodes were made by 10:20 wt. % platinum supported carbon black (Pt/C) within 60:70 wt. % polytetrafluoroethylene (PTFE) as a binder and wet roofing agent and Nafion solution as a proton conductor between the catalyst layer and Nafion117 membrane as shown in Figure 1.

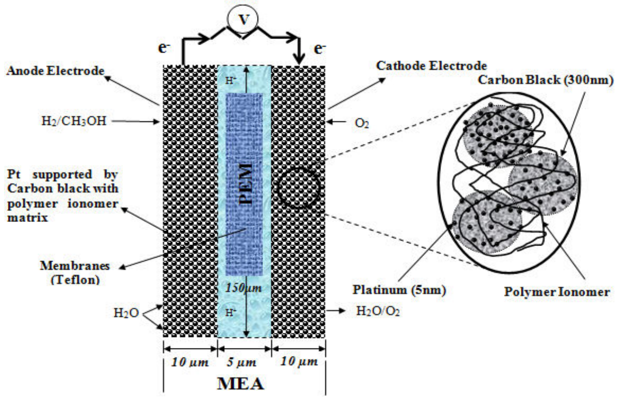

Fig. 1 Schematic of the basic of electrodes catalyst layer in MEA

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This paper has focused on the design preparation of electrodes with low platinum loading and it is characterization by using scanning electron microscopy (SEM). The aim of the paper is to review the latest details on the development of electrodes catalyst layer as well as the progress of reduction in the URFC stack cost by lowered platinum catalyst loadings in the latest stack designs.

2 The major components of URFC system

In Figure 2 will showing various parts that make a fuel cell device in a sequential manner in which they are assembled. For a fuel cell assembly, there are many parts that combine together to make it a cell and to carry out the reactions. The polymer electrolyte membrane based unitized reversible fuel cells can operate as electrolyzer to split water into hydrogen and oxygen by using electric power. When fed hydrogen and oxygen or air, the same cell/stack set-up can operate as a fuel cell to supply electric power. In actual operation, URFCs can be reversed and switched so that they can act as both an electrolyzer and a fuel cell. Due to its low self discharge, a URFC system that includes a hydrogen storage unit is attracting attention for its role in long term energy storage and back-up power, and can thus replace a secondary battery in some applications [5,6-8]. Figure 2 shown the sketch of PEM-URFC for single cell structure, the configuration of a URFC with a proton exchange membrane is a commonly used "conventional" proton exchange membrane fuel cells, consisting of a membrane electrode assembly, gas diffusion layers, and bipolar plates with flow channels [6-8,10].

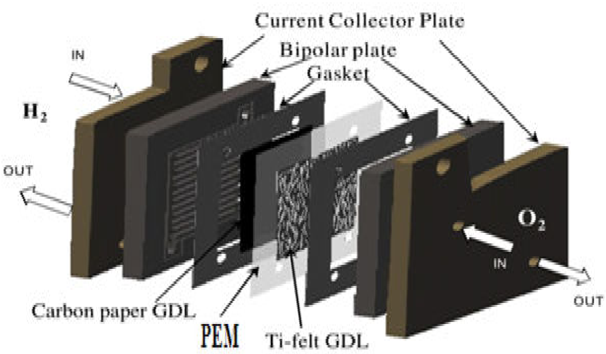

Fig. 2 Schematic components of PEM-URFC for single cell structure [6]

3 URFC Stack

The URFC stack consists of many cells which contain a ribbed bipolar plate, the anode, electrolyte matrix and cathode as shown in Figure 3. The bipolar plate allows the cells to be connected in series, and allows gas to be supplied to the anode and cathode. It is common for a stack to consist of approximately 50 or more cells which will produce a usable voltage [4,5]. Nevertheless, the cost of a PEFC stack is still prohibitive for mass production and the introduction of low cost materials and process is necessary. Moreover, industrial production needs a further quality control to guarantee that every PEMFC stack will have well-defined performance. This goal can be achieved only when single cell substitution in a stack is allowed. Stack disassembly and replacement of failed cells are possible only upon introduction of a new production process that permits: (1) quality control, (2) long range use without any change or decrease of performance, (3) long-range storage (4) low cost [9,10].

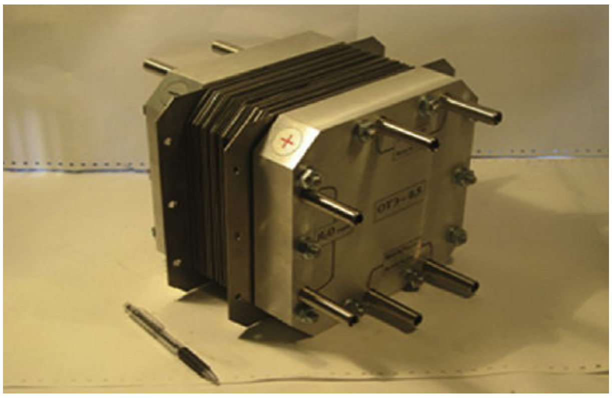

Fig. 3 URFC stack [4]

3.1 Description designs of the unitized regenerative fuel cells

URFC electrode designs have typically used proven and tested methods to produce (electrode/membrane/electrode) interface. Most widely used is the transfer print technique followed by hot press or roll press of the design for more intimate contact of active materials [11]. The regenerative fuel cells can be operated as an electrolyzer splitting water into hydrogen and oxygen with the help of electric energy. The same set-up works as a fuel cell supplying electric power when fed with hydrogen and oxygen (air). RFCs offer a solution where long term energy

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storage is required [12,13]. The possible storage system for the conversion of electrical energy consists of a hydrogen production unit, a storage medium and a unit which converts the chemical energy stored in the hydrogen back to electricity (with help from oxygen or air). Such a system is preferably connected to a renewable energy source, such as solar or wind, which provides an electrolyzer cell with enough energy to split water into hydrogen and oxygen. The gases are either stored or used directly in a fuel cell. In a fuel cell the opposite reaction to electrolysis takes place, i.e. hydrogen and oxygen (or air) is recombined to produce electricity, heat and water. A system like this, with both an electrolyser and a fuel cell, is called a regenerative fuel cell (RFC). A much smaller and compact unit, as shown in Figure 4, which is the unitized regenerative fuel cell, where the electrolyser and fuel cell are combined into one unit and only one of the two modes can be operated at one time. Usually the electrolyser is operated first to produce the hydrogen and oxygen, which are stored and later supplied back to the same unit when desired, which then operates as a fuel cell. Thus, a URFC is a simpler and more compact system than the RFC and it uses only one electrochemical cell [12,13,14].

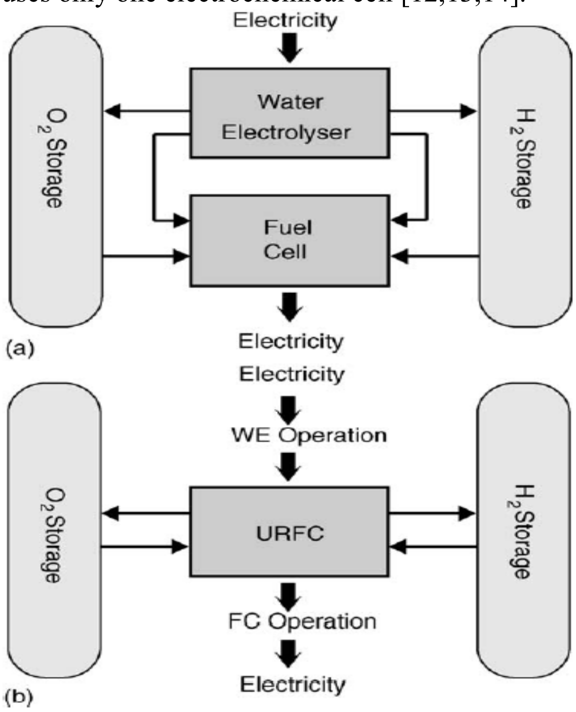

Fig. 4 Concept of the: (a) regenerative fuel cell and (b) unitized regenerative fuel cell [11]

3.2 Electrodes of unitized regenerative fuel cells

The electrodes are typical gas diffusion electrodes. The backing layer of the electrode is a porous carbon cloth/paper with a hydrophobic coating of Teflon, for the electrochemical reactions to take place at useful efficiency. Therefore, must be catalyzed. The electrodes are sites where the energy conversion reactions, which use fuel for oxidation at the anode and reduction at the cathode [15]. The electrodes of unitized regenerative fuel cell are electrochemical cells working both as fuel cells and water electrolyzers. In water electrolysis mode, the water is electrolyzed to hydrogen and oxygen which are recombined to produce electricity in the subsequent fuel cell mode. With the advantages of being free of self-discharge and theoretically higher energy densities [16,17]. The demands on fuel cell electrodes are perhaps even more extreme than those on the electrolyte. The ideal electrode must transport gaseous or liquid species, ions, and electrons; at the points where all three meet, so-called triple point boundaries, the electrocatalysts must rapidly catalyze electro-oxidation (anode) or electro-reduction (cathode). Furthermore, the electrocatalyst is typically restricted to a very thin layer adjacent to the electrolyte, and another layer, the "gas diffusion layer" serves the role of transporting electrons and gases to/from the rest of the MEA [15-17]. An image of a single-cell of electrode for MEA of fuel cell is shown in Figure 5.

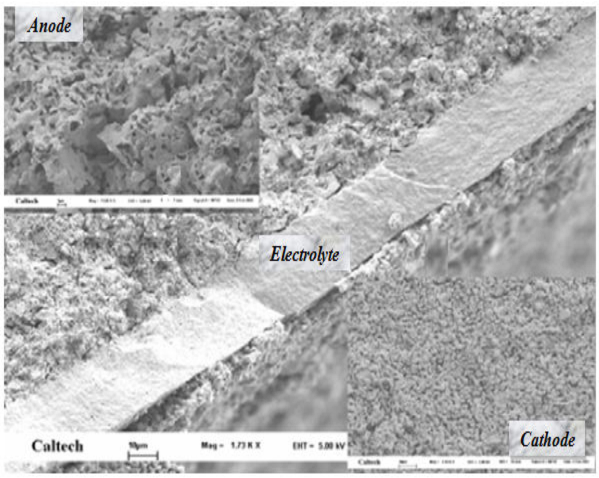

Fig. 5 SEM image of a single-cell of electrodes of URFC [17]

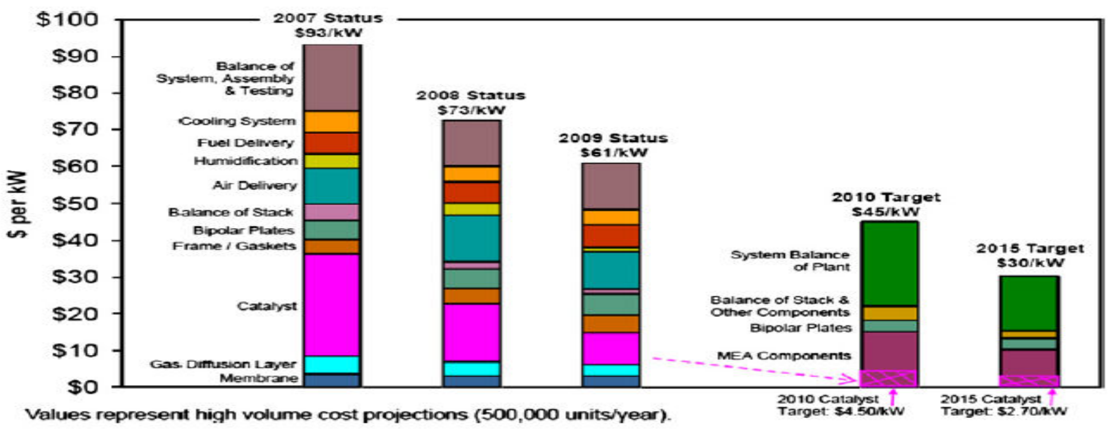

Fig. 6 Breakdown of fuel cell cost [9]

4 Lifetime of URFC stack

The lifetime required by a commercial fuel cell is over 5000 operating hours for light-weight vehicles and over 40,000hr for stationary power generation with less than a 10% performance decay. The department of energy (DOE) targets to achieve a life time of 40,000hr by 2011 with 40% efficiency for distributed power and 5,000hr durability by 2015 with 60% efficiency for transportation. A few years ago, the fuel cell cost has been reduced from $275/kW in 2002, $108/kW in 2006, and $94/kW in 2007 to $73/kW in 2008, which equates to almost $6000 for an 80-kW system but, still more than twice as expensive as internal combustion engine systems [18,19,27]. The Pt loading has been reduced by two orders of magnitude in the past decade and there is still room for further loading reduction. The 2010 and 2015 DOE targets for the fuel cell cost is $45/kW and $30/kW, respectively, for transportation applications. Figure 6 shown the breakdown of fuel cells cost [9,20,28]. The cost of prototype URFC stacks may currently exceed $1,800/kW to $2,000/kW, but producers are confident that mass-scale production for vehicles could reduce the cost to $100/kW. However, the cost of URFC should be lower than $50/kW. Improved designs and materials are required, along with higher power density [21,22]. A discussion of cost breakdown and projections for PEM-URFC systems is provided below with cost details in Tables 1.

Table 1 Cost Projections for PEM-URFC Stack

PEM-URFC Stack	Prototype		Mass Production		Target	
	$/kW	%	$/kW	%	$/kW	%
Membrane	250	14	14	16	13	25
Electrode	710	39	50	49	14	48
Bipolar plate	825	45	30	29	9	17
Pt catalyst	25	1	3	3	2	4
Peripherals	8	0	1	1	1	2
Assembly	8	0	2	2	2	4
Total	1826	99%	100	99%	50	100%

The Electrodes currently dominate the PEM-URFCs cost prototype, as they are manufactured manually. Electrodes cost may be reduced from between $1,500/m^2$ to $150/m^2$ through mass production and new technologies that require less Pt. Current systems require 0.6-0.8 mg Pt/cm^2, equal to around 1 g/kW. The goal is to arrive at 0.2 mg/kW [23,25,26].

5 Conclusions

The outcome of the review is reported the recent details on the development of electrodes catalyst layer for URFC with details on the progress of reduction in the URFC stack cost by lowered pl

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-atinum catalyst loadings in the latest stack designs and materials. Therefore, there is still a need for further reductions in the stack cost through improvements in the design and performance of the electrodes membrane assembly for URFC stack. The following conclusion it was find out from the review can be summarized as follows:

1. The catalyst layer led to a better performance in all process directions. Therefore, the membrane electrode assembly to be preferred for reversible fuel cell applications. If the high efficiency of stack is aimed at the additional costs for the platinum.
2. For the both of side electrodes with a low concentration of PTFE in the supporting layer produced clearly a lower frequency arc at high over potentials, which are believed to reflect water, related transport limitations.
3. For the increasing the clamping force of the gasket, the electrical contact between electrodes and plates is improved, but a lower cell resistance does not necessarily imply a better cell performance. Deformation of the plates plays an important role and greatly affects the cell performance.
4. The better performance for the stack that is when there is less contact between electrode and electrolyte that lead to reduce the power density at higher current density in the URFC stack.

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