

Anion Exchange Membranes for Alkaline Fuel Cells

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Abstract: This paper provides a thorough review of alkaline fuel cell, listing its benefits, which make it a potentially viable alternative to the traditional sources of energy generation. The article also lists the various drawbacks this technology faces, which prevents it from being commercialized on a large scale. It also addresses the major problems such as carbonization in the fuel cell, which renders the process inefficient and the alternative by using different materials so as to make the electricity generation process of the fuel cell more efficient. Although there has not been any consensus for the best set up of the alkaline fuel cell, the author suggests the best available configuration for optimum utilization of the technology. A lot of research can still go in to alkaline fuel cell technology so as to commercialize the technology and derive maximum benefits for humankind.

Keywords: Anode, Cathode, Fuel, Membrane

1. Introduction

Fuel cells are considered to be one of the most environmental friendly energy sources for the 21st century. A fuel cell is an energy conversion device, which produces electricity by electrochemically combining fuel (H₂) and oxidant (O₂ from air) through electrodes and across an ion-conducting electrolyte [2].

The flow of ionic charge through the electrolyte is balanced by the flow of electronic charge through the external circuit, which produces electricity [2]. Alkaline fuel cells have an impressive specific power density even at low temperatures and they are a viable option to the energy crisis created due to the non-renewable, exhaustible sources of energy due to their clean emissions, energy security and high efficiency. Fuel cells can be classified into five major types based on the electrolytes used in the cells.

- Alkaline Fuel cells (AFC)
- Proton Exchange Membrane Fuel Cells (PEMFC)
- Solid Oxide Fuel Cells (SOFC)
- Phosphoric Acid Fuel Cells (PAFC)
- Molten Carbonate Fuel Cells (MCFC)

1.1 History and Early Usage

Fuel cell technology is one of the oldest energy production techniques but the exact origin of this technology remains unknown. Sir Humphrey Davy [2] in 1802 created the first simple cell based on a compound (C/H₂O, NH₃/O₂/C), which delivered a feeble electric shock. It is said that Christian Freidrich Schonbein discovered the actual concepts of fuel cells and published his work in the January issue of Philosophical magazine, according to the Department of Energy, USA in 1839 [1]. Another attempt of power generation was made by Thomas Edison [5] in 1882 when he built a coal burning power generation station in lower Manhattan. However all these attempts proved highly inefficient due to their low thermal efficiencies. The AFC, which uses KOH as the liquid electrolyte, was the first fuel cell to be put into practical service in NASA's Apollo Space Programs in the early 20th Century.

1.2 Benefits of AFC over other Fuel cells

The reaction kinetics are not so high in the acidic conditions in the PEMFC. As the AFC has an alkaline media, the reaction kinetics are more facile in an AFC, which results in higher cell voltages [2]. AFCs also are relatively easy to handle and also have a rather low operating temperature (23-70^oC) as compared to SOFC (>700^oC) and other fuel cells.

1.3 Drawbacks of AFC

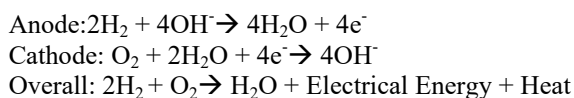
The aqueous electrolyte used in the AFC is sensitive to the presence of CO₂ in the feed stream of air, which is fed across the cathode. The reaction which results, leads to the precipitation of large metal carbonate crystals (K₂CO₃) which may block pores of the gas diffusion layer on the electrodes resulting in reducing the efficiency of the fuel cell [1]. This phenomenon is called as carbonization or CO₂ poisoning. Electrode flooding and electrode drying due to the variation in the amount of electrolyte present is also a challenge, which needs to be tackled to increase the efficiency of the fuel cell. Various methods are suggested in this review to overcome the mentioned drawbacks of the AFC to quite some extent to make it a technology for the future.

2. Main Components and working principle of AFC

Any fuel cell is divided into three main components. The electrodes, electrolyte and the external circuit make up a single fuel cell. Inter connector plates are often used when it is desired to make a stack of multiple fuel cells.

The fuel (H₂) is fed over the anode whereas the air containing oxygen is fed across the cathode electrode. In an AFC generally the liquid electrolyte used is aqueous KOH solution. But presence of any CO₂ in the air feed stream leads to the formation of carbonate precipitation via formation of large metal carbonate crystals which may block the pores of gas diffusion layer on the electrode. If the electrolyte is not highly concentrated then the hydrogen that is charged at the anode reacts with the hydroxyl ions that get

transferred from the cathode through the electrolyte, generating water molecules and electrons. The electrons are then transferred through the external circuit back to the cathode where the oxygen reacts with water molecules forming hydroxyl ions. The reactions can be represented as follows.



The heat liberated can be removed by re-circulating the electrolyte, which also increases the efficiency of the cell [6]. The water generated can be removed by evaporation.

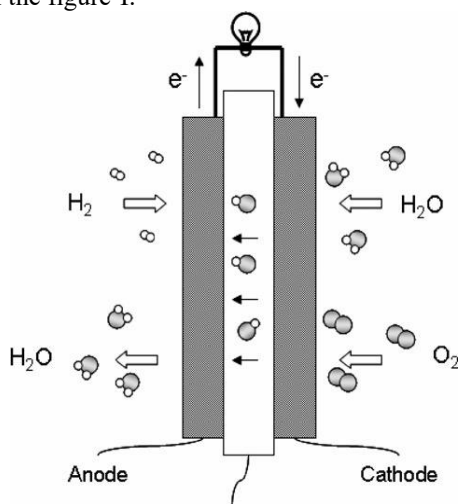
3. Overcoming drawbacks of AFC

Carbonization or CO_2 poisoning remains the most important challenge, which prevents the commercialization of AFC on a large scale. Carbonization prevents the use of AFC in extra terrestrial applications such as vehicle propulsion. Some techniques such as circulating the electrolyte or use of liquid hydrogen to condense CO_2 out of the air stream have been used to tackle the problem but have not yielded any significant results.

Also tackling fuel crossover and increasing the efficiency of AFC would give a boost to the use of this technology on a large scale in day-to-day life. Following is a method suggested by the author, which tend to overcome the mentioned drawbacks of AFC to some extent.

3.1 Use of Anion conducting polymer electrolytes

One of the major drawbacks of the traditional AFC is that the K^+ ions in the liquid electrolyte are sensitive to any CO_2 molecules that may be present in the feed stream of air across the cathode, leading to carbonization. One of the methods to overcome the same is the use of membrane electrode assembly having a solid polymer electrolyte membrane or an anion conducting polymer electrolyte membrane in the AFC [1], which plays the role of separator as well as conductive support between the two electrodes as shown in the figure-I.



Anion exchange membrane
Figure I

3.1.1 Advantages of suggested assembly:

- It eliminates the negative effects of Carbonization as the conducting species is fixed in a solid polymer and there are no mobile cations present (K^+). Solid crystals of metal carbonates are thus not formed.
- Further as no liquid caustic is present there is electrode flooding or corrosion involved in the assembly.
- The said assembly reduces the size and the overall weight of the fuel cell thus diversifying the domain of operations.
- It also improves the efficiency and life of the fuel cell due to slowing of performance degradation with time.

3.1.2 Structure of the AEM

The efficiency of the fuel cell depends on the operating temperature, pressure and relative humidity of the gas streams as well as the properties of the membrane, which is an important component in the assembly.

The main function of the membrane is to act as an ionic conductor and electronic insulator. Under operating conditions the membrane should have the minimum fuel crossover i.e. flow of H_2 from the anode to cathode. The ionic conductivity must be high enough ($\geq 100 \times 10^{-3} \text{ S cm}^{-1}$) with a stringent control over the membrane morphology at the same time to ensure mechanical stability. Judicious selection of cationic group to get a high concentration of charges in the membrane ensures a high ionic efficiency [1]. Also it is suggested to keep the membrane as thin as possible to ensure good mechanical stability even when immersed in water.

3.1.3 Transport Mechanism

The role of the AEM is to conduct OH^- ions at very high rates from cathode to anode where the reduction and oxidation of O_2 and H_2 occurs. It is assumed that the majority of the OH^- is transported through the membrane by Grotthuss mechanism. [1] The OH^- diffuses through H bonded network of water molecules by formation/cleavage of covalent bonds. The diffusion in this case occurs due to concentration and/or electric potential gradients and also due to the convective and migration transport.

3.1.4 Recent developments in AEM

Introduction of quaternary ammonium group to the polymer matrix is an effective method to prepare an AEM. Chloromethylation, quaternization and alkalization are amongst the various methods that can be implemented to prepare the membrane amongst which chloromethylation and quaternization affects the ionic conductivity of the membrane. [7]

Polyphenyl oxide (PPO) and Polyvinyl Alcohol (PVA) are amongst the suitable candidates for preparing the membrane in an AFC as along with KOH they improve the ionic conductivity and also the thermal and chemical stability of the membrane. [4] Cross-linking of the polymer membrane leads to increases ion incorporation in the membrane that leads to a greater ionic conductivity. Fluorinated polymers remain the best option for preparing the membranes as they provide unique molecular properties such as low surface

tension and low surface tension leading to excellent chemical and mechanical stability.

It has been observed that very thin AEMs achieved the highest power output. PD/C based catalysts promoted by Au (4:1) have reported a remarkable 170mWcm^{-2} for a cell operated at 80°C . [3] Addition of oxides significantly improves activity and stability of catalysts. Transition metal carbides are also an interesting option due to their remarkable catalytic activities.

4. Conclusion

Thus carbonization, which is one amongst the major problems that hinder the commercialization of the fuel cell, can be tackled by using a membrane electrode assembly as having a solid polymer electrolyte membrane.

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Author Profile



Aniket Khade received his Bachelors in Chemical Engineering Degree from University of Pune in 2015. He is currently pursuing his Masters Degree in Chemical Engineering from Lamar University in Texas, USA. He has interests in upcoming technologies for power generation and has published an article titled "Fuel Cell Technology and Applications".