PEM Fuel cell as a non-conventional drinking water source

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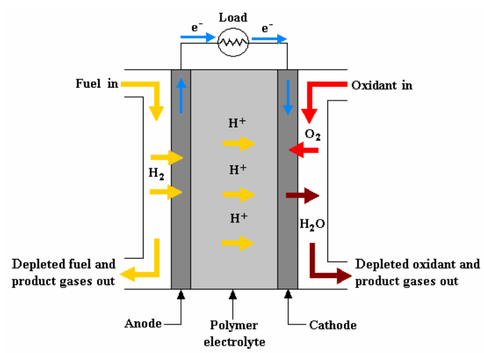
***Abstract*:** The scarcity of potable water is a worldwide problem and researchers all over the globe are trying to address this issue. The other major area of focus world over is the energy crisis. Fossil fuels are not only getting depleted day by day, but are also responsible for pollution, which is another serious issue. A fuel cell device comes to our aid as an alternative source of energy. A proton exchange membrane fuel cell (PEMFC) reacts hydrogen with oxygen to release the exothermic heat and provide water as a byproduct. Thus a PEM fuel can be seen as a probable candidate that can address all the three major issues of energy crisis, pollution and drinking water scarcity, simultaneously. In the current review paper, the potential of a PEMFC has been analysed w.r.t the various variables and parameters like the reaction stoichiometry, temperature, pressure, etc. that affect the oxygen transport, fuel cell power and working so as to maximise heat and water production.



At Anode: $H_2 \rightarrow 2H^+ + 2e^-$

At Cathode: $(1/2)\ O_2 + 2H^+ + 2e^- \rightarrow H_2O$

Overall Reaction: $H_2 + (1/2)O_2 \rightarrow H_2O$

Keywords: *PEM fuel cell, drinking water, cell characteristics, transport*

1. Introduction

The value of water in the human life and lifestyle is not a subject of discussion. A major portion of our own body consists of water. It not only plays a vital role as a part of the blood stream, but also has many other functions to perform in the body. Not just that, it being a good solvent for a wide range of chemicals, finds its applications in many day to day activities in our daily routine. The industries are no less dependent on water. As pointed out already, it finds its applications as a solvent. Due to its intrinsic thermal properties, it is used as a cooling medium in heat exchangers and likes. Steam is also a major utility finding its significance in most of the high temperature applications. A major portion of the entire usage of electricity is derived from hydro-electric power stations. In short water finds its invaluable demand in domestic, industrial and irrigational sector.

Realising the significance and dependence of biosphere on water, nature has covered about two-thirds of our mother earth with water. Yet, there's a saying, "Water water everywhere, not a drop to drink". A major part of India and other countries have been affected by water crisis. There are continual reports of people dying due to dehydration, globally, due to insufficient water quantity. Poor water quality leads to various diseases, cholera, diarrhoea, typhoid, being common.

Another major problem that concerns the globe is that of energy crisis. Although the first law of thermodynamics speaks of a never depleting quantum of energy, the second law of thermodynamics limits the conversion of it into usable form. Fossil fuels have been a major source of concentrated usable form of energy. But again their excessive and uncontrolled use in the past have depleted them significantly. Most of the fossil fuels are very close to their peak points of availability and usage. They are either going to reach the zenith in the near future, or are past the peak point. The problem just doesn't end at availability. The environmentalist all over the globe have voiced their concern over the pollution problem posed by burning them.

Hence the entire focus has shifted to alternative and non-conventional sources of energy. Hydrogen is supposed to be the cleanest of all available fuels. As it contains no carbon, hence all that the combustion of hydrogen with air (oxygen) produces is water. This feature of hydrogen has made it very popular amongst researchers all over the world and novel strategies of its usage, applications and storage are being continually explored. A lot of concern and focus is also placed on refining the already existing technologies and coupling them with inter-disciplinary technologies and applications so as to have multiple approaches and benefits.

One such approach that has triple benefits of utilizing alternate source of energy, being pollution-free and providing water for use, is the usage of fuel cell. A fuel cell utilizes chemical energy of its constituents and converts it into heat or electricity, as designed/modified. Amongst the several types of fuel cells, a proton-exchange membrane [PEM] fuel cell is one of the most widely used and studied. Hence, this paper summarizes the use of a PEM fuel cell as an alternate source of drinking water.

2. Proton-Exchange Membrane Fuel Cell [PEMFC]

2.1 Construction and Working

A fuel cell provides an electrochemical environment containing an anode and a cathode, separated by a membrane, for the reaction of gaseous hydrogen and oxygen to form liquid water, as depicted by the following reaction:

$H_2 + (1/2)O_2 \rightarrow H_2O$ (1)

At the anode, where oxidation takes place, hydrogen diffuses to the anode catalyst dissociates into protons and electrons, which are provided to the external circuit. The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit (supplying power) because the membrane is electrically insulating. Simultaneously at the cathode, oxygen molecules react with the electrons, provided by the anode side and travelled through the external circuit, and are reduced in an acidic environment to form water - the only waste product, either liquid or vapour. The protons reach the anode side through the PEM, thus completing the circuit and the material balance.

Thus, the reactions taking place are:

At Anode: $H_2 \rightarrow 2H^+ + 2e^-$ (2)

At Cathode: $(1/2)\ O_2 + 2H^+ + 2e^- \rightarrow H_2O$ (3)

2.2 Water from PEMFC

As shown in reaction (1), water is produced at the anode by the combination of hydrogen and oxygen. However, there are issues related to the use of this water as a source of drinking water owing to its contamination by the electrodes and the membrane. Initially used electrodes got degraded during the cell operation and hence used to contaminate the water produced with benzene and sulphur acids. Hence in the Apollo program launched by the US, the electrodes were sintered with nickel electrodes which do not degrade. The water was examined and it was concluded by the researchers that it was in compliance with the dictums laid down by the National Aeronautics and Space Administration (NASA) and the US Environmental Protection Agency (US EPA).

The water production rate in kg/s in a PEMFC is given by, rate of water formation = $\frac{(18)iA}{2F}$

where i is the current density in A/cm^2, A is the area of the membrane, cm^2, 18 kg/kmol is the molecular mass of water, and F is the Faraday's constant (96500 C/mol). Hristovski et.al produced about 19.3 kg/d water with 2392 A current.

As shown in Fig. 2, as the current increases, the power density rises to a peak and then decreases. This is due to oxygen mass transport resistance due to water flooding. Contrary to this, the cell voltage keeps on decreasing almost linearly with the current. Fig. 3 shows that while the electric power experiences a peak with the increase in the current, the water production rate increases linearly. This indicates that there is a trade-off between maximum power generation and maximum water generation.

Thus the graph can be divided into three regions, R1 is the stage before the peak, R2 is the peak region, and R3 is the post-peak region. Cell operation in R3 is rejected because of sudden and increased power drop due to blockage of the gas diffusion layer (GDL) because of water flooding and oxygen mass transport limitation.

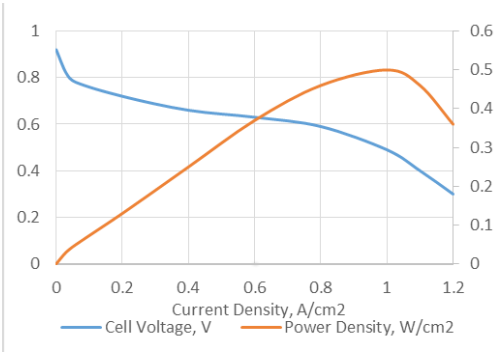


Figure 2: *Variation of Cell Voltage and Power density with Current Density*

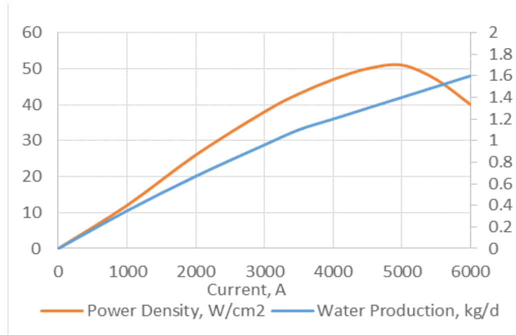


Figure 3: *Variation of Power density and Water Production rate with Current*

Hence in order to maximise the water production as well as electricity generation, it is required to increase the limiting current *density, without having its adverse effects.*

3. Factors affecting cell performance and water production

Reduction of water flooding and increase in cell potential can be achieved by material parameters like properties of the electrolyte membrane, GDL, micro-porous layer and gas flow channel and operational parameters like relative humidity, stoichiometric reactant flow rate, pressure and temperature. The quantity and quality of drinking water produced is also found to be affected by the quantity and quality of the moisture provided to the membrane. The membrane should be fully hydrated by external humidification measures. This would ensure high proton transfer and hence bring about increased cell performance. A part of this can be achieved by recycling the water produced. But heavy recycling has shown to drastically reduce the amount of drinking water produced. Hence optimal humidification is suggested.

3.1 Humidification of inlet reactants (hydrogen and air)

The transport of water across the membrane is effected by three phenomena, viz., electro-osmotic drag which is the transport of water by protons from anode to cathode, back-diffusion from cathode to anode due to pressure gradient and convection, which is nominal. If dry hydrogen concentration is maintained at anode and electro-osmotic drag is insufficient to keep the membrane hydrated then there must be sufficient amount of back-diffusion from cathode to anode to keep the ohmic resistance in check and not let the cell performance drop. It has been found that limited humidification of cathodic inlet gas reduces back diffusion and hence dehydrates the membrane. Hence inlet conditions of the gases at the anode must be sufficiently in favor to counteract the cathodic limitations.

3.2 Polymer membrane characteristics

The thickness of the polymer membrane plays a vital role on cell performance and water production, especially when there are limiting humidification conditions. A thin membrane is appreciated when the anode gases are relatively dry, because the back-diffusion is sufficient to keep it wet. It has been shown that membrane resistance is independent of the current density upto 120 micrometer, but increases for higher thicknesses. However, thin membranes accelerate the diffusion of hydrogen and oxygen which reduces the cell performance. To tackle this problem a modification in the conventional Nafion membrane has been suggested. The membrane may be catalyzed by hygroscopic nanoparticles of Pt or TiO_2 or SiO_2 which make the PEM self-hydrating. These PEMFCs have also exhibited higher cell performances.

3.3 Pressure, Temperature and Composition

The total air inlet pressure has an almost linear relationship with the exit cathodic gases relative humidity. This is true when the partial pressure of water is a function of cell temperature and the cell temperature is maintained constant. So if the inlet pressure increases, the amount of water vaporized decreases, hence the exhaust has lower water content and there is more water remaining in the cell. Hence it may be concluded that a higher pressure gives more amount of drinking water. This doesn’t affect the cell performance because higher pressure give higher gravimetric amounts for less volume. Moreover, the increased pressure increases the current density thus increasing the cell voltage. There is also increased mass transport of gases due to increase in the partial pressure. However, there is addition power requirement.

Cell operating temperature has a major influence on the relative humidity, which is the ratio of partial pressure to saturation pressure. Increased temperature increases the saturation pressure, hence the relative value decreases. This has adverse effects on the call performance and the rate of drinking water.

The anode gains water by humidified hydrogen and back diffusion and loses by evaporation and electro-osmosis. The cathode gains the water by humidified oxygen and the reaction (3) while loses by back diffusion and evaporation. This is the net water mass balance. Many researchers have also proposed models for the water mass balance. The amount of air has been found to be 2-4 stoichiometrically. A lower value adversely affects the cell performance.

4. Conclusion

In this paper, the PEMFC was analyzed as a potential drinking water resource along with production of energy. Also analyzed were the various parameters that affect the trade-off between cell performance and the amount of water produced. As discussed, the membrane should be minimally wetted for having high water production rates without affecting the cell performance. The cathodic humidification has more relevance on the current than that posed by the anode. Moreover, cell operation at higher pressures is desirable, however, this would incur pressurizing costs. Also cell operation above 60 ^{o}C decreases the cell performance. In order to have more drinking water produced, the value of the limiting current density must be increased. Increasing the numbers of membranes at low current densities would be a good option for PEMFC operation to produce reasonable amounts of drinking water.

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