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Modeling charge transfer in a PEM fuel cell using solar hydrogen

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ABSTRACT

Hydrogen is an energy carrier that can be used in industry, residences, transportation, and mobile applications. One of the main attractions for hydrogen is the environmental advantage over fossil fuels. However, Polymer Electrolyte Membrane Fuel Cells, (PEMFC), is an integral part of the future hydrogen economy, they are highly efficient and a low-polluting technology. Numerous applications exist; one of the promising applications is the automotive industry. For this report a comprehensive literature survey is conducted. The findings of the literature survey include hydrogen production and fuel cell models that fit into two broad categories, that is, analytical and empirical. This work is a presentation of our original research and development regarding the production and utilization of a solar hydrogen and its use in a PEM single cell. In order to facilitate the understanding of the charge transfer phenomena in the PEM single cell, a modeling tool with visual basic was developed. All the experiences and results were illustrated in this work.

1. Introduction

Hydrogen is an energy carrier that can be used to store, move, and deliver energy produced from other sources. It's the simplest element on Earth and the most abundant element in the universe; but despite its simplicity and abundance, hydrogen doesn't occur naturally as a gas on Earth. It is always combined with other elements. Water, for example, is a combination of hydrogen and oxygen. Hydrogen is also found in many organic compounds, notably the "hydrocarbons" that make up fuels such as gasoline, natural gas, methanol, and propane.

To generate electricity using hydrogen, pure hydrogen must first be extracted from a hydrogen containing compound. Then it can be used in a fuel cell. Hydrogen can be produced using diverse, domestic resources including fossil fuels, such as coal (preferentially with carbon sequestration), natural gas, and biomass or using nuclear energy and renewable energy sources, such as wind, solar, geothermal, and hydroelectric power to split water. This great potential for diversity of supply is an important reason why hydrogen is such a promising energy carrier.

Hydrogen can be produced at large central plants, semi centrally, or in small distributed units located at or very near the point of use, such as at refueling stations or stationary power sites. The electrolysis uses an electric current to split water into hydrogen and oxygen. The electricity required can be generated using any of a number of resources. However, to minimize greenhouse gas emissions, electricity generation using renewable energy technologies, such as

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Nomenclature

A	area, cm^2
A_{ac}	empirical constant, V
b	empirical coefficient, mA/cm^2
E	reversible voltage, V
F	Faraday constant, C mol^{-1}
I	current, A
i	current density, A/cm^2
i_0	exchange current density, A/cm^2
L	width, μm
m	concentration loss coefficient, V
n	concentration loss coefficient, cm^2/mA
n_e	number of electrons transferred
P	pressure, atm
X_w	water fraction
R	gas constant, J K^{-1} mol^{-1}
R_{diff}	diffusion resistance
r	specific surface resistance, Ω cm^2
T	temperature, K
V	cell voltage, V
We	electrical work, J
k	electro − oxidation rate of H_2

Greek letters

α	charge transfer coefficient
ΔH	enthalpy variation, J mol^{-1}
ΔH	Gibbs free energy, J mol^{-1}
ΔH	voltage losses, V
ζ_{air}	cathode air stoichiometric ratio
θ_{H_2}	surface coverage of H_2
λ	wetness
σ	resistivity of the membrane efficiency

Superscripts and subscripts

a	anode
ac	anode cathode
act	activation
c	cathode
conc	concentration
eh	electro-oxidation of hydrogen
m	membrane
max	maximum (current)
ohm	Ohmic
th	theoretical
tot	total
w	water

wind, solar, geothermal, and hydroelectric power, nuclear energy, or coal and natural gas with carbon sequestration are preferred.

However while fuel cells have advanced other technologies have as well and fuel cells have remained a few years behind. Fortunately fuel cells are now coming into the market.

For these systems designed to consume hydrogen directly, the only products are electricity, water and heat. Fuel cells are an important technology for a potentially wide variety of applications including on site electric power for households and commercial buildings; supplemental or auxiliary power to support car, truck and aircraft systems; power for personal, mass and commercial transportation; and the modular addition by utilities of new power generation closely tailored to meet growth in power consumption. One of these promising areas for fuel cells is the automotive industries which already have buses and cars running on fuel cells. PEM fuel cells are non emission energy conversion devices, and their main byproduct is water. Hydrogen and oxygen (air) are used as the fuel and oxidant respectively.

The desire is to use existing sustainable energy techniques such as wind power to produce the hydrogen using electrolysis. The advantages of fuel cells are many. They have the potential for zero emissions, high efficiency, quiet operation, high energy density, plus high reliability and long life due to few moving parts. Polymer Electrolyte Membrane (PEM) fuel cells are now an efficient and commonly used power source. The goal now is to fully penetrate well established markets [1,2].

In this Work; The first section concerns the fundamental operations regarding the Hydrogen production and the PEM fuel cell area, the second will be dedicated to the test of this modeling tool with results discussions and the final is dedicated to the conclusion.

1.1. The hydrogen production technologies

Researchers are developing a wide range of technologies to produce hydrogen economically from a variety of resources in environmentally friendly ways [2–4].

1.1.1. Natural gas reforming

Hydrogen can be produced from natural gas using high temperature steam. This process, called steam methane reforming, accounts for about 95% of the hydrogen used today in the U.S. Another method, called partial oxidation, produces hydrogen by burning methane in air. Both steam reforming and partial oxidation produce a "synthesis gas", which is then reacted with additional steam to produce a higher hydrogen content gas stream.

1.1.2. Gasification

Gasification is a process in which coal or biomass is converted into gaseous components by applying heat under pressure and in the presence of air/oxygen and steam. A subsequent series of chemical reactions produces a synthesis gas, which is then reacted with steam to produce a gas stream with an increased hydrogen concentration that then can be separated and purified. With carbon capture and storage, hydrogen can be produced directly from coal with near zero greenhouse gas emissions. Since growing biomass consumes CO_2 from the atmosphere, producing hydrogen through biomass gasification releases near zero net greenhouse gases.

1.1.3. Renewable liquid reforming

Biomass can also be processed to make renewable liquid fuels, such as ethanol or bio oil, which are relatively convenient to transport and can be reacted with high temperature steam to produce hydrogen at or near the point of use. Researchers are