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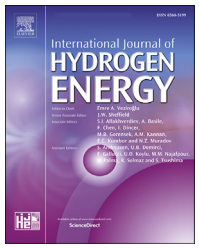

Experimental investigation of electrolytic solution for anion exchange membrane water electrolysis

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ABSTRACT

The effect of species and concentration of electrolytic solution on the performance of anion exchange membrane (AEM) water electrolysis is experimentally examined. When potassium hydroxide (KOH) or potassium carbonate (K_2CO_3) solution is applied for the electrolytic solution, electrolysis is successful under mild alkaline conditions, whereas electrolysis with pure water is quite difficult due to the high resistance of the AEM. AEM electrolysis performance with K_2CO_3 solution is superior to that with KOH solution, even at similar pH of around 12. Hydrogen content in the anode gas compartment and relative humidity of produced hydrogen are also measured during the electrolysis.

Introduction

In the promotion of the use of renewable energy, the role of hydrogen (H_2) as the energy carrier is a key for buffering the fluctuating and/or intermittent power from renewable energy sources [1]. As the conversion device from renewable energy into H_2, a water electrolyzer is the simplest and most realistic. Two major technologies currently in use for water electrolyzers [2] are alkaline (solution) electrolysis [3] and proton exchange membrane (PEM) electrolysis [4]. Alkaline electrolysis using liquid electrolyte consisting of 20–30 wt% potassium hydroxide (KOH) solution is the mature technology and is dominant in large scale industrial applications. Because H_2 produced by an alkaline electrolyzer is derived with strong alkaline solution from the stacks, the balance of plant (BOP) for the H_2 purification process is complex and not suitable for buffering an intermittent power supply. In contrast, PEM electrolysis is suitable for intermittent power input, and also

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Nomenclature

Symbols

i	current density, A cm^{-2}
F	Faraday constant, 96485 C mol^{-1}
n_{drag}	electro-osmotic drag coefficient
R	gas constant, 8.314 J mol^{-1} K^{-1}
RH	relative humidity, %
Q_{H2}	flow rate of hydrogen, m^3 s^{-1} (L min^{-1})
R_{cell}	ohmic resistance of cell, Ω cm^2
R_{ele}	electric contact resistance, Ω cm^2
R_{mem}	membrane resistance, Ω cm^2
T_{cell}	cell temperature, K (°C)
T_{dew}	dew-point temperature of produced hydrogen, K (°C)
t	time, s (min)
V_{cell}	cell voltage, V
γ_H	hydrogen content in oxygen at the anode, vol. %
ΔP_H	pressure difference of hydrogen across membrane, bar
δ	thickness of anion exchange membrane (AEM), m (μm)
ε_H	hydrogen permeability through membrane, mol cm^{-2} cm s^{-1} bar^{-1}
η_{F_H2}	Faraday efficiency of hydrogen
η_{F_O2}	Faraday efficiency of oxygen
σ_{AEM}	ion conductivity of an AEM, S cm^{-1}
ϕ_H	net flux of permeated hydrogen, mol cm^{-2} s^{-1}

Abbreviations

AEI	anion exchange ionomer
AEM	anion exchange membrane
AEMFC	anion exchange membrane fuel cell
BOP	balance of plant
CCM	catalyst-coated membrane
CCS	catalyst-coated substrate
CL	catalyst layer
DI	deionized
FS	full scale
GDL	gas diffusion layer
IEC	ion exchange capacity
MEA	membrane-electrode assembly
PEM	proton exchange membrane
PEMFC	proton exchange membrane fuel cell
PFA	perfluoroalkoxy alkane
PGM	platinum-group metal
PTFE	polytetrafluoroethylene
RD	reading
STP	standard temperature and pressure
TCD	thermal conductivity detector

capable of operation at higher current density (>3 A cm^{-2}). However, a major drawback of PEM electrolysis is its high capital cost per power input. The acidic environment of PEM limits the type of material that can be used for cell components (i.e., bipolar plates and current collectors) to titanium (Ti) and that of the catalyst to platinum-group metals (PGMs). The use of these precious materials is a major reason for the high stack cost of a PEM electrolyzer. According to the data provided by a manufacturer of a PEM electrolyzer [5], the cost share of the bipolar plate is about half of the total cost of the stack, whereas the cost share of the membrane-electrode assembly (MEA) is about a quarter of the total stack cost. Therefore, to reduce the stack cost, the cost reduction of the bipolar plate will be relatively more effective than that of the catalyst.

These technical advantages of PEM electrolysis over alkaline electrolysis are mainly attributed to the membrane potential and cell structure. High proton conductivity and high mechanical/chemical stability of the PEM enables stable electrolysis up to high current density (3–5 A cm^{-2}). In addition, because PEM can act not only as an electrolyte but also as a separating diaphragm as a barrier for produced gases in the PEM electrolyzer, the electrodes (catalyst layers) can be adhered closely to the membrane (i.e., zero-gap structure), thus allowing gaseous products of hydrogen (H_2) and oxygen (O_2) to be produced at the backside of the catalyst layers, which in turn yields a low and stable ohmic loss regardless of gas production rate (i.e., current density). Because in a PEM electrolyzer, H_2 is produced from pure water, a simple BOP can purify H_2 gas, thus enabling the system to buffer an intermittent and/or fluctuating power input.

When a membrane performing under alkaline (basic) conditions is applied to the electrolyte, the material restriction for the cell components can be relaxed. In particular, the material Ti of the bipolar plates can be replaced by a cheaper material such as stainless steel, which would significantly reduce the stack cost, because the cost share of Ti-bipolar plates is significant in the total stack cost of PEM electrolyzer. Alkaline conditions might enable the use of less precious catalysts, although the cost share of the catalyst is not significant. An alternative material for the electrolyte is an anion exchange membrane (AEM) that has high internal pH. When such an AEM is applied as the electrolyzer based on the same structure as the PEM electrolyzer, a low-capital-cost device is possible and still retain the advantages of PEM electrolysis.

Active development of fuel cells using an AEM (i.e., AEMFCs) has been carried out by numerous researchers [6–8], and several types of AEM have already been commercialized. Aiming to improve the performance and stability of AEMFCs, innovative AEMs have been developed by numerous researchers [9,10]. Among the commercialized AEMs, A201 supplied by Tokuyama is recognized as the reference standard at present due to its performance and quality stability. A201 consists of a hydrocarbon main chain and quaternary ammonium salts [11]. The properties of A201 have been reported, such as ion conductivity, ion exchange capacity (IEC), water uptake, swelling ratio, and water-transport number [12–14]. It should be noted here that many AEMs (including A201) easily degrade in high pH environments (>14), despite being operated under alkaline (basic) conditions [10,15].

The same as the PEM in the PEM electrolyzer, the AEM in the AEM electrolyzer serves as the electrolyte as well as the barrier between H_2 and O_2, and thus a zero-gap structure can be configured with an MEA. In the last few years, several research groups have successfully developed electrolysis

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