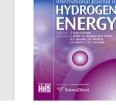


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Evaluation and optimization of the alkaline water electrolysis ohmic polarization: Exergy study



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ARTICLE INFO

Article history: Received 11 February 2016 Received in revised form 21 March 2016 Accepted 21 March 2016 Available online 13 April 2016

Keywords: Water electrolysis Exergy Energy Ohmic overpotential Ionic conductivity Hydrogen bubbles

ABSTRACT

A model is created in order to investigate the effect of different material parameters on the ohmic overpotential of the alkaline water electrolysis for hydrogen production, which influences the exergy efficiency of the water electrolysis. In this research, it was demonstrated that the electrode material parameters and electrolyte conditions of the water electrolysis components such as electrode and membrane resistivity, distance between the electrodes, oxygen and hydrogen bubbles that covers the electrode surface, electrolyte concentration, electrolyte ionic conductivity, and temperature have various effects on the ohmic overpotential, which consequently affect the exergy efficiency of the alkaline water electrolysis. The results of our model has illustrated that the highest exergy loss is due to hydrogen bubbles followed by the electrolyte ionic resistance and oxygen bubbles resistance, respectively. The model has also provided a strong direction for how to optimize the exergy efficiency by reducing the ohmic overpotential, which is affected by various material parameters and operating conditions.

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Introduction

The environmental pollution and the diminution of fossil fuel have increased the interest of the research and development of renewable energy technologies. Hydrogen is the most abundant element in the universe, is considered to be environmentally friendly and to have high energy density. On planets such as Earth, hydrogen is found as part of the molecules of water, organic material, and natural gas. Hydrogen is expected to play an important role in the near future especially as an energy carrier for sustainable research and development. Water electrolysis is a well-known process and is currently adopted in many applications in order to produce hydrogen with high purity [1,2]. Water electrolysis is particularly suitable for use in combination with photovoltaics (PVs) because hydrogen production by electrolysis of water is a mature and efficient technology. Various technologies are available to produce hydrogen via water electrolysis.

The most common water electrolysis is alkaline water electrolysis, polymer exchange membranes (PEM), and solid oxides. The concept is the same for most technologies, which

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http://dx.doi.org/10.1016/j.ijhydene.2016.03.119

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		m	membrane
А	Area, cm ²	Ohm	ohmic
C	Coulomb, C	w	water
c	The Concentration of dissolved gas, mol m^{-3}	р	partial pressure, kPa
	diffusion coefficient, $cm^2 s^{-1}$	Р	pressure, kPa
D _v d	Bubble diameter, cm	Q	electrical charge, C
и Е		Qj	the heat loss, kJ
	electrode potential, V	Rg	universal gas constant 8.314 J mol $^{-1}$ K $^{-1}$
E _{act}	activation overpotential, V	Re	Reynolds number
E _{rev}	ohmic overpotential, V Fourier number	R	electrical resistance, Ω
F _o	Faraday's constant, C mol ⁻¹	Rions	ionic resistances, Ω
F	volume fraction	R ₁	the electrical circuit resistance (External), Ω
f		R'_1	wiring and connections electrical resistance, Ω
f _G G	gas evolution efficiency Gibbs free energy, kJ	R _{bubble;} 0	$_{ m D2}~$ oxygen bubbles resistance, Ω
i i	current density, mA cm ⁻²	R _{membra}	$_{ m ane}$ membrane resistance, Ω
	exchange current density, mA cm ⁻²	Ranode	anode resistance, Ω
ι _ο Η	enthalpy, kJ	R _b	Bubble radius, cm
	the apparent conductivity, S cm $^{-1}$	Sgen	the entropy generation, kJ
K _d h	the specific conductivity, S cm ^{-1}	r	production rate, $m^3 h^{-1}$
k _{water}		T_{amb}	the ambient temperature, K
L	length, cm the hydraulic radius, cm	t	time, s
m M	•	U	electrical voltage, V
M	molecular weight, g mol ⁻¹ number of moles of electrons	Vr	bubble volume, cm ³
n	number of moles of electrons	V_{G}	volume rate of evolved gas, cm ³ s ⁻¹
Greek symbol		$\eta_{\rm act}$	activation polarization, V
α	transfer coefficient	$ ho_{ m j}$	the resistivity of component j, Ω cm
$\alpha_{\rm act}$	the activation transfer coefficient	σ_{o}	the interface conductivity, S $\rm cm^{-1}$
θ	gas bubble surface coverage percentage, %	$\sigma_{\rm el}$	electronic conductivity, S cm ⁻¹
$\varepsilon_{\rm b}$	efficiency	$\sigma_{ m io}$	ionic conductivity, S cm $^{-1}$
η	overpotential, V	Superscript	
$\eta_{ m ohm}$	ohmic polarization, V	-	reversible
Culture		rev	
Subscrip		t,n	thermoneutral
ele	electrolyte	act	activation

is two electrodes and an electrolyte that allows the transport of ions. The alkaline water electrolysis usually operates with electrolyte concentrated with NaOH or KOH. The operating temperature for alkaline water electrolysis and PEM water electrolysis is between 60 and 90 °C, while the solid oxide is between 600 and 900 °C. The alkaline water electrolysis has been widely used in industrial application and for a large number of built units already in operation, while the PEMs water electrolysis still have limited application in terms of production capacity because of the limited lifetime and corrosion of the cells [3,4]. Hydrogen can be produced using a number of different processes such as water electrolysis, thermochemical process, and direct solar water splitting process [5]. Currently, hydrogen is mostly being produced from fossil fuels such as natural gas, coal and oil, using the following thermochemical process: steam reforming, gasification, and partial oxidation. The most frequently used process is the catalytic steam reforming of natural gas and coal gasification.

The water electrolysis process carries significantly higher costs than hydrogen production from fossil fuels [6]. Hydrogen production via water electrolysis process represents less than 5% of world hydrogen production [7], which is used for small scale hydrogen production whereas large-scale hydrogen production is prohibitively expensive or impossible to implement with usages such as spacecraft. The alkaline water electrolysis has many generous advantages such as flexibility, availability, and high purity compared to the thermochemical processes (steam reforming or coal gasification) [8]. While possessing these advantages, hydrogen production via water electrolysis still required improvement in the efficiency and cost of the material and installations, and for this reason we are performing our study on the effect of the materials' parameters and water electrolysis geometry and conditions on the alkaline water electrolysis exergy efficiency.

The alkaline water electrolysis has two types of losses [9]: ohmic overpotential and activation overpotential. The ohmic polarization is caused by the electrodes' resistance, electrolyte resistance, membrane resistance, internal connection wire resistance, and hydrogen and oxygen bubbles resistance. The most critical factors governing the ohmic losses in alkaline water electrolysis are the electrode and membrane material resistivity, electrolyte conductivity and concentration, and electrode and electrolyte geometry. Activation polarization is the voltage overpotential required to overcome the activation energies of the electrochemical reactions on Download English Version:

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