CHAPTER 5 GENERAL CONCLUSIONS

This research aims to study the hydrogen production and to improve the efficiency of the electrolysis process. The scopes of the work are to study parameters affecting energy consumption in hydrogen production from alkaline water and to create the mathematical model of the conservation of mass, momentum and energy. This work begins with a study of fundamental factors of electrochemistry. The mathematical model of void fraction, conductivity and ionic resistance is studied. Consequently, the mathematical model of electrical conductivity under a convection state is solved by the transport equation for both gaseous and liquid phases. The model results give good agreement with the experimental results. The experiment has been developed to measure void fraction, validate and improve the mathematical model. The void fraction is measured with a system based on gas production rate changes. From the results, it is found that the overall electrolyte conductivity is declined with an increase of solution temperature and the height of electrodes since the rise of solution temperature affects the diminishing reversible potential and the height of electrode causes the accumulation of gas bubbles on the electrode. On the other hand, the accumulation of bubble diameter results in an increase of conductivity. This is because bubble size is related to the frictional force between the liquid and gas phases. For validation, the experimental data show a good fit over the complete solution temperature range with a relative difference of 2.16% at 313 K and 0.85% at 343 K of 300 $mAcm^{-2}$. At 500 $mAcm^{-2}$, a relative difference of 2.87% can be found at 313 K and 0.39% at 343 K. In Mathematical model of Ionic Resistance, it has analyzed the behavior of a solution resistance at room temperature, without migration and convection. As it is expected, resistance of solution is dependent on time and positions of electrodes. In particular, the conductivity of solution is related to the time, distance and diffusion coefficient of ions. As the time is escalated, a reduction of the electrolyte conductivity is occurred, leading to an enhance of the electrolyte resistance and subsequently, the higher ohmic loss.

Base on the experimental results, the concept of experimental design technique is applied to a correlation of factors for hydrogen production rate and efficiency. The experiment is divided into six effects. The effects of current density, frequency, duty cycle, operating temperature, materials and flowing electrolyte of the electrolysis process are studied. It is found that the most important factor is the current density since a higher current density discharges a larger amount of electrons. These electrons take part in electrochemical reactions; thereby enhancing the amount of hydrogen production. In addition, the concentration is also important as it allows the convenient passage for ions and electrons. For the effect of frequency and duty cycle, it has been found that the efficiency is inversely proportional to the hydrogen production rate. The efficiency is higher when the power supply is in a low duty cycle and low frequency and the hydrogen production rate is higher when the power supply is in a high duty cycle and low frequency. This is due to the transfer of electrons at the interface between the electrode surface and electrolyte; thereby enhancing the amount of hydrogen production. The conductivity of the electrolyte is decreased with an augment of void fraction as the motion of the ions and electron transfer becomes difficult near the interface area. This results in the diminish of the efficiency of the system. Therefore, in the development and improvement of electrolyzers, it is important to understand the behavior of these factors in order to minimize the bubble effect which holds a key to the electrolyzer efficiency improvement.

For the effects of temperature on the hydrogen production rate, the experiments are conducted at different temperature varying between 303 K and 353 K. It has been observed that the rate of hydrogen production and efficiency are increased at the higher temperature. The maximum hydrogen production rate is 839 $mlmin^{-1}$ at 353 K with the efficiency of 27.97%. Moreover, a mathematical model has been developed in this research by means of regression analysis method to predict hydrogen production rate. This model is a function of temperature and current density. A comparison between simulated and measured values shows that the model and the experimental results agree well with 8.07 % of error. In the case of electrode materials, it is found that at the higher current density, the potential and hydrogen production rate are increased whereas the efficiency is dwindled. At the current density of 600 $mAcm^{-2}$, hydrogen production rate are 818, 703 and 684 $mLmin^{-1}$ with 25.70, 21.24 and 19.93% efficiencies when using stainless steel covered with nickel, stainless steel and copper, respectively. As a result, the stainless steel covered nickel is the most suitable electrode material for hydrogen production rate and efficiency due to the activation energy is lowered. Finally, for the effect of flowing electrolyte on the mixing-gases (hydrogen and oxygen) production rate, the electrolyzer performance was tested using terminal current measurements involving current of up to 30 A, while different circulation techniques (with and without pumping) are compared to improve the efficiency of the electrolysis process. Gas bubble is formed and covers the electrode surface which is assumed as an additional electrical resistance to the system, leading to the low efficiency of the electrolysis process. The flowing electrolyte can reduce the bubble layer thickness on the electrode surface. The physical properties of the electrolyte related conductivity such as bubble layer at electrodes surface can be reduced by improving mass transport which is consisted in the electrical conductivity of the electrolyte. The results show that at 30 A the gases generated from the circulation with and without pumping are 2.31 $Lmin^{-1}$ and 1.76 $Lmin^{-1}$, respectively.

This study demonstrates that factors of hydrogen production can lead to the improvement of properties of electrolysis. The current and current characteristics have influence on the rate of gas production and efficiency of energy consumption. In other words, the flowing electrolyte can be applied to a reactor and the selection of materials can be introduced to a coating or surface treatment of electrodes. Besides, some possibility are suggested for the future development of the efficiency such as the effect of rest time period on the growth rate of bubble size and the bubble blowup on the surface electrode. Finally, suitable techniques should be approved and reviewed carefully to support to large scale industries with cost reduction and complicated product development.