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Investigation of alkaline water electrolysis performance for different cost effective electrodes under magnetic field

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ABSTRACT

Alkaline water electrolysis is the easiest methods for hydrogen production because of their simplicity. Although the simplicity is an advantage; reducing the energy consumption and maintaining the durability and the safety of these systems are the main challenges. In this paper, alkaline water electrolysis system, that uses cost effective electrode materials and magnetic field effects are presented. Cost effective electrodes such as high carbon steel, 304 stainless steel, 316L low carbon steel and graphite material are used for the hydrogen production. After the selection of the best electrode pair, effects of magnetic field to hydrogen production and change of current density are investigated for KOH electrolytes in different concentrations (5 wt%, 10 wt% and 15 wt%). According to the experimental observations the direction of the Lorentz Force affects the hydrogen production and current density. When the Lorentz Force is directed upward, it enhances the hydrogen production for 5 wt% and 15 wt% KOH solution by almost 17%. The increase in current density for 5 wt %, 10 wt% and 15 wt% concentration is 19%, 5%, 13%, respectively. Forced convection in the magnetic field enhances the separation of gas bubbles from electrode surface. Downward directed Lorentz Force decreases hydrogen production and current density values significantly. For 5 wt%, 10 wt% and 15 wt% the hydrogen production decreases by 14%, 8%, 7%, respectively. Similarly, current density for downward directed Lorentz Force decreases by 11%, 7%, 4%, respectively.

Introduction

Hydrogen shows a great potential as a fuel among sustainable energy production methods. Although hydrogen is the largest and the simplest energy carrying element; hydrogen molecules are not directly available in the nature. Hydrogen energy can be converted to heat energy by different techniques. Especially it can be converted directly into electrical energy more efficiently through fuel cells [1–3].

Studies related to hydrogen energy increase and become more popular day by day. It is being suitable energy storage option and the "fuel of future" as demand for energy rises for different applications. As it is a clean energy carrier, hydrogen energy generating methods do not have adverse effects to the environment. There are approximately ninety different

Abbreviations: HCS, high carbon steel; SS, stainless steel; LCS, low carbon steel; MHD, magneto hydrodynamic.

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hydrogen production methods. They can be separated into four main groups: biological, chemical, thermal and electrochemical methods. In these methods, generally, hydrogen can be derived by processing of hydrocarbons or water electrolysis. Compared to other hydrogen production methods, water electrolysis has not been used commonly for the requirement of higher electricity energy (4.5–5 kWh/m^3 H_2 in most industrial electrolysis) [1,4]. At present, the amount of hydrogen produced by water electrolysis is only about 5% [5]. Despite this, water electrolysis is simple, relatively clean and provides purer hydrogen than other methods. Also, water electrolysis technique does not require massive facilities. Electricity for this electrolysis can be supplied through solar, hydropower, wind power or ocean power. These methods can provide sustainable and renewable hydrogen production [6,7]. Efficiency of electrolysis cell is an important factor in the sustainability of hydrogen production. The overall efficiency value of electrolysis cell is generally below 40% [8].

For these reasons, there is a big interest to increasing efficiency of electrolysis cells and thereby reducing hydrogen production costs as much as possible. More efficient electrolysis cell design can be separated into two main groups. One of them is providing cheaper electricity and the other is developing cost effective electrode materials and reducing energy consumption [9,10]. Especially, researchers focused on behavior of electrode and electrolyte materials under different conditions since these are the two important components of electrolysis. Alkaline or acidic aqueous solutions, distance between the electrodes, cobalt and tungsten based ionic activators used to decrease energy requirements per mass [11]. Stojic et al. [1] investigated water electrolysis with KOH aqueous solutions for different temperatures and they concluded that the increase in temperature enhances conductivity of solutions which reduces electrical energy consumption required to produce per mole of hydrogen. Souza et al. [12] used different electro active materials like platinum (Pt), nickel (Ni), 304 stainless steel and low carbon steel. They investigated that LCS exhibits better efficiency value than Pt electrode materials for water electrolysis process.

Researchers tried to increase the performance of water electrolysis by using different physical field effects such as super gravity field, ultrasonic field and magnetic field. Thanks to field effects, it minimized adverse effects of bubble coverage on electrode surface area correspondingly and increased the distribution of bubbles in electrolyte. Field effects make it possible for the effective separation of bubbles. Reducing voltage drop, reaction overvoltage, diffusion of bubbles in electrolyte to minimize electrolyte resistance enhances mass transfer in electrolysis cell. These factors also reduce cell voltage and increase cell efficiency significantly [5,13,14]. Particularly magnetic field effects are simple and effective for water electrolysis studies.

Magnetic field effects for electrolysis systems are studied by various researchers, especially effect of alkaline or acidic solution (change in concentration, conductivity etc.), effect of electrode materials, geometric specifications of electrodes, and effect of voltage change and magnetic flux density (B) are investigated. For example, Iida et al. [15] used magnetic field and measured cell voltage of an alkaline solution (KOH) and an acidic solution (H_2SO_4). They reported that larger reduction in cell voltage was achieved in magnetic field and this reduction amount depends strongly on concentration of electrolyte solutions and strength of magnetic field. Matsushima et al. [16] used glass electrode to observe convection due to magnetic field and coverage effects. They created an equation function of contact angle and magnetic field through experiments. Lin et al. [17] used different materials for electrode which have different behavior under magnetic field, such as nickel, platinum, and graphite. In another study, Lin and Hourng [18] investigated water electrolysis under magnetic field and pulse potential to produce hydrogen more efficiently. Pulse potential provides acceleration of bubbles and it results in the increment in mass transfer, particularly on 10 wt% duty cycle and 10 ms pulse on-time. Effects of magnetic field to mass transport mechanism in electrochemical cells are well established. Magnetic field results in induction of convection which increases the limiting current for diffusion. To show that effect, Aaboubi

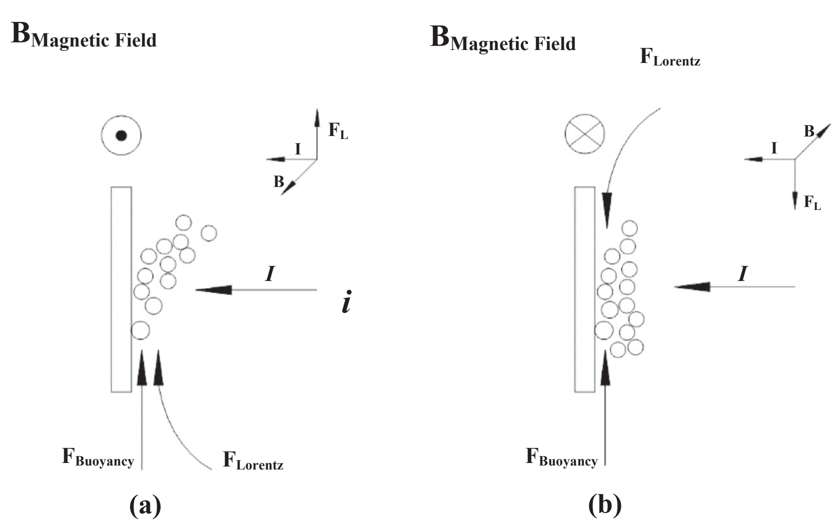

Fig. 1 – Schematic view of MHD effect, (a) Lorentz Force upward, (b) Lorentz Force downward [15].