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Study the Influences of Both (NaOH and KOH) at Different Electrolyte Concentrations and Times on Hydrogen Production via Electrolysis Process

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KEYWORDS

Hydrogen, Electrolysis, NaOH, KOH, Efficiency.

ABSTRACT

There are various ways to reduce emissions harmful to the environment, including carbon dioxide gas produced from different industries that depend on fossil fuels, which is considered a non-renewable energy sources that will end one day. Recently, there has been a strong focus on finding alternative and renewable ways to produce energy. One of these ways is to use hydrogen as a resource for many applications, including the most important electricity generation.

This study deals with the mechanism of hydrogen production through the electrolysis of water, which was represented by the use of a model of the electrolysis cell, through which factors affecting the amount of hydrogen produced such as time, concentration, and electrolyte type. Two different catalysts (electrolyte type) were employed in this study, namely sodium hydroxide NaOH and potassium hydroxide KOH, they were used as electrolysis in order to evaluate the levels of hydrogen production. Experimental results showed that the potassium hydroxide catalyst was better than the sodium hydroxide, due to the activity of potassium ion in the electrolyte medium, which plays an important role in the dissolution process and hydrogen production. The best amount of hydrogen gas production was (140 ml) at 3 minutes, 4 amperes, 10 volts, and a concentration of 5 g/L of KOH. Faradaic efficiency was used to evaluate hydrogen production in both electrolysis mediums. The experimental results showed that the highest Faraday efficiency was 0.179% at a concentration of 5 g/L.

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دراسة تأثير كل من (KOH و NaOH) عند تراكيز و أزمنة مختلفة للإلكتروليت على إنتاج الهيدروجين عبر عملية التحليل الكهربائي

نعمة صالح، موسى ماي.

ملخص: هناك طرق مختلفة لتقليل الانبعاثات الضارة بالبيئة منها غاز ثاني اكسيد الكربون الناتج من الصناعات المختلفة التي تعتمد على الوقود الأحفوري والذي يعتبر من مصادر الطاقة الغير متجددة التي ستنتهي في يوما ما. وفي الآونة الأخيرة أصبح هناك تركيز قوي حول ايجاد طرق بديلة ومتجددة لإنتاج الطاقة. احدى هذه الطرق استخدام الهيدروجين كمورد للعديد من التطبيقات من اهمها توليد الكهرباء تتناول هذه الدراسة ألية انتاج الهيدروجين من خلال التحليل الكهربائي للماء. التي تمثلت باستخدام نموذج لخلية التحليل الكهربائي والتي يتم من خلالها دراسة العوامل التي تؤثر على كمية انتاج الهيدروجين مثل الزمن والتركيز ونوع المنحل بالكهرباء. تم استخدام محفزين (نوع المنحل بالكهرباء) مختلفين في هذه الدراسة وهما هيدروكسيد الصوديوم وهيدروكسيد البوتاسيوم كمحلل لتقييم مستويات انتاج الهيدروجين. أظهرت النتائج التجريبية ان محفز هيدروكسيد البوتاسيوم أفضل من هيدروكسيد الصوديوم بسبب نشاط ايون البوتاسيوم في الوسط المنحل بالكهرباء والذي يلعب دور هاما في عملية الذوبان وانتاج الهيدروجين. كانت أفضل كمية لإنتاج غاز الهيدروجين (140 مل) عند 3 دقائق، 4 امبير، 10 فولت وتركيز 5 جم/ لتر في هيدروكسيد البوتاسيوم. وكذلك تم استخدام كفاءة فاراداي لتقييم انتاج الهيدروجين في كل من وسطي التحليل الكهربائي. من خلال النتائج العملية اظهرت ان الكفاءة الفارادية الاعلى كانت 0.179% عند تركيز 5 جم/ لتر.

الكلمات المفتاحية – بالهيدوجين، التحليل الكهربائي، KOH، NaOH، الكفاءة.

1. INTRODUCTION

Hydrogen is an abundant element on Earth. But, in terms of its chemical properties, hydrogen cannot be stored in its standard state. It exists in states with a lower energy level like in water molecules and hydrocarbons. The use of electrolysis for the production of hydrogen from the spilt water into its components by using electricity is becoming increasingly common, accessible, and affordable [1][2]. It is well known [3][4] that the hydrogen production process is achieved through the use of an electrolyser, which is a device that contains two electrodes and an electrolyte separating them. With the application of an electric current between the anode and cathode electrodes, water molecules can dissociate into hydrogen and oxygen gases. One of the applications of the production hydrogen is used in fuel cells to produce electricity by combining atoms of hydrogen and oxygen. In this case, hydrogen reacts with oxygen across an electrochemical cell similar to that of a battery to produce electricity, water, and amount of heat [5]. In addition, the importance of using hydrogen as a source of electricity (fuel cell) via the electrochemical process has been increased. This plays a signification role in providing a cost-effective solution for reducing carbon emissions [6]. Also, the importance of the electrolysis method lies in the fact that the only source of hydrogen is pure water, while other methods, for example the steam reforming method produce co2 with hydrogen because they use methane in their production, this causes many problems in environmental like Ozone hole etc and lot of studies indicated that using hydrogen can have helped for reducing CO2 emission by amounts up to 60-80% compared from the traditional energy sources [7][8][9]. Also, in order to migrate global warming, hydrogen can provide the long-term, stable and cost-effective options to reduce CO2 emissions thought such as steel, maritime, aviation, and ammonia manufacturing process [10]. Water electrolysis can take place in acidic, pH-neutral, or alkaline conditions [11]. Various electrolytes are used for hydrogen production studies. The choice of the right electrolytes significantly impacts the efficiency of the process [12]. The mechanisms and activity of different electrolyte materials have been conducted under kinetically alkaline aqueous conditions. In the literature, the scientific research is focused on using KOH-based alkaline electrolysers, or NaOH-based ones for developing and producing hydrogen [13]. Biswajit et al. conducted [14] that the rate of hydrogen production in some cases increases with increase in concentration of potassium hydroxide and sodium hydroxide solution as an electrolyte. The behavior can be attributed to the changes in electrical conductivity of the solution due to increase catalyste concentration in the solution. Generally, an ion conducts electricity in an infinitely dilute solution of electrolyte most efficiently per mole. This situation changes the electric potential between two electrodes in aqueous solution. Cations and anions are attracted to the respective electrodes and the potential difference propels the ions across the electrodes gap. All these processes are based on a very complicated mechanism. It was reviewed [15][16] that the electrolyte's impact on the electrochemical reactions occurs through two mechanisms: one via the chemisorption of adsorbents in the inner Helmholtz layer involving the electron transfer, and the other through weak van der Waals interactions between the electrode and spectator (supporting) ions in the electrolyte at the outer Helmholtz layer. In addition, some alkali metal cations in aqueous electrolytes can cause notable changes in the reaction frequency through non covalent interactions with water molecules and surface adsorbents which exhibit the catalytic activity that promotes the production process [17][18]. In this work will give some knowledge on producing the hydrogen and discuss experimental results for two different electrolysis mediums. To achieve this aim, several major objectives were assigned to assess the use of different electrolyte mediums with various parameters for producing hydrogen including;

- Understanding the hydrogen energy in general.
- Design an electrical cell model.
- Production of hydrogen by an electrolysis method .

2. Experimental procedures

2.1. Materials

Different engineering materials were employed to set up the experiment. Stainless steel was used to manufacture and set the electrodes. Due to its good corrosion resistance and high surface area, austenitic stainless steel was widely applied in steam-generating plants and nuclear reactors [19][20] and thus, it was selected as electrodes (anode & cathode) in the current electrolysis cell. The water filter case is used to process the reaction within the electrolysis solution. A nylon laboratory was used to close the cups and maintain the solution concentration. Glasses such as conical flasks, sticks and graduated cylinders to measure the hydrogen.

2.2. Electrical devices

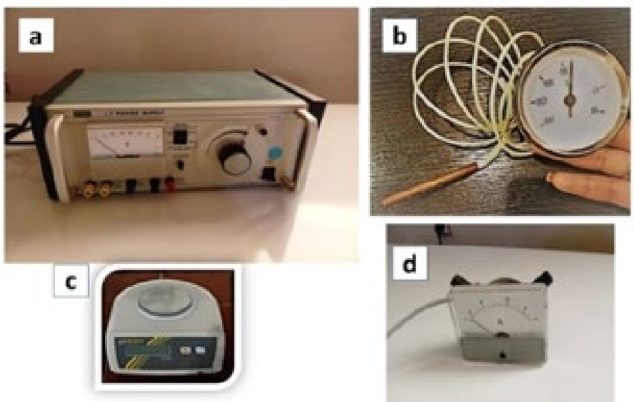

Figure 1: electrical devices used.

There are some electrical devices were used for test measurements, see Figure 1. No.(a) is power supply IRWIN L-T. It has been used to provide a variable voltage and high current to meet need requiring a higher output. No.(b) The Fahrenheit temperature scale was used. No.(c) The electronic balance used for measuring the amount of salt in the experiment. No.(d) The Ammeter device used to measure current. Measured in Amber (A).

Digital Multi meter (AC/DC), DT9205A LCD, No.(a) was used, see Figure 2. This device was providing with a resistance capacitance tester with low battery indication / overload indication / Auto power off function. No.(b) The resistance OHMS 4 amps was used. An electrical resistance is the opposition to the movement of electrons as they flow through a circuit.

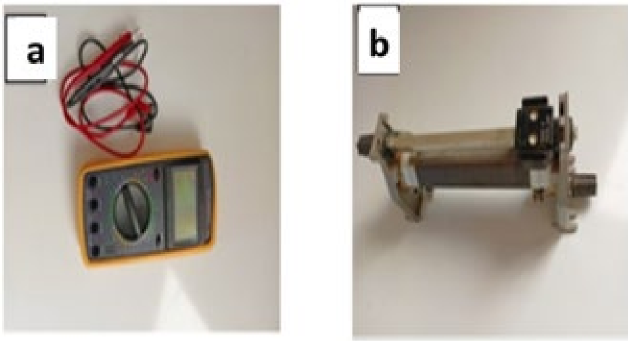

Figure 2: Digital Multi meter (AC/DC) and OHMS 4 Amps used.

2.3. Preparation of hydrogen cell

2.3.1. Cell Preparation

Within the electrolyte cell, it used an electrolyte composed of an aqueous solution of potassium hydroxide (KOH) and/or sodium hydroxide (NaOH). Through the process, the oxygen ions migrate the electrolytic material, leaving hydrogen gas dissolved in the water stream. The hydrogen gas is readily extracted from the water stream directed into a separating chamber. To setup and operating the cell, L-T power supply model was used to maintain, and generate regulated DC voltage. The reading was recorded for each experiment according to the required affecting parameter, see Figure 3.

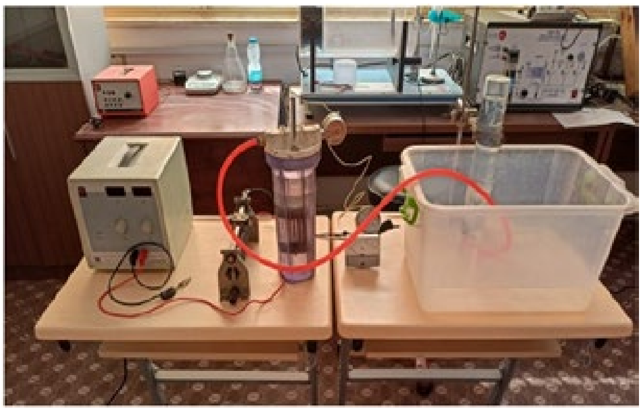

Figure 3. Set up the used hydrogen cell.

The electrodes are made of stainless steel 316 shown in Figure 4. The two electrodes are flat plate shape, each of them is 24cm height and 5cm width. The thicknesses of each plate is 1.5 mm and the gap between the two plates is 2 mm. The flat plates electrodes are separated by a non-electrical conducting material which is resistive teflon. The electrodes are immersed in water where the process of splitting water into hydrogen and oxygen occurs when electrical current generated by the power supply.

Figure 4. The electrodes of the cell.

2.3.2. Electrolysis preparation

Number of steps was used to prepare the electrolysis media for both KOH and NaOH solution. Different concentration used to evaluate their effect on the rate of hydrogen production. Sensitive balance is used to measure the weights of the chemical salts in the experiment. Also, filter paper or semi-permeable paper is used to separate the fine solids in a liquid during a filtration process. Glass tube used for mixing the salt powder within the solution for achieving a good homogenous electrolyte media. In this work, for preparing 5,10,15 g/l , KOH powder salt was rinsed in 1000 ml tap water. The solution was doped in water until the homogenous solution reached. The concerted solution was used as the electrolysis medium to conduct the test. The same procedure was applied for all concentration rang in both KOH and NaOH, see Figure 5.

Figure 5. Electrolysis media for both KOH and NaOH solution.

2.4. Measurement of hydrogen

In the currently work, we used the displacement of water from graduated measuring cylinder or graduated test tube placed inside a water bath to measure and collect the hydrogen production, It is well known [21], see Figure 3.

2.4.1. Effects of various electrolyte concentrations

The used of suitable catalyst for hydrogen production process is critical factor to develop electrolysis of water. Hence, it is an urgent desire to develop many different electro-catalysts with different performance to promote H_2 production. Both KOH and NaOH electrolysis were used in this work to identify the H_2 production process. Also, the comparison between the used of both electrolysis may play a role to understand the effects of their concentration on the process. Three different concentrations (5 g/l, 10 g/l and 15g/l) were tested for both KOH and NaOH, respectively.

2.4.2. Effects of various times on hydrogen production

Two scenarios were studied in this part, one related to the influences of time upon the hydrogen production at different applied currents. The other was related to changes in H_2 production at different applied voltages as a time changes.

2.5. Faradic efficiency

Faradaic hydrogen production rates have been experimentally measured in good agreement with the electrochemical nature of the reactions occurring under electrochemical reforming conditions. In this work, we employed this property to explain the funding from the experimental results.

3. RESULT AND DISCUSSIONS

3.1. Effect of concentration at different current

The experimental result show that the use of KOH to produce hydrogen in all different applied currents was better compared with that of using NaOH. The influences of applied current were clear observed, see Figure 6. As the operating current increased the production of hydrogen increased. This was noted in both catalysts used (NaOH & KOH). The reason can be attributed the electrolysis process enhanced as current increased. In addition, the experimental result showed a little increase in H_2 production (KOH) at 15 g/l compared with that of 10g/l in all different currents. This result may explain in terms of the solubility of KOH in the solution which may effected on the electrolysis process specially in the range of (10g/l and 15g/l). The same trend was observed into NaOH medium which show a slightly increase in H_2 production in 15g/l compared with that in 5 and 10 g/l. Also, this can be related to the solubility and the increase in the applied current (4A). However, the result showed that the value of H_2 production in 5g/l for both (2A & 3A) was higher compared with that of (10 and 15 g/l). This may be explained in terms of low concentration of electrolyte affected on the adsorption of ions on the electrode surface. It was reported that the transport number of cations tends to decrease slightly at higher concentrations of salts [22].

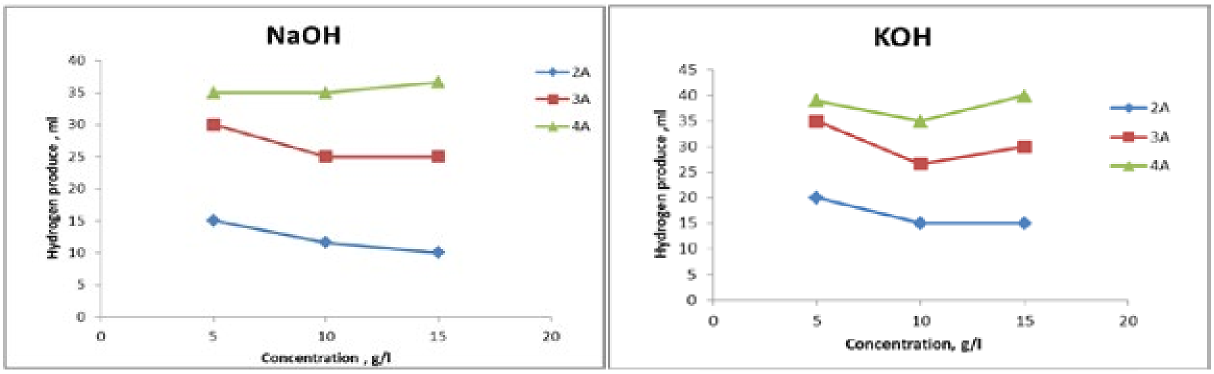

Figure 6. The effect of electrolyte concentration on H_2 production at different currents.

3.2. Effect of concentration at different voltages

At low concentration (5g/l) the result show that the rate of H_2 production in KOH was higher that than NaOH medium for both different applied voltages. At high concentration (15g/l) the rate of H_2 production in KOH recorded best result than NaOH medium for different applied voltage. There is a little change in H_2 production (at 10g/l) in NaOH compared with that (at 5g/l). This may be attributed to the solubility of NaOH salt. However, as the concentration of salt (15g/l) the rate of H_2 production was mainly stable as 10g/l, or a slightly increase, see Figure 7. It may be concluded that, as the voltage increases the electrolyte efficiency decreases and also becomes optimized with a certain range of concentration [23]. This may be due to higher ionic conductivity in solution. This results may be summarized as the inverse relation between voltage and changes of electrolyte concentration is due to concentration polarization (the resistance of electrolyte) and changes in the concentration of hydrogen ions, or water.

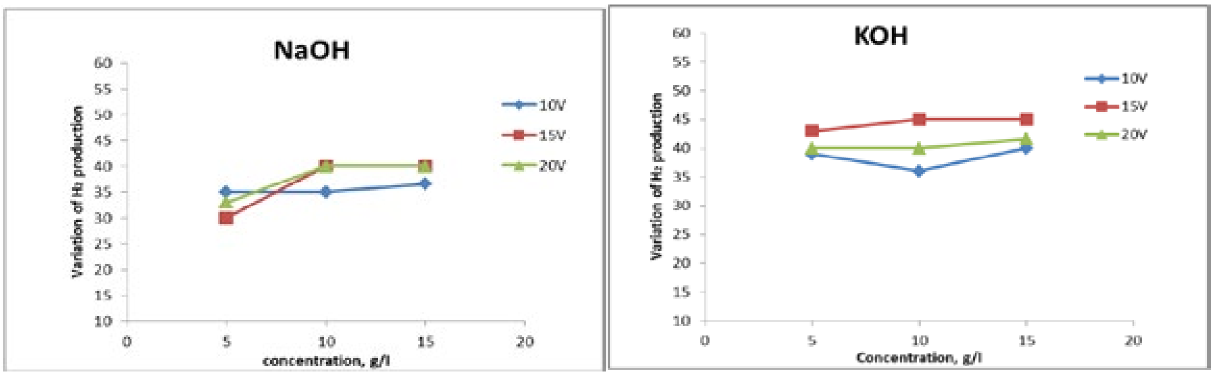

Figure 7. The effect of electrolyte concentration on H_2 production at different voltages.

3.3. Effect of time at different currents

3.3.1. Time vs currents (10v and 5g/l)

Generally, the result show that as a time increased the rate of H_2 production increased, in both electrolysis mediums. In this part, the results were conducted constant (10v and 5g/l) at condition. Also, the improvement in experimental result into KOH was higher than that in NaOH. The reason may be referred to the enhancement of KOH electrolyte KOH due to its conductivity. Figure 8. show that the amount of H_2 production at (4A) applied amperage was the highest value (about 140ml at 3mins). The result may be attributed to the increase in the time of reaction lead to more H_2 production. Also, the mechanism of catalysis is slightly different for NaOH & KOH. It was reported that [24] the activation energies are larger in the presence of KOH. The higher reaction rate in the presence of KOH solutions may be played a key role in this behavior.

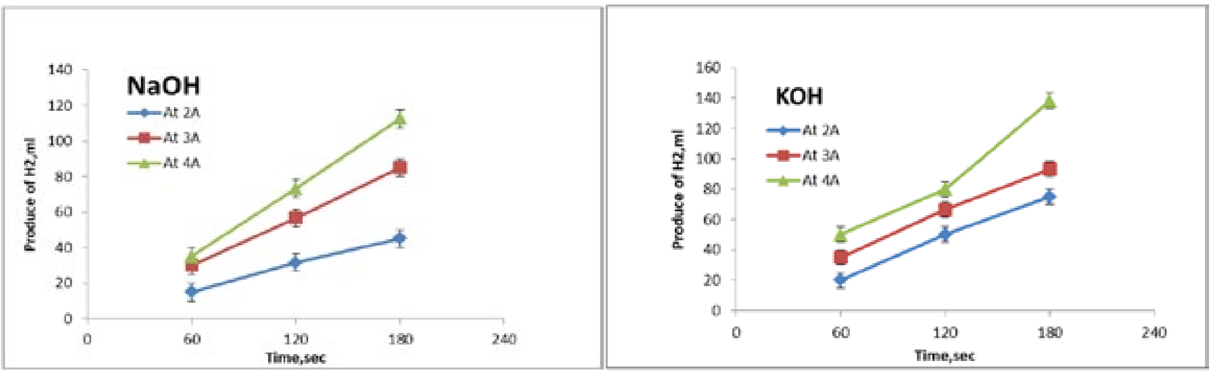

Figure 8. The changes in H_2 production at different currents (10v and 5g/l).

3.3.2. Time vs currents (10v and 10g/l)

The same trend can be noted as the concentration of solution increased at constant voltage (10v and 10g/l). The higher operation time led to the more hydrogen produce. The obtained results show that the higher the applied current led to the best hydrogen production over the tested times. In addition, it was mentioned [25] that the greater pH condition is, the more hydrogen gas volume obtained. pH condition relates with concentration of H+ ion (acidic condition) or OH- (base condition) in solution. Also, more hydrogen production depends on the number of ions present in the electrolyte solution as a time increased. The presents higher H+ ions within the solution due to the dissolution process may play a significant role in H_2 production as time increased. It was clear understand that the steps of formation of H_2 molecules within the electrochemical process controlled the hydrogen production rate. This is related with time, where the increase in tested time result more number of H_2 molecular production, see Figure 9.

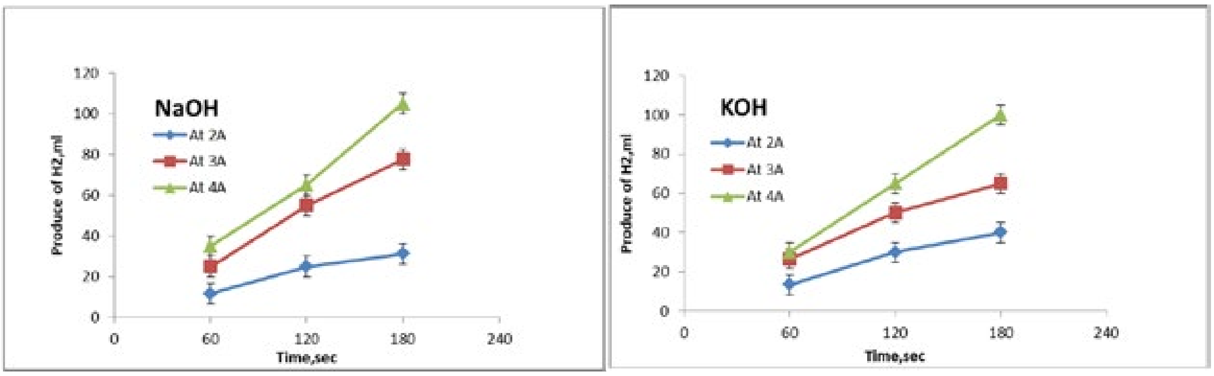

Figure 9. The changes in H_2 production at different currents (10v and 10g/l).

3.3.3. Time vs currents (10v and 15g/l)

Generally, as a time increase the H_2 production increase in both electrolysis mediums within all different currents. Also, the increase in applied current lead to the increase of H_2 production for both NaOH and KOH medium. It clear that the result from KOH medium showing more H_2 production compared with that in NaOH medium as show in Figure 10 This may be attributed to more conductivity obtained of using KOH than that of NaOH as catalyst, see Table 1. The results show that the use of higher concentration of electrolyte (10v &15g/l) led to a little change in the rates of hydrogen as a time increased. This may have explained in terms of as changes in concentrations may affected on the solution conductivity [26].

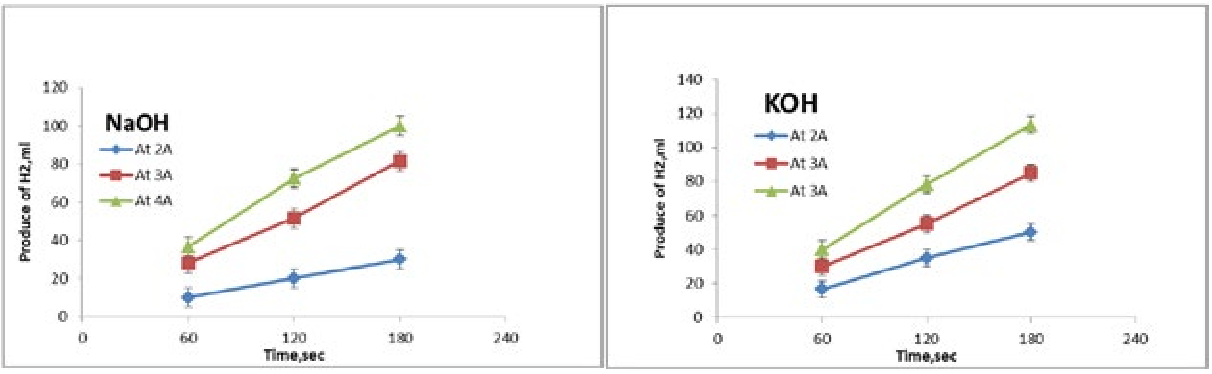

Figure 10. the changes in H_2 production at different currents (10v and 15g/l).

It was reported that the quality of the water is a critical variable in the water electrolysis. The presence many minerals can cause fouling or. contamination coatings which can also be formed on either the cathode and/or anode surface. The solubility of high content of salt may be effected on the water quality due to the increased of mineral in the solution. The increased in such mineral (i.e chloride, magnesium, and calcium) at higher concentrations can affect the electrolysis process.

3.4. Effects of time at different voltages

3.4.1. Time vs voltages (4A and 5g/l)

Generally, as the time increase the rate of H_2 production increase in all different applied voltages. Also, we noted that the use of KOH as electrolyte give higher H_2 production result that of NaOH. The changes in H_2 production was conducted at (4A and 5g/l) at different voltages due to the changes in density of K+ and Na+, this make the potassium ions more activity to produce hydrogen. This can be attributed to increase the conductivity which affected on the improvement of electrolysis process. As well as, more time may be caused in decreasing the density of K+ in the solution where the temperature increased and enhanced the rate of H_2 productivity.
See figure 11.

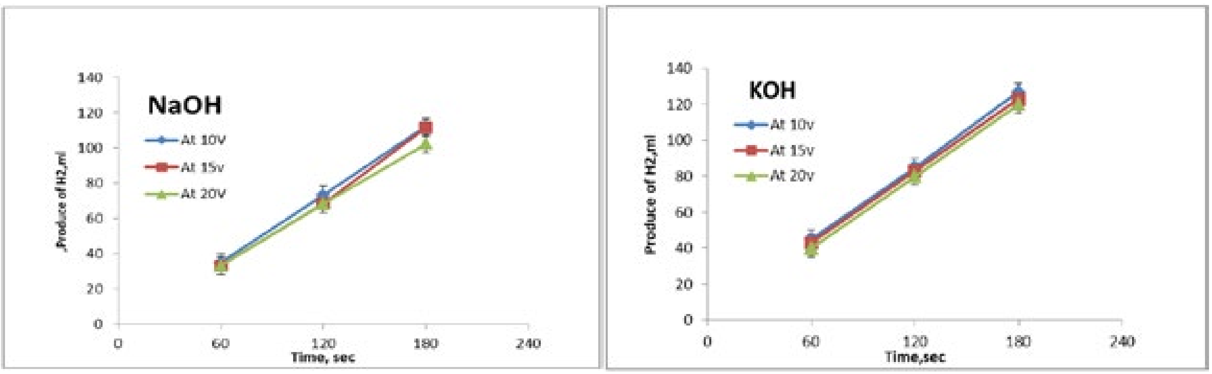

Figure 11. The effect of time on H_2 production at different voltages (4A & 5g/l).

3.4.2. Time vs voltages (4A and 10g/l)

Generally, as time increase the rate H_2 production increase in all different applied voltage. In KOH medium, clear different trend of curve, was noted at applied (20v) compared with (15v). The different can be attributed to the increased of power input which may effected on H_2 production process. In NaOH, there is no change in the trend of the curve (20v) compared with that (15v), which may be referred to that the more applied voltage on all different times has no change in H_2 produce (15v & 20v), see Figure 12.

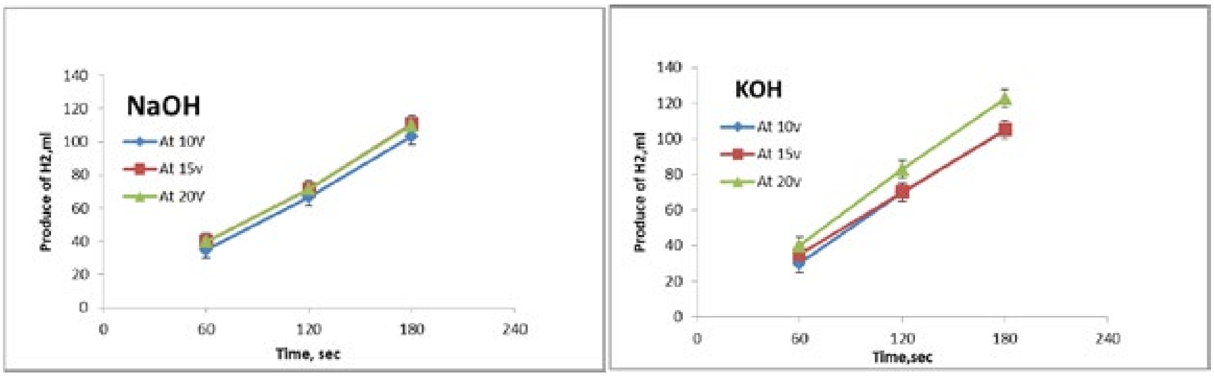

Figure 12. The effect of time on H_2 production at different voltages (4A & 10g/l).

In other words, there is stability in the result as the change in applied voltage in NaOH. However, in KOH, the changes in result may be referred to the activity of K+ ions, which has some affected on splitting process. The results were supported in other work [25], which indicated that the present of KOH may increase the reactivity of the catalyst surface with water to generate gaseous (hydrogen and oxygen).

3.4.3. Time vs voltages (4A and 15g/l)

Generally, sharply increase in H_2 production as a time increase in all different voltages for both electrolysis mediums. There is improvement in H_2 production in KOH medium compared with that in NaOH. The result shown that a little improvement in H_2 production (20v) compared with that (10v and 15v) in NaOH, see Figure 13. It was reported that the greater the voltage causes, the electric current is also greater, and the reaction of decomposition of water that occurs will also be greater and gas formation will also get faster and higher. In addition, the use of stainless steel as an electrode may play a role in this results. The material is used to pass an electric current from a power source to a material. Stainless steel electrodes were chosen in this study because this material has high electrical conductivity, excellent corrosion resistance, making it suitable as an electrode in this electrolysis research. The electrochemical activation of such material in KOH electrolytes improves the activity significantly and that the surface composition can be tailored with KOH concentration [26], this was supported by others [27] which concluded the increased of hydrogen production on stainless steel surface compare with other materials surface.

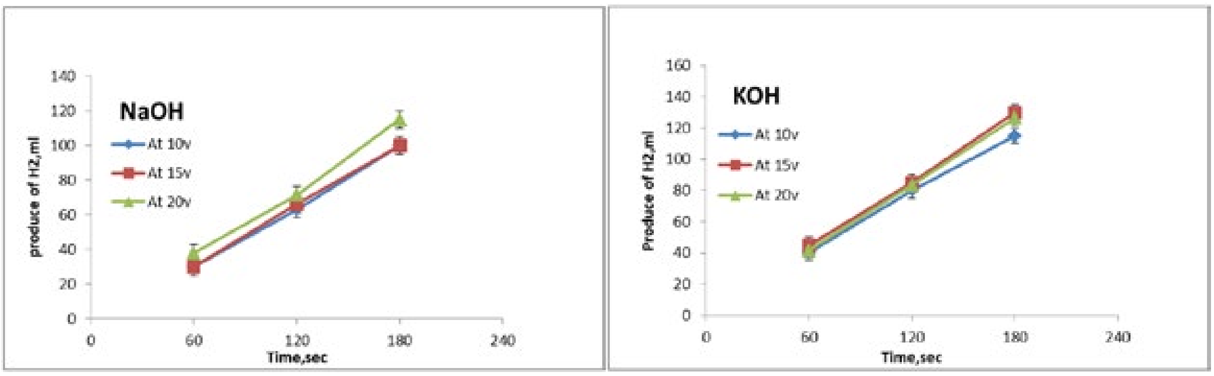

Figure 13. The effect of time on H_2 production at different voltages (4A & 15g/l).

3.5. Faradic Efficiency

From the experimental results, see table 1 it can be seen that faradic efficiency of using KOH is higher than that in NaOH in this work. The reason can be referred to the activity of K+ in the electrolyte medium which may play a role the splitting process. In the literature, it was reported that, both the charge transfer resistance (R ct) and the cell resistance (R cell) decreased with increasing KOH concentration, thus increase in the current density [28]. In addition, it was referred that the presence of both anions and cations play a significant role in the process [29]. This trend can be explained by the introduce of several factors such as pH, conductivity, and, more importantly, specific adsorption of certain cations on the electrode surface [30]. It was observed, for both NaOH and KOH, a decrease in H_2 evolution activity was observed when larger cations (N+ or K+) were present in the solution (high concentration). However, low concentration leads to better hydration of smaller cations which thus are less likely to adsorb on an electrode surface provide more H_2 production. The result showed that there is a little decrease in the faradic efficiency at high concentration 15g/l compared with that in 5g/l. The formation rates of hydrogen and Faradaic efficiency at different current are presented in Table 1. The use of different concentration of NaOH and KOH as catalysts for production hydrogen indicated that a good faradic efficiency was recorded at 5g/l. The formation rate of hydrogen increased and reached a maximum value of 3.37×10^{-7} mol/s.cm^2 at constant 10V, with a corresponding current density of about 49.38 mA/cm^2 and a Faradaic efficiency of 0.13 % for NaOH. A little improved was noted by using KOH and the rate of H_2 recorded of 3.83×10^{-7} mol/s.cm^2 under the same current density of about 49.38 mA/cm^2 where the efficiency was 0.179% for KOH. As the concentration of a catalysts increased (15g/l), the hydrogen production rate decreased and a Faradaic efficiency of 0.119 % for NaOH and 0.137% for KOH. Low hydrogen formation rates with corresponding low Faradaic efficiencies at higher concentration indicate that more than one process occurs at the cathodic electrode within the cell [31].

Table 1. applied current and faradic efficiency for H_2 production.

Operation Parameter			**NaOH**		**KOH**	
Conc. (g/l)	**Current (A)**	**Current density (mA/cm^2)**	**rH$_2$ mol.s^{-1} .cm^{-2}**	**Faradic efficiency η%**	**rH$_2$ mol.s^{-1} .cm^{-2}**	**Faradic efficiency η%**
5g/l	2	24.7	$1.377\text{x}10^{-7}$	0.110	$2.30\text{x}10^{-7}$	0.140
	3	37.1	$2.60\text{x}10^{-7}$	0.135	$2.76\text{x}10^{-7}$	0.149
	4	49.38	$3.37\text{x}10^{-7}$	0.130	$3.83\text{x}10^{-7}$	0.179
10g/l	2	24.7	$9.19\text{x}10^{-8}$	0.071	$1.22\text{x}10^{-7}$	0.095
	3	37.1	$2.37\text{x}10^{-7}$	0.120	$1.99\text{x}10^{-7}$	0.101
	4	49.38	$3.22\text{x}10^{-7}$	0.125	$3.06\text{x}10^{-7}$	0.119
15g/l	2	24.7	$9.19\text{x}10^{-8}$	0.071	$1.53\text{x}10^{-7}$	0.119
	3	37.1	$2.45\text{x}10^{-7}$	0.127	$2.60\text{x}10^{-7}$	0.135
	4	49.38	$3.06\text{x}10^{-7}$	0.119	$3.52\text{x}10^{-7}$	0.137

To calculate efficiency can be following this steps:

1. Convert the amount of Hydrogen from ml to mol.
Example: 45ml = 45/ (1000x22.4) = $2.0089\text{x}10^{-3}$ mol.
Where 22.4 is ideal gas volume.

2. Calculate the rate of Hydrogen by follow equation:

$$r_{H_2} = \frac{V}{t.A}$$

Where A is the cathode geometric surface area ($81cm^2$), V is the volume of solution (mol), t (sec) is required for hydrogen collection.
Example:

$$r_{H_2} = \frac{2.0089\times10^{-3}}{180\times81} = 1.377x10^{-7}\ mol.s^{-1}.cm^{-2}.$$

3. Calculate efficiency by follow equation:

$$\text{Faraday efficiency }\% = \frac{2F\times r_{H_2}}{I}\times100$$

Where r_{H_2} is the hydrogen formation rate ($mol/sec.cm^2$), I is the generated current density (mA/cm^2) and F is the Faradaic constant (96485 C/mol).
Example:

$$I\ =\ \left(2A\times\ 1000\right)/\,81\ =\ 24.7\ mA.cm^{-2}$$

$$\eta = \frac{2\times96485\times1.277\times10^{-7}}{24.7}\times100 = 0.11\%$$

4. CONCLUSIONS

The factors that affect the amount of hydrogen production, such as voltage, amperage and time, the concentration and electrolysis type (KOH & NaOH) were discussed. The following conclusions can be reported as.
1. In 5g/l, the production of H_2 at different voltages and constant current at 4A is decreased in both (NaOH and KOH) electrolyte mediums. However, in10g/l, H_2 values was stable at 15v and 20v in NaOH. But, it was increased in both 15 and 20v into KOH medium.
2. Rate of H_2 production increasing with increase time at different currents and concentrations and the best recorded result was (140ml) at 3 min, under 4A and 5g/l. Also, hydrogen is increased at different voltages and the best recorded result (120ml) at 3 min, under 20v, and 10g/l. So this was clear at 20v, but generally the production is stability with time at different voltages. All these finding was for KOH medium.
3. The results upon the effect of electrolyte concentrations at different currents showed that the best value of H_2 was in 15g/l (4A). Also, the effect of electrolyte concentrations at different voltages on H_2 showed that the best H_2 values were at high concentration (15g/l) and the applied voltage of (15v).
4. Good efficiency was recorded at the maximum value of H_2 production for two electrolysis mediums, at 5g/l when the voltage is constant (10v) and current density ($49.38mA/cm^2$), the efficiency was 0.130%, for NaOH, and it was 0.179% for KOH.

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