

HYDROGEN PRODUCTION FROM ALTERNATIVE AQUEOUS SOURCES: A FEASIBILITY STUDY

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ABSTRACT

This paper presents the production of hydrogen from various aqueous sources (de-ionized water, fufu effluent, sea water, run-off water, tap water, and urine). Two sets of hydrolysis experiments (with and without the dissolution of NaCl (35 g/l) into the aqueous media) were conducted using 12 V (DC supply) with graphite electrodes. The current utilized and volume of hydrogen produced was measured, while hydrogen flow rate, power, and effectiveness were estimated. The significance of the addition of NaCl to the aqueous media was analyzed using a *t*-test. It was observed that the dissolution of NaCl into the aqueous media had an appreciable effect on the values of pH, volume and flow rate of hydrogen produced, current utilized, power consumed, and effectiveness compared to the values obtained without NaCl dissolution. This was corroborated by the result of the *t*-test ($t_{\text{critical}} (2.0452) < t_{\text{observed}} (4.1139)$ with a *p*-value of 0.0032 at 95% confidence interval), indicating the significance of the dissolution of NaCl into the media. The results showed that urine, followed by sea water, fufu effluent, run-off water, tap water, and de-ionized water, had the highest volume and flow rate of hydrogen, whereas the value of effectiveness was highest for de-ionized water, followed by tap water, sea water, urine, fufu effluent, and run-off water. Run-off water and fufu effluent were also demonstrated to be potential sources of hydrogen production outside urine and sea water.

Keywords: Hydrogen production; Power; Nigeria; Urine; Wastewater

1. INTRODUCTION

The health and environmental implications of burning fossil fuels are of global and local concern. Some disadvantages of fossil-based fuels include their significant contribution to global warming, which leads to climate change and has caused several natural disasters, extreme weather conditions, widespread diseases, ocean and sea level rise, etc.; their non-renewable and unsustainable characteristics given the finite nature of existing reserves; and acid rain, which irritates the skin and destroys vegetation (Giwa et al., 2010; Saksono et al., 2015).

A key advantage of hydrogen (H₂) as an energy carrier is that carbon dioxide is not produced when it is burned, only water vapor. Apparently, H₂ does not pollute and impact the environment negatively; hence, a “Green Environment” can be attained. H₂ has the potential to run a fuel-cell engine with greater efficiency compared to an internal combustion engine

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(Nasruddin et al., 2016a). With the use of an equal quantity of fuels, a fuel cell-car (H_2 -powered) will travel at least twice the distance as a gasoline-fueled car (Amoo & Fagbenle, 2014).

H_2 is a multipurpose energy carrier with the potential for widespread use in electricity generation for the institutional, industrial, residential, commercial, transportation, and agricultural sectors. H_2 has almost three times the energy content as natural gas and produces environmentally friendly emissions upon combustion (Nasruddin et al., 2016b). H_2 , unlike oil and gas, is not a fuel but rather a medium for transporting energy. H_2 can be produced from a variety of feedstocks. These include fossil resources (natural gas) as well as renewable resources (biomass and water) with input from renewable energy sources (wind, solar, wave, or hydro-power).

Various process technologies can be used for H_2 production, including chemical, biological, electrolytic, photolytic, and thermo-chemical (Bouazizi et al., 2014; Holladay et al., 2009; Slamet et al., 2015). Local feedstock availability, the level of development of the technology, market demand, and costs and policy issues will largely determine the selection and timing of the different options for H_2 production. Numerous feedstocks (methane from different sources, agricultural and municipal wastes), available on a geographical basis, can be explored for H_2 production. However, electrolysis of water has been widely used for large-scale production of pure H_2 , especially from renewable sources, with about 5% of H_2 produced from renewable sources (via electrolysis of water) and around 95% synthesized from fossil fuels (through gasification, pyrolysis, steam reforming etc.) (Slamet et al., 2015). However, these processes are still intermediate technologies since they require a large amount of energy to produce H_2 (Luo et al., 2009). For H_2 to be a renewable energy carrier, it should be produced from renewable energy sources (Ni et al., 2006). However, about 95% of H_2 produced recently is from non-renewable sources, such as natural gas steam reforming (Ni et al., 2006). Consequently, it is imperative to identify and develop feasible wastewater sources for practical, renewable H_2 production.

Several chemicals, including hydrazine and metal hydrides, have been considered as promising H_2 sources (Wang et al., 2012). Nevertheless, most of these are highly toxic, costly, and flammable; in addition, their supply is not sustainable (Wang et al., 2012). Societal need for alternative energy sources has motivated recent research on the utilization of wastewater as a useful fuel (Boggs et al., 2009). Several studies have investigated wastewater from various sources (milk water, kitchen water, urine, olive pucker water, etc.) for the production of H_2 (Aggarwal et al., 2013; Boggs et al., 2009; Slama, 2013; Wang et al., 2012) with the aim of accomplishing fuel production and remediation of harmful compounds that currently pollute the environment (Boggs et al., 2009; Slama, 2013). Prominent among these studies was one in which H_2 was produced from urine, as reported by other authors (Aggarwal et al., 2013; Boggs et al., 2009; Slama, 2013).

To the best of our knowledge, the literature on the production of H_2 from any feedstock is scarce in Nigeria, although a recent study by Amoo and Fagbenle (2014) reported an assessment of the economic impact of H_2 as a future energy carrier on the transportation, power, and energy sectors of the country. This paper presents for the first time the production of H_2 from different aqueous sources. Thus, the aim of this study was to investigate the feasibility of H_2 production from selected aqueous media (AM) using electrolysis.

2. MATERIALS AND METHODS

2.1. Materials, Apparatus, and Equipment

This study focused on the production of H₂ from selected AM using electrolysis. The AM investigated in this study were fufu effluent (FE), de-ionized water (DIW), sea water (SW), urine, run-off water (ROW), and tap water (TW). The SW was collected at Bar beach, Lagos Island, Lagos State, Nigeria, while the urine (early morning) was collected from the authors. The availability of these media in the immediate environment informed their selection for this study. The apparatus used for this study included an electrolytic chamber, common salt (NaCl; 99% pure), graphite electrodes, a collecting chamber, a burner, connecting tubes, a 12 V (DC) battery, and other glassware. The equipment utilized included a pH meter (model: pH 211), an EC meter (model: HI 86303), and a salinity meter (model: HI 86303). These meters were all produced by Hanna Instruments, USA.

2.2. Characterization of Aqueous Samples

Prior to the electrolysis (hydrolysis) of the AM selected for the production of H₂ in this study, the aforementioned media were tested for their pH, resistivity, and salinity using the pH meter, EC meter, and salinity meter, respectively.

2.3. Experimental Setup and Procedure

The DIW was used as a control experiment as it contains no free ions that could affect the experimental results. Two sets of experiments were conducted without a change in the experimental setup. The first set of experiments was carried out without the addition of common salt (NaCl) to the AM; whereas the second set of experiments was conducted with the addition of NaCl. This was done to investigate the effect of NaCl on H₂ production from the AM. These experiments were run for a period of 30 mins. Common salt was used as an additive to reduce the activation energy of the hydrolyzed liquid and thus increase the production of H₂. Common salt was also selected due to its availability and cost implication. The concentration of NaCl added to the AM was 35 g/l, as preliminary studies indicated that no significant improvement in H₂ production was observed when less NaCl was added.

For the two sets of experiments, 1 litre of the various aqueous sources was electrolyzed in the electrolytic chamber by passing a 12 V direct current through it. Graphite electrodes were used as the anode and cathode of the experimental setup because they are cheap and readily available. Since H₂ was produced at the cathode in this study, the cathode was keenly observed while activity at the anode was ignored. It is worth noting that the experiments were carried out under an ambient condition at room temperature (27°C). H₂ is naturally explosive at high pressures and temperatures and as such was not stored. The H₂ produced was collected over water, and the volume of displaced water was measured as the volume of H₂ produced based on Archimedes' Principle. This was achieved by filling the collection chamber to the brim with water prior to the commencement of the experiments. A connecting tube was used to supply the collection chamber with H₂, while another connecting tube was used to collect the displaced water, which was thereafter measured. The H₂ produced was dried using borax as a drying agent and then passed into a burner. The H₂ was burnt using the burner for boiling water. The H₂ produced could be used for domestic as well as industrial applications and can also be fed into a fuel cell to produce electricity. The experimental setup of this study and the schematic diagram are presented in Figures 1 and 2, respectively. Three replicates of the two sets of experiments were carried out with the average values reported in this study.

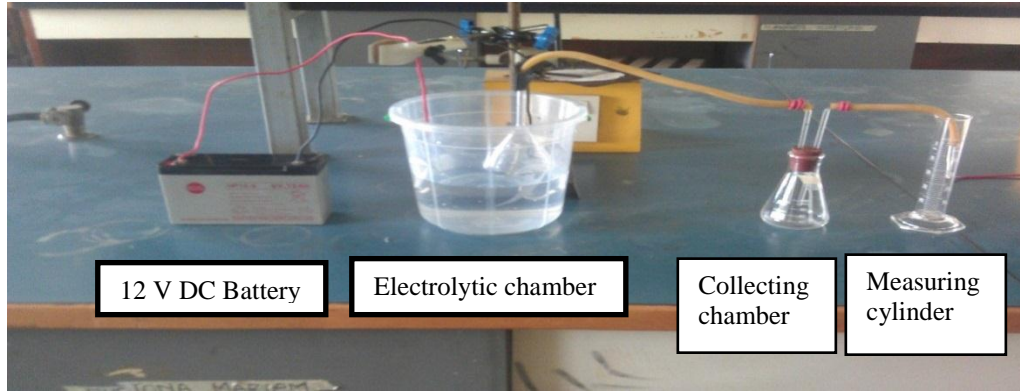


Figure 1 Pictorial view of experimental setup

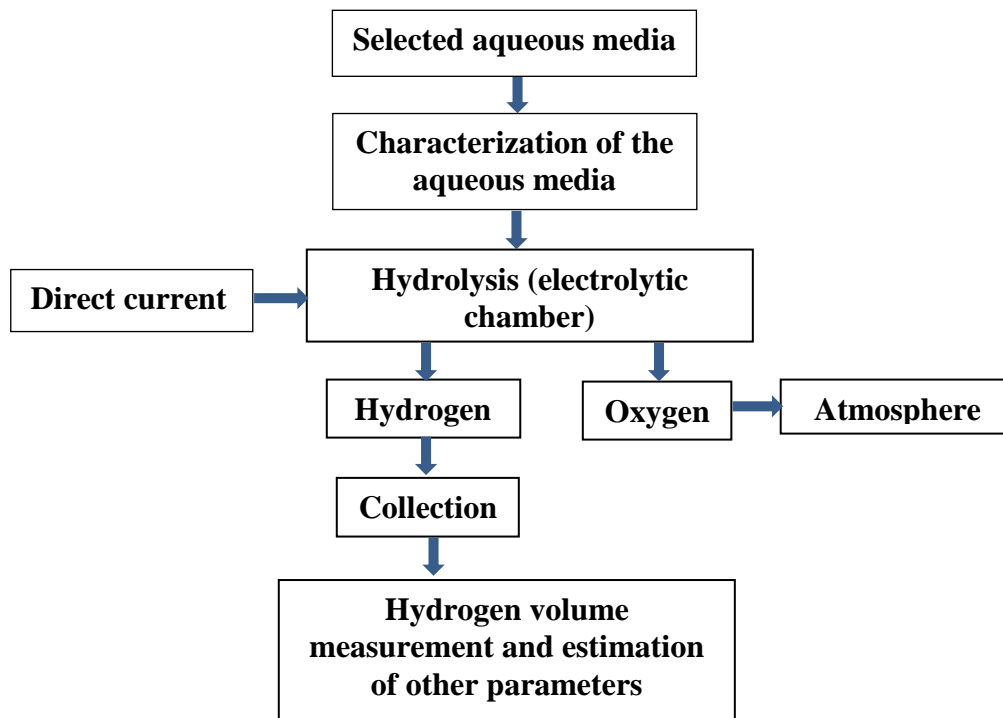


Figure 2 Schematic diagram of the study

2.4. Hydrolysis Parameters

The volume and flow rate of the H₂ collected, the amount of current utilized and electric power consumed, and the effectiveness of the hydrolysis of all the AM were estimated using Equations 1–3. Also, the Faradic, thermal, and energy efficiencies were estimated using Equations 4–7 (Zeng & Zhang, 2010).

$$Q_V \left(\frac{g}{h} \right) = (v \text{ (cm}^3) \times \rho_{\text{hydrogen}} \left(\frac{g}{\text{cm}^3} \right)) / t(h) \quad (1)$$

$$P_a(W) = V \times I \quad (2)$$

$$\varepsilon \left(\frac{\text{kWh}}{g} \right) = 0.5 P_a / 1000 Q_V \quad (3)$$

$$\eta_{\text{energy}} = \frac{283.8 \text{ (kJ)}}{VIt} \quad (4)$$

$$\eta_{\text{faradic}} = \frac{1.23}{E_{\text{cell}}} \quad (5)$$

$$\eta_{thermal} = \frac{1.48}{E_{cell}} \quad (6)$$

where Q_V is the flow rate of H₂ produced (g/h); v is the test tube volume (cm³); t is the time taken (h); $\rho_{hydrogen}$ is the density of H₂ (0.00008988 g/cm³); P_a is the power of electrolyzer (W); V is the voltage (V); I is the current (A); ε is the effectiveness of electrolysis (kWh/g); η_{energy} is the energy efficiency at 25°C; $\eta_{faradic}$ is the Faradic efficiency at 25°C; $\eta_{thermal}$ is the thermal efficiency.

3. RESULTS AND DISCUSSION

3.1. Preliminary Study

A preliminary study was carried out in order to provide an overview of the main study. A glowing splint introduced to the gas obtained at the cathode (H₂) burned with a pale blue flame and made an explosive sound. This confirmed that H₂ was produced at the cathode.

3.2. Characterization of Aqueous Media

The AM from various sources selected for this study were characterized by their pH, resistivity, and salinity. The pH, salinity, and resistivity were measured before their hydrolysis and without the addition of NaCl, while only pH was determined after the addition of NaCl. Table 1 presents the aforementioned properties for the AM used in this study.

3.2.1. pH value

The pH is a measure of the acidity or alkalinity of solutions on a scale from 1 to 14, with ultra-pure water possessing a neutral pH of 7.0. The pH of the AM before and after the addition of NaCl is provided in Table 1. Prior to the addition of NaCl, FW, urine, ROW, and TW were found to be acidic, with a pH value of less than 7; while DIW and SW were alkaline, with pH values above 7. Of all the measured AM, FW was the most acidic, with a pH value of 5.09; while the most basic AM was SW (pH = 7.92). After the addition of NaCl, only two of the four acidic media were found to have pH values in the acidic region. As seen in Table 1, FE (pH = 5.12) and urine (pH = 6.4) are the only acidic AM, while the rest reside in the basic region, with pH values above 7. Of the AM used in this study, SW had the high alkalinity, followed by DIW, ROW, tap water, urine, and FE. The change in pH was observed to be significant for ROW (0.4) and urine (0.2), while the rest witnessed slight changes (0.02–0.03) in pH. Generally, the pH of all the AM was changed by the dissolution of NaCl into them. It can be observed (Table 1) that only SW had a pH higher than the control aqueous medium (DIW), which may be attributed to the presence of salts in sea water.

Table 1 Properties of aqueous media from various sources

Liquids	Before adding salt		After adding salt		pH difference
	pH	Resistivity (MΩ/cm)	Salinity (mg/l)	pH	
DIW	7.42	4.20	0.01	7.44	0.02
FE	5.09	4.56	10.01	5.12	0.03
SW	7.92	110.10	31.20	7.95	0.03
Urine	6.20	50.20	25.20	6.40	0.20
ROW	6.70	6.20	21.10	7.10	0.40
TW	6.99	5.00	11.20	7.01	0.02

3.2.2. Salinity

Salinity refers to the concentration of dissolved salts in water, measured in terms of total dissolved salts (TDS) per unit of mg/l. The salinity of DIW was found to be 0.01 mg/l, which is the smallest value of salinity measured for this study (see Table 1). This result implies that DIW

contains as little as 0.01 mg of dissolved salt per litre, which can be attributed to the fact that the water has been demineralized. It can be observed in Table 1 that SW had the highest salinity (31.2 mg/l), followed by urine (25.2 mg/l), ROW (21.1 mg/l), TW (11.2 mg/l), and FE (10.1 mg/l). It can be deduced from these results that the level of salinity of the AM can be linked to the mineral contents present in them. For instance, the mineral contents found in FE include phosphate ions, chloride, and magnesium, which would have been dissolved into the water during the fufu sieving process. Also, the dissolution of chloride, fluoride, and other compounds in TW and ROW, and the dissolution of chloride, magnesium, and potassium ions found in urine, can be attributed to their level of salinity. In the present study, the salinity of SW was the highest (31.2 mg/l compared to other AM). In addition, sodium and chlorine ions are the predominant ions in sea water, and the concentrations of magnesium, calcium, and sulphate are also substantial.

3.2.3. Resistivity

Resistivity is the electrical resistance of a conductor of unit cross-sectional area and unit length, and is used to compare the ability of various materials to conduct electricity. In this study, resistivity is a measurement of the opposition of AM to the flow of a current over distance. Pure water has been reported to have a resistance of 18.2 MΩcm (Bevilacqua, 1998). From Table 1, it can be observed that SW and DIW have the highest and lowest resistivity—110.10 MΩcm and 4.2 MΩcm, respectively. It can also be seen that the control medium has the lowest resistivity due to its relative lack of minerals, while SW has the highest resistivity because of its high mineral content. It is evident that the higher the salinity of the aqueous medium, the greater its ability to resist the flow of current through it (Table 1). The measured resistivity of the AM was highest for sea water, followed by urine, ROW, tap water, FE, and DIW.

3.3. Hydrogen Production Parameters

3.3.1. Volume of hydrogen collected

The volume of H₂ liberated during hydrolysis of the various AM with and without dissolution of NaCl is shown in Figure 3. In the first set of experiments (without NaCl), it was observed that urine, SW, and FE released the most H₂, with values of 2.0, 1.9, and 1.3 cm³, respectively. DIW produced the lowest volume of H₂ (0.1 cm³). These results may be added to the chemical composition and mineral content of these AM, with DIW being demineralized. The second set of experiments was characterized by the dissolution of NaCl in the AM, and the quantities of H₂ produced are presented in Figure 3.

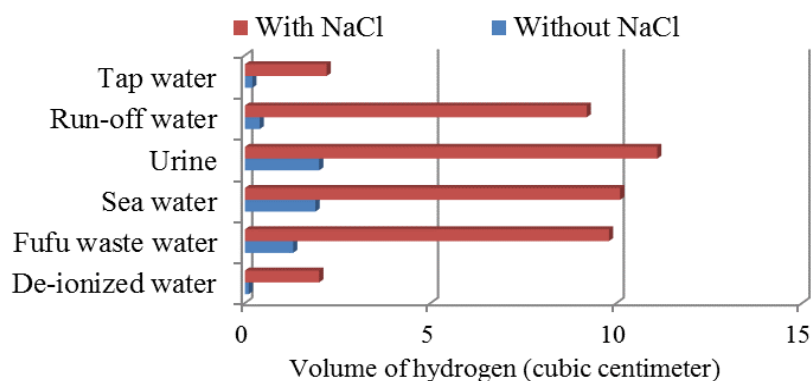


Figure 3 Volume of hydrogen produced during hydrolysis

SW, urine, FE, and ROW yielded high volumes of 10.1, 11.1, 9.8, and 9.2 cm³, respectively; while volumes of 2.0 and 2.2 cm³ were recorded for DIW and TW, respectively. These results demonstrate a considerable increase in the volume of H₂ liberated for all the AM due to the

addition of NaCl. From Figure 3, ROW exhibited the most significant change (from 0.4 cm³ to 9.2 cm³) in H₂ volume as a result of the dissolution of NaCl. This was closely followed by ROW (8.8 cm³), FE (8.5 cm³), and SW (8.2 cm³). However, DIW yielded the smallest change (1.9 cm³) in H₂ volume, slightly less than that of TW (2 cm³). This may be connected to the presence of ions in TW, as the same pH difference (0.2) was recorded for both AM (see Table 1). Apparently, the salinity, resistivity, and pH values of the AM earlier reported under sub-section 3.2 were found to influence the volume of H₂ produced.

3.3.2. Flow rate of hydrogen liberated

The flow rates of H₂ produced from the AM are presented in Figure 4. These values were estimated using Equation 1. Flow rates of H₂ from the hydrolysis of DIW, FE, SW, urine, ROW, and TW without the addition of NaCl were 0.032, 0.421, 0.615, 0.647, 0.129, and 0.065 g/h, respectively. It can be observed that the same pattern exists in both Figures 3 and 4. This is because a linear relationship exists between the two parameters. Also, the flow rates of 0.647, 3.171, 3.268, 3.592, 2.977, and 0.712 g/h were estimated for DIW, FE, SW, urine, ROW, and TW, respectively. Under the two sets of experiments, urine had the highest flow rate while DIW had the lowest. From Figure 4, it is apparent that the dissolution of NaCl in the media increased the flow rate of H₂ production. The flow rates (without NaCl addition) of three of the AM (FE, SW, and urine) investigated were found to be in agreement with previous studies, which reported 0.33 g/h (urine) and 0.78 g/h (industrial wastewater) (Abdel-Monem et al., 2013; Mahmoud et al., 2013). Also, the H₂ flow rates of TW, urine, and FE on dissolution with NaCl as obtained in this study were found to be considerably higher than those reported in a previous work (Slama, 2013). In addition, the flow rates of H₂ (with and without NaCl) as achieved here were within the range of H₂ flow rates (0.0749–11.68 g/h) reported in the literature, except for DIW and TW without NaCl dissolution (Call & Logan, 2008).

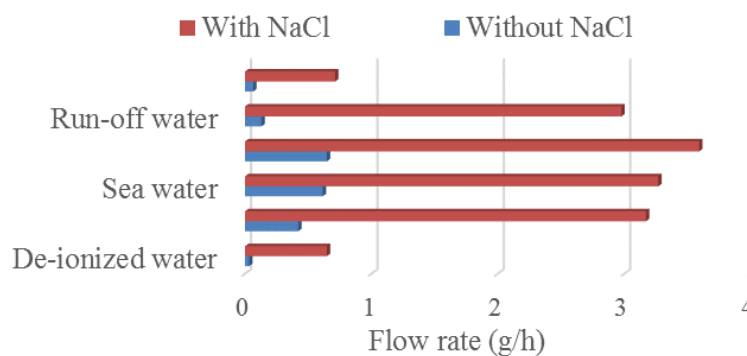


Figure 4 Flow rate of hydrogen produced during hydrolysis

3.3.3. Current utilized

An illustration of the amount of current involved in the hydrolysis (with or without dissolution of NaCl) of the various AM is provided in Figure 5. It can be observed that without the dissolution of NaCl, 0.03, 0.04, 0.18, 0.2, 0.04, and 0.04 Ampere (A) were utilized for the hydrolysis of DIW, FE, SW, urine, ROW, and TW, respectively. Urine (0.2 A) and SW (0.18 A) demonstrated a relatively high current compared to the other AM, in the range of 0.03–0.04 A. As expected, the quantity of current used during hydrolysis increased when NaCl was dissolved into the AM. The values of 0.2, 0.21, 0.93, 0.87, 0.24, and 0.21 A were measured for the hydrolysis of DIW, FE, SW, urine, ROW, and TW, respectively, when NaCl was dissolved within them. Urine and SW were expected to provide high resistance to current flow due to their relatively high resistivity, as evident in their consumption of more current during hydrolysis than other AM.

3.3.4. Electric power consumed

Figure 6 shows the power consumed during the hydrolysis of the AM. For the first set of experiments, the power consumed by the hydrolysis of DIW, FE, SW, urine, ROW, and TW was 0.3, 1.0, 2.2, 2.4, 0.8, and 0.5 W, respectively. These values can be attributed to the level of resistance of the AM to the flow of current, which is due to the chemical composition of the AM. It can also be seen that the hydrolysis of the DIW consumed the lowest power (0.3 W), while urine hydrolysis consumed the most power (2.4 W). With the dissolution of NaCl into the AM, the power consumed during hydrolysis was determined to be 2.4 W (DIW), 5.5 W (FE), 10.4 W (SW), 11.2 W (urine), 4.4 W (ROW), and 2.5 W (TW). These values demonstrated a considerable increase when compared to those obtained without the addition of NaCl. Urine and SW showed a significant change of 8.8 and 8.2 W, respectively, which can be linked to their considerably high resistivity and moderately high salinity (see Table 1). The power consumed for the production of H₂ from TW, urine, and FE after the dissolution of NaCl was moderately lower than reported in an earlier study (Slama, 2013).

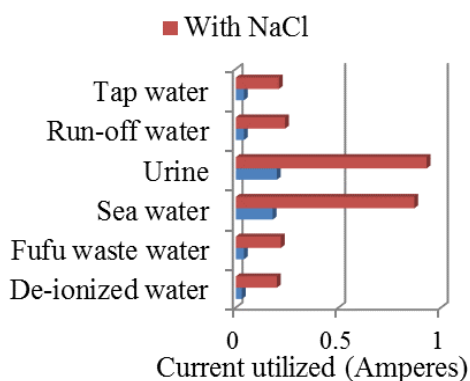


Figure 5 Current utilized during hydrolysis

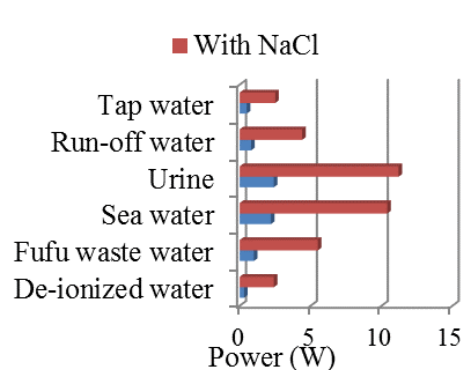


Figure 6 Power consumed during hydrolysis

3.3.5. Effectiveness of hydrolysis

In relation to this study, effectiveness is the ratio of the power consumed during hydrolysis of the AM to the volume of H₂ produced. The effectiveness of the hydrolysis of the AM was estimated using Equation 3 and the results are shown in Figure 7. For the first set of experiments, DIW was observed to have the highest value of effectiveness (20.23 kWh/g), closely followed by TW (13.35 kWh/g), urine and ROW (6.68 kWh/g), SW (6.32 kWh/g), and lastly, FE (2.05 kWh/g). The high values of effectiveness estimated for DIW and TW were due to the production of a low volume of H₂ from low power consumption (Figures 3 and 6). The high power consumed in the production of a high volume of H₂ was responsible for the moderate values of effectiveness for SW, urine, and ROW. However, FE recorded the lowest value of effectiveness (2.05 kWh/g) because this medium produced a relatively high volume of H₂ with moderate power consumption. For the experiment involving the addition of NaCl into the AM, the effectiveness of DIW, FE, SW, urine, ROW, and TW was 6.68, 1.63, 5.75, 5.59, 1.52, and 6.07 kWh/g, respectively. The same pattern of effectiveness can be seen for the two experiments, except in the case of ROW. The low effectiveness value of ROW is due to the fact that the addition of NaCl has the highest effect on this medium in the production of H₂, as mentioned earlier (see Figure 3). The power consumption achieved in this study is considerably lower than the 11 kWh/g (industrial wastewater) and 196 kWh/g (urine) reported in previous studies (Abdel-Monem et al., 2013; Mahmoud et al., 2013) and may be due to the lower power consumption coupled with increased H₂ production demonstrated in this work.

3.3.6. Hydrogen production efficiencies

The energy efficiency of H₂ production for each medium was estimated using Equation 4 and is

provided in Figure 8. It can be observed that higher energy efficiencies were achieved for DIW (0.066 and 0.438), FE (0.055 and 0.328), ROW (0.063 and 0.328), and TW (0.066 and 0.328) compared to those of SW (0.015 and 0.073) and urine (0.014 and 0.066) with and without NaCl dissolution in the media. These values are generally low because H₂ production was carried out in this study for 30 mins and a longer duration would likely increase H₂ yield.

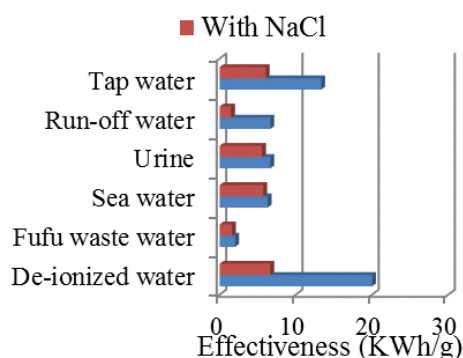


Figure 7 Effectiveness of hydrolysis

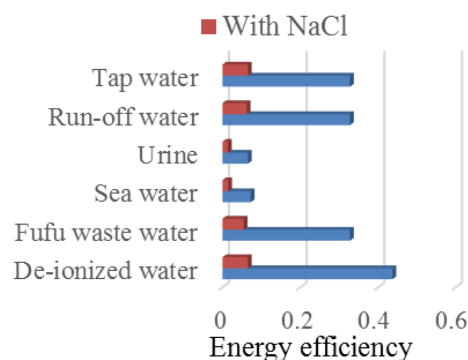


Figure 8 Energy efficiency of aqueous media

The energy efficiencies were found to be substantially higher without the addition of NaCl, which can be attributed to the dissolution of NaCl in the media, in turn lowering the activation energy and, subsequently, reducing the energy efficiency by increasing both current and power consumed during hydrolysis. It is pertinent to note that the energy efficiencies reported here did not take into consideration the volume of H₂ produced by each medium, as is the case with effectiveness.

Faradic efficiency (μ_{Faradic}) expressed in percent is the theoretical energy required to break water molecules in the actual cell voltage. It is also a measure of cell efficiency considering cell voltage. In this study, the μ_{Faradic} calculated using Equation 5 was 10.25% at 25°C. The Faradic efficiency obtained in this work was less than 100% since there were losses in the cell during the hydrolysis; this outcome is in agreement with the literature (Zeng & Zhang, 2010). Thermal efficiency (μ_{thermal}) is a definite energy input in the actual cell voltage expressed in percentage. Moreover, it is the additional cell voltage above the reversible voltage required to maintain the thermal balance. The thermal efficiency of the hydrolysis of the AM was estimated to be 12.33% (at 25°C). Since the hydrolysis is exothermic in nature, it is expected that the thermal efficiency would be less than 100% as heat would be lost to the environment. Comparison of this work with a previous study (which used microbial electrolysis cells for H₂ production) showed that the thermal efficiency for the production of H₂ from TW and FE on dissolution with NaCl was slightly higher, whereas the thermal efficiency for urine was slightly lower (Slama, 2013). However, the use of microbial electrolysis cells has been reported to have higher efficiency than traditional electrolysis (Call & Logan, 2008).

3.4. Statistical Analysis of Parameters

A *t*-test was conducted on the data (volume of H₂ produced, current and power consumed, and effectiveness) obtained in this study. The purpose of the *t*-test was to check the significance of the dissolution of NaCl into the AM during hydrolysis. Correlation coefficients and *p*-values of 0.827 and 0.006, 0.340 and 0.053, 0.999 and 0.024, 0.997 and 0.012, and 0.340 and 0.053 were obtained for the volume of H₂, the flow rate of H₂, the current utilized, the power consumed, and effectiveness, respectively. These results showed that the dissolution of NaCl into the AM was significant, as evident in the *p*-values, except for the flow rate of H₂ and effectiveness. Also, positive and strong relationships existed between the data (hydrolysis with and without NaCl dissolution) for all the parameters except effectiveness. In considering the data garnered

from the two sets of experiments, the t -test showed that $t_{\text{critical}} (2.0452) < t_{\text{observed}} (4.1139)$ with a p -value of 0.0032 at 95% confidence interval and a correlation coefficient of 0.8507. This revealed that the obtained hydrolysis data (with and without dissolution of NaCl) were statistically dissimilar, which further supports the significance of NaCl dissolution in AM in the production of H₂.

4. CONCLUSION

This study presented the feasibility of H₂ production from AM via hydrolysis. Two sets of experiments were conducted with and without the dissolution of NaCl in the AM. Of all the AM hydrolyzed, with or without NaCl dissolution, urine, SW, ROW, and FE yielded a relatively high volume of H₂ compared to the other AM. It can be seen from the resulting trend that both the salinity and resistivity of the AM influenced the volume and flow rate, current, and power consumed. In terms of effectiveness for hydrolysis carried out without the dissolution of NaCl, FE, SW, and urine yielded relatively high values, whereas ROW, FE, SW, and urine gave higher values when NaCl was dissolved within them. The t -test carried out on the obtained data demonstrated the significance (p -value = 0.00032) of NaCl dissolution in the AM. This study revealed the possibility of using ROW and FE (which constitutes an environmental nuisance) as an H₂ production source outside the use of SW and urine.

5. ACKNOWLEDGMENT

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