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Harnessing Egypt's Formation Water for Green Hydrogen Production via Electrolysis

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***Abstract*—**The purpose of this study is to utilize the formation water produced in Egyptian oil and gas wells as a feedstock for electrolysis to produce hydrogen gas. In this study, hydrogen is produced via electrolysis of such highly-saline waste liquid (formation water) which is eventually produced together with oil/gas. It also, emphasizes the benefits of employing the electrolysis technique (as eco-friendly technique, which uses electrons as clean reagents, with zero-CO_2 emission) while producing high purity hydrogen gas and outlines the valorisation of wasted formation water, to be a potential source of hydrogen. Lastly, the article outlines the procedures used for producing hydrogen using electrolysis of various electrolytes, for the purpose of comparison, i.e., acidic, alkaline, and neutral media using two types of electrodes' materials, i.e., graphite rods and aluminium sheets as the cathodes and the anodes during the electrolysis process. Current-potential relations are recorded with an aim to check the method's efficiency levels. The research concludes that a power saving of more than 75% could be achieved for hydrogen gas production using formation water compared to the case of using acidic electrolyte. Moreover, the exploration of hydrogen production from different formation water samples demonstrated the versatility and potential of these sources, especially when mixed, offering promising possibilities for sustainable electrolysis. These results have profound implications for advancing sustainable energy production and offer valuable contributions to the ongoing efforts towards decarbonisation and environmental sustainability**.** This opens up the opportunities and potential benefits of green hydrogen production in Egypt.

***Keywords*—** Green Hydrogen, Electrolysis, Formation Water, Water cut, Oil production.

1. INTRODUCTION

For a long time, hydrogen has been promoted as a sustainable and clean substitute for conventional fossil fuels. Green hydrogen, in specifically, shows immense potential because it comes from renewable energy sources. It is produced via electrolysis, where no-carbon in involved in the production cycle. Therefore, it can help both satisfy energy requirements and reduce greenhouse gas emissions. The process of electrolysis occurs depending on electricity using alternative energy sources, such as solar and/or wind energy making it a sustainable process [1].

It is well-reported that hydrogen gas can be produced via different technologies including microbial hydrogen production, photocatalytic water splitting and water electrolysis together with the use of natural gas and coal for hydrogen gas production. A coloured-code for hydrogen gas depends on its production procedure. This research's focus as previously established, water electrolysis is a method of splitting water into hydrogen and oxygen through electricity, which itself includes different electro-catalysts [2]. The latter is a proven technology for the production of high purity hydrogen with insignificant amount of impurities.

A well-known problem in several Egyptian oil and gas fields, especially the older ones, is *"water cut"*. Water cut % describes how much water from the reservoir's formation is produced along with oil and/or gas production. The water cut increases as these fields become older because naturally occurring water is encroaching into the reservoir. Zohr field being the largest gas field in Egypt, is a recent example of this issue. According to studies and data collection, water infiltration difficulties were having a substantial influence on production halfway in the year 2023, resulting in a reduction in output [3].

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In this regard, green hydrogen production using electrolysis of formation water from Egyptian wells is a viable option for clean and sustainable energy [4]. Electrolysis can be used to convert the formation water into hydrogen gas and oxygen gas-depending on salinity of the water, which can then be utilized as a fuel source [5]. Green hydrogen production, particularly through the electrolysis of water using renewable energy sources like solar and wind energy, is considered the best method for environmentally friendly hydrogen fuel production [6]. Egypt's ability to produce green hydrogen has the potential to completely replace its reliance on fossil fuels making it free to be used as a feedstock rather than a fuel, changing its energy landscape. Hydrogen may be produced on a large scale by the beneficial application of the water produced during the production of oil or hydrocarbons through electrolysis. In Egypt, solar energy may be used to generate renewable energy for the electrocution process that creates hydrogen. This goes a long way toward making the technology of producing hydrogen at a higher scale viable. Egypt therefore aims to become environmentally friendly and generate green hydrogen in energy at the same time as it is generating new revenue in the hydrogen sector [4]. Since Egypt has high water cut, by implementing electrolysis technology, it is possible to produce green hydrogen from formation water, contributing to a more sustainable energy future in Egypt. Thus, this paper investigates the viability and usefulness of using Egyptian oil and gas wells' formation water for electrolysis to produce green hydrogen.

The last issue to address is the scarcity of fresh water for electrolysis. Many countries that are shifting to greener energy are struggling with the feedstock for their electrolysers, whether it is freshwater that is not widely available—especially in Scandinavian and European countries; or seawater which needs either desalination or treatment before splitting.

When it comes to producing hydrogen on large scale, studies showed that solid oxide electrolysis (SOE), alkaline water electrolysis (AWE), proton exchange membrane electrolysis (PEM), and different kinds like carbon-assisted water electrolysis (WE) and alkaline anion exchange membrane water electrolysis (AEM) are the primary electrolysis processes for large scale hydrogen production. However, there has been few studies using newest technologies just to investigate the efficiency of hydrogen under certain conditions; therefore, using these electrolysers would be a further step after studying the behaviour of formation water using low cost and sustainable materials.

It is the aim of the current study to investigate the possibility of using formation water as electrolyte for the electrolytic production of hydrogen gas. The current voltage relations are measured in an acrylic cell with good separation of hydrogen gas to enable its collection with high purity. The measurements were compared with those obtained in acidic and alkaline media at graphite and Al electrodes.

2. PRODUCED FORMATION WATER AND HYDROCARBON PRODUCTION ISSUES

As previously mentioned, The production of formation water during the extraction of natural gas and oil can account for a large percentage, sometimes as high as 80%, of the entire production [7]. This affects the strategies for managing waste and the expenses associated with extracting and producing these resources. Activities related to finding and producing these fuels create a lot of wastewater, which includes formation water, water used in injection, and the residues from the treatment of these waters, making it the largest source of waste in these operations. The treatment and management of the water produced from these activities are environmental concerns due to the presence of contaminants such as oil, grease, and harmful substances that could damage marine life and the quality of water. The worldwide ratio of water produced to oil is estimated to be 2.4, with these ratios changing over time, like in 2009 where it was 3:1, and in terms of financial investment, it could vary from 10:1 [8]. This indicates that a large volume of water is produced for every barrel of oil produced, highlighting the significant volume of water used in the extraction of natural gas and oil. On a worldwide scale, the production of oilfield produced water (OPW) is projected to rise as a result of a growing need for oil, along with an increase in global production operations [9]. In Fig. 1, it is predicted that the amount of produced water from traditional onshore and offshore fields worldwide will double in the next decade, rising from 158,900 million barrels per day mmb/d) to 243,000 million barrels per day (mmb/d) [9]. This means that the disposal of significant amounts of produced formation water will increase in the future, highlighting the importance of following treatment regulations. Environmental studies have expressed worry about the potential harmful effects of ongoing discharge of produced water in offshore and onshore locations [10].

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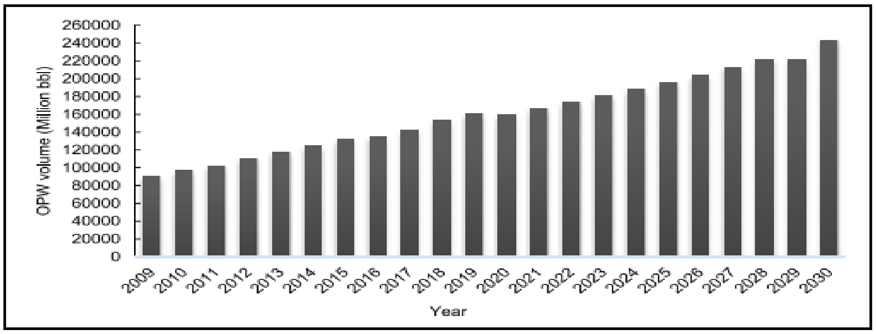

Fig. 1 Global produced water volumes [9]

Fig. 2 shows the gap between oil production and consumption for the years 1965 to 2025 using the grey prediction model "GM (1,1)". During the years 1965 to 1986, Fig. 2 indicates that there was excess, with production surpassing consumption. In 1965, there was an excess of 1023 barrels per day, which decreased to 50 thousand barrels per day by 1986. From that point onward until 2012, deficits were present, showing that the need for oil had been steadily rising in relation to growing economies during that time. From 1986 to 2012, this disparity expanded, peaking at 5434 thousand barrels per day in 2012. According to GM (1,1), it is anticipated that the gap between oil production and consumption will be in the negative range from 2012 to 2025, with a projected daily difference of -9875.92 thousand barrels by 2025 [11].

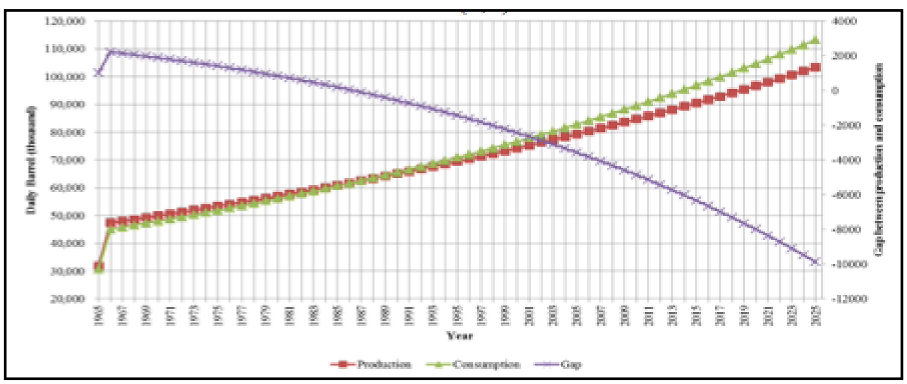

Fig. 1 GM (1,1) of Oil production, consumption and the gap between them [11].

3. METHODS AND MATERIALS

I. Cell 1

A prototype was prepared using graphite rods from waste batteries as electrodes for proof of concept. The setup was an acrylic container attached to it the graphite rods connected in parallel for electricity to pass as shown in Fig. 3.

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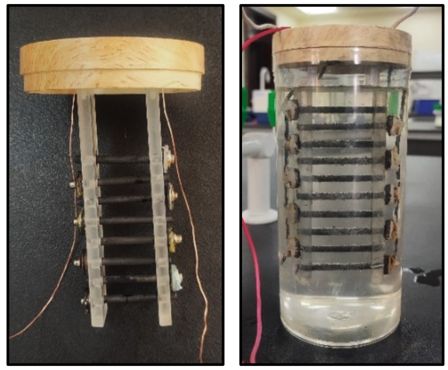

Fig. 2 First Prototype Cell

The first medium prepared was NaCl of concentrations 35% in distilled water, making it similar to seawater for comparison. When sodium chloride is mixed with water, it breaks down into sodium ions (Na^+) and chloride ions (Cl^-). These ions play a crucial role in allowing electricity to flow during electrolysis. Electrolysis is the process of running an electric current through a solution. Sodium metal (Na) is created at the cathode, but it frequently reacts with water to produce sodium hydroxide (NaOH) because of its high reactivity. Chlorine gas (Cl_2) is formed at the anode. Hydrogen gas (H_2) can also be generated at the cathode by reducing water molecules if the electric potential is high enough.

At the cathode (the negative terminal), water molecules accept electrons producing hydrogen gas as:

$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ (1) ---in seawater-like medium

At the anode (the positive terminal), chloride ions (Cl^-) give up electrons and turn into chlorine gas:

$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$ (2) ---in seawater-like medium

Overall reaction:

$2\,NaCl(aq) + 2H_2O \rightarrow Cl_2(g) + H_2(g) + 2\,NaOH(aq)$ (3)

Second medium, 0.1 M NaOH was prepared using distilled water. In this electrolysis experiment, sodium hydroxide acts as an electrolyte, providing hydroxide ions (OH^-), which are required to facilitate the conduction of electric current inside the solution. Even though it plays a part in the process, sodium hydroxide helps the cathode and anode transfer electrical charge rather than actively participating in the electrolysis reaction.

The current was measured against the voltage and recorded for comparison. The electrolysis reaction at the electrodes (in alkaline and neutral media) can be represented as follows:

At the cathode (negative electrode):

$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ (4) ---in neutral/alkaline media

At the anode (positive electrode):

$4OH^-(aq) \rightarrow O_2(g) + 2H_2O + 4e^-$ (5-a) ---in alkaline medium

$2H_2O \rightarrow O_2(g) + 4H^+ + 4e^-$ (5-b) ---in neutral medium

Overall reaction:

$2H_2O \rightarrow 2H_2(g) + O_2(g)$ (6)

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Thirdly, Sulphuric Acid H_2SO_4 . 0.5mole H_2SO_4 was added to distilled water. In this setup, sulfuric acid serves as an electrolyte, providing hydrogen ions (H+) when dissociated in water, necessary for the conduction of electricity through the solution. It is the sole ions which are reduced at the cathode producing hydrogen gas (Eq. 7) also it facilitates the movement of charged ions between the electrodes. The overall electrolysis reaction can be represented as follows:

At the cathode (negative electrode):

$$2H^+(aq) + 2e^- \rightarrow H_2\,(g) \quad (7)$$

At the anode (positive electrode):

$$2H_2O \rightarrow O_2\,(g) + 4H^+(aq) + 4e^- \quad (8)$$

Overall reaction:

$$2H_2O \rightarrow 2H_2\,(g) + O_2\,(g) \quad (9)$$

Lastly, the formation water, a natural-highly saline electrolyte, acted as the electrolyte. The used formation water sample has a pH of 5.8 and salinity of 125,000 mg/L. Likewise, current was passed through the waste formation water and voltage readings were recorded. Table 1 below displays the recorded readings of the cell's potential vs the corresponding current of the 4 electrolytes.

Table 1: Recorded Potential vs Current during the electrolysis of the 4 electrolytes at graphite rods-assembly as shown in Fig. 3.

0.1 M NaCl		0.1 M NaOH		0.5 M H_2SO_4		Formation Water	
Ecell/Volt	Current /mA	Ecell/Volt	Current /mA	Ecell/Volt	Current /mA	Ecell/Volt	Current /mA
1.42	18.1	1.2	20	1.2	10	1.3	20
2.3	60	2.3	56.1	2.1	134.2	2.3	50
3.3	170	3	123.1	3	190	3.4	175.1

It was observed after the electrolysis process of the formation water, some of the dissolved solids in the water were accumulated on the electrodes as shown in Fig. 4. This was proved to be the reason for the formation water to have a catalytic property due to its dissolved solids, which is more investigated in the following experiment.

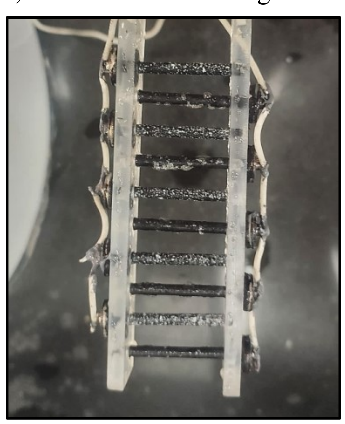

Fig. 3 The dissolved solids in the water accumulated on the electrodes after the electrolysis process

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II. Cell 2

In this experiment, another investigation of formation water's behaviour was made by comparing the water to 2 different media the acidic medium and the basic medium using different electrodes. A setup of the cell was made in the lab as shown in Fig. 5 consisting of the electrolyte and aluminium sheets of dimensions 130 mm length x 30 mm width x 2 mm thickness for the cathode making a surface area of 78 cm²; and for the anode its dimensions were 105 mm length x 30 mm width x 2 mm thickness equivalent to 63 cm² surface area.

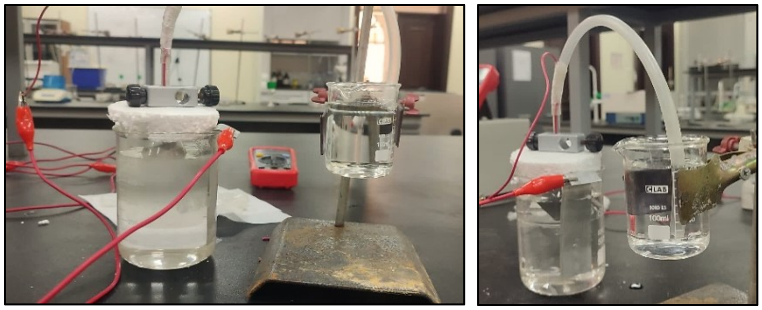

Fig. 4 Second Prototype Cell from 2 different angles

The first medium used was alkaline, which is 0.1 M NaOH. Sodium hydroxide is often used as an electrolyte in Alkaline Water Electrolysers (AWE) for the purpose of hydrogen and oxygen generation, owing to its effectiveness in facilitating the process. Research has shown that sodium hydroxide plays a crucial role in enhancing the efficiency of electrolysis systems, leading to increased rates of hydrogen production [12]. In addition, sodium hydroxide functions as a catalyst, enhancer, or precursor in various hydrogen production methodologies, such as electrolysis, thereby accelerating the rates of hydrogen generation and the absorption of carbon dioxide throughout the procedure[13]. Moreover, scholarly inquiries have validated that the employment of sodium hydroxide can reduce the necessary operational temperature for electrolysis, thereby further ameliorating the overall efficacy of hydrogen production mechanisms[14]. Overall, sodium hydroxide's properties make it a valuable component in electrolysis for sustainable and efficient hydrogen and oxygen generation processes.

0.1 M NaOH was prepared using distilled water. In this electrolysis experiment, sodium hydroxide acts as an electrolyte, providing hydroxide ions (OH^-), which are required to facilitate the conduction of electric current inside the solution. Even though it plays a part in the process, sodium hydroxide helps the cathode and anode transfer electrical charge rather than actively participating in the electrolysis reaction. The current was measured against the voltage and recorded for comparison. The electrolysis reaction at the electrodes (in alkaline and neutral media) can be represented as shown above (See Equations 4-6).

The second medium used was the acidic, by using Sulphuric Acid H_2SO_4 . Sulphuric acid is often used as an electrolyte in electrolysis for the generation of hydrogen and oxygen because of its capacity to improve efficiency and prevent passivity. According to Lin et al.'s experiment, maintaining a high pH level at the anode and a low pH level at the cathode significantly improves the efficiency of hydrogen production, leading to higher production rates and improved energy efficiency [15]. Furthermore, studies conducted by Sun and Hsiau highlight the fact that the electrolyte concentration—sulphuric acid in this case—has a major effect on how well the electrolysis setup functions, producing the best results at particular concentration thresholds in the anode and cathode pathways [16]. Furthermore, Krüger et al.'s analyses highlight the critical function of sulphuric acid in SO_2-depolarized electrolyser systems by employing it to produce both sulphuric acid and hydrogen, indicating the versatility and effectiveness of sulphuric acid as an electrolyte in a variety of electrolysis processes [17].

As for the concentrations, 0.5 mole H_2SO_4 was added to distilled water which equals to 15 mL of H_2SO_4 for 500 mL of distilled water. In this setup, sulphuric acid serves as an electrolyte, providing hydrogen ions (H^+) when dissociated in water, necessary for the conduction of electricity through the solution. It is the sole ions which are reduced at the cathode producing hydrogen gas (Eq. 4) Also it facilitates the movement of charged ions between the electrodes. The overall electrolysis reaction can be represented as shown above (See Equations 7-9).

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Lastly, the formation water, nothing was added to the water, on the contrary the formation water itself acted as the electrolyte and the catalyst without the need of any additional element. This formation water sample has a pH of 5.8 and salinity of 125,000 mg/L. Likewise, current was passed through the waste water and voltage readings were recorded. Table 2 below contains the recorded readings of the cell's current vs its potential of the 3 electrolytes. As shown in the table the sulphuric acid test was conducted twice, before adding the formation water to the cell and after adding it, to investigate if there has been any difference in the electrodes performance.

Table 2: Recorded Potential and Current during the electrolysis of the 3 Electrolytic Media at Al-Al binary electrochemical cell.

H_2SO_4		NaOH		Formation Water		H_2SO_4 (after)	
Ecell/Volt	Icell /A	Ecell/Volt	Icell /A	Ecell/Volt	Icell /A	Ecell/Volt	Icell /A
8.84	0.28	1.13	0.14	0.62	0.12	1.87	0.15
10.41	0.36	2.12	0.28	0.9	0.31	3.07	0.33
11.7	0.48	3.06	0.41	1.33	0.58	4.1	0.57
12.6	0.57	4.18	0.51	1.68	0.88	5.5	0.87
13.48	0.68	5.2	0.53	1.85	1.04	6.6	1.15
14.67	0.85	6.2	0.59	2.2	1.35	7.2	1.42
15.67	1.01	7.4	0.6	2.4	1.53	8.6	1.67
16.53	1.18	8.2	0.56	2.64	1.75	10.2	1.8
17.42	1.39	9.1	0.57	2.92	2.04	11.9	2.13
17.73	1.58	10.1	0.62	3.16	2.3	14.4	2.51
18.16	1.78	11.3	0.65	3.33	2.5	16.02	3.06
18.65	2.06	12.4	0.68	3.33	2.7	16.3	3.33
17.8	2.13	13.3	0.7	3.5	3.03	17.3	3.84
17.9	2.27	14.4	0.72	3.94	3.25	18.07	4.18
18.08	2.37	15.1	0.73	4.7	3.51	18.68	4.4
18.35	2.57	16.1	0.75	4.97	3.73	18.78	4.71
18.2	2.67	17.2	0.78	5.01	4.02	19.39	5.03
18.28	2.76	18.1	0.8	5.18	4.26		
18.47	2.88	19.2	0.83				
18.68	3.06	20.3	0.84				
18.84	3.5	21	0.81				
19.03	3.82	22.1	0.83				
19.27	4.02	23.1	0.86				
19.9	4.52	24.1	0.89				
20.5	5.02						

III. Cell 3

For the third experiment, a different setup was prepared to separate the gases produced in the electrolysis process as shown in Fig. 6. This experiment evaluates the possibility of different formation water samples from different wells and fields to produce hydrogen. Samples are tested under the same conditions of 5 Ampere current and aluminium sheets as electrodes. The tables below (Table 3) show the recorded time vs capacity of 1 litre of each of the water samples. It should be noted that aluminium was bare and not coated therefore its dimensions were different giving a different surface area for each electrolysis process.

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Fig. 5 Third Prototype Cell

For further investigation of the water's properties and salinity two samples were mixed together as a single electrolyte. The sample M160 was mixed with Edfu well sample as it showed the least efficiency to test the possibility and behaviour of water from different formations when mixed together; also the last sample is a mix sample located at 36 inch outfall line to the Gulf. Table 4 demonstrates the recorded readings for all 3 electrolytic mixed samples using aluminium sheets as electrodes.

Table 3: Variation of cell current vs. cell potential during the electrolysis of formation water obtained from three different well, i.e., Edfu, J-10 and M120.

Well Edfu			Well J-10			Well M120		
Time/s	Ecell/volt	Icell /A	Time/s	Ecell/volt	Icell/A	Time/s	Ecell/volt	Ecell/A
30	23.30	5.01	**30**	16.70	5.01	**30**	17.40	5.02
60	22.00	5.01	**60**	16.10	5.01	**60**	17.20	5.02
90	21.80	5.01	**90**	15.50	5.01	**90**	17.00	5.02
120	19.80	5.01	**120**	15.50	5.01	**120**	16.80	5.02
150	18.50	5.01	**150**	15.45	5.01	**150**	16.65	5.02
180	18.30	5.01	**180**	15.40	5.01	**180**	16.50	5.02
210	17.60	5.01	**210**	15.40	5.01	**210**	16.50	5.02
240	17.30	5.01	**240**	15.20	5.01	**240**	16.40	5.02
270	17.10	5.01	**270**	14.80	5.01	**270**	16.30	5.02
300	16.70	5.01	**300**	14.70	5.01	**300**	16.20	5.02
330	16.50	5.01	**330**	14.50	5.01	**330**	16.20	5.02
360	16.20	5.01	**360**	14.50	5.01	**360**	16.00	5.02
390	17.60	5.01	**390**	14.10	5.01	**390**	15.90	5.02
420	17.60	5.01	**420**	14.00	5.01	**420**	15.80	5.02
450	17.80	5.01	**450**	13.80	5.01	**450**	15.70	5.02
480	17.90	5.01	**480**	13.80	5.01	**480**	15.60	5.02
510	18.10	5.01	**510**	13.80	5.01	**510**	15.60	5.02
540	18.20	5.01	**540**	13.80	5.01	**540**	15.60	5.02
570	18.30	5.01	**570**	13.80	5.01	**570**	15.40	5.02
600	18.50	5.01	**600**	13.80	5.01	**600**	15.40	5.02

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Table 4: Time vs Capacity for non-mixed and mixed well samples

Well M160			Mixed Wells onshore			Wells Edfu+M160		
Time/s	**Ecell/volt**	**Icell/A**	**Time/s**	**Ecell/volt**	**Icell/A**	**Time/s**	**Ecell/volt**	**Ecell/A**
30	29.70	3.50	**30**	23.10	5.03	**30**	10.50	5.02
60	29.70	3.35	**60**	23.10	5.06	**60**	10.70	5.02
90	29.70	3.11	**90**	23.10	5.09	**90**	10.75	5.02
120	29.70	2.86	**120**	23.10	5.12	**120**	10.80	5.02
150	29.70	2.61	**150**	23.10	5.15	**150**	10.10	5.02
180	29.70	2.36	**180**	23.10	5.17	**180**	9.40	5.02
210	29.70	2.53	**210**	23.10	5.17	**210**	9.40	5.02
240	29.70	2.70	**240**	23.10	5.18	**240**	9.40	5.02
270	29.70	2.73	**270**	23.10	5.21	**270**	9.40	5.02
300	29.70	2.76	**300**	23.10	5.23	**300**	9.40	5.02
330	29.70	2.82	**330**	22.95	5.27	**330**	9.40	5.02
360	29.70	2.88	**360**	22.80	5.30	**360**	9.40	5.02
390	29.70	2.92	**390**	22.20	5.30	**390**	9.40	5.02
420	29.70	2.96	**420**	21.60	5.31	**420**	9.40	5.02
450	29.70	3.04	**450**	20.35	5.16	**450**	9.40	5.02
480	29.70	3.12	**480**	19.10	5.00	**480**	9.40	5.02
510	29.70	3.21	**510**	19.07	5.00	**510**	9.45	5.03
540	29.70	3.30	**540**	19.05	5.00	**540**	9.50	5.03
570	29.70	3.33	**570**	18.93	5.00	**570**	9.75	5.04
600	29.70	3.35	**600**	18.80	5.00	**600**	10.00	5.05

4. RESULTS AND DISCUSSION

The first demo cell (Fig. . 3) proved that hydrogen can be produced from formation water; giving different potential to the water a current was conducted indicating the production of hydrogen same as the other 3 media. A comparison was made using these three readings for better understanding of the formation water's behaviour. The corresponding graph shown (Fig. 7), demonstrated the comparison between the four media: NaCl, NaOH, H_2SO_4 and formation water proving that formation water can be used as an electrolyte for electrolysis with its trend yielding between the alkaline and acidic media.

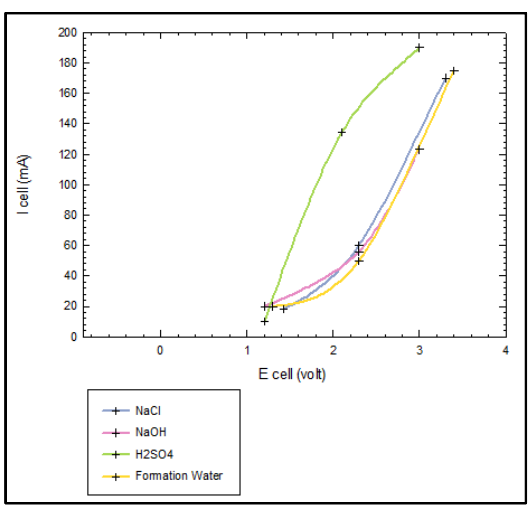

Fig. 6 Potential vs Current of 4 electrolytes

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To prove the formation water's catalytic property and due to the dissolved metals ions in the waste water that affected the electrodes, the sulphuric acid trial was carried out after the formation water to measure its performance as mentioned. The readings showed an enhancement in the sulphuric acid's performance requiring less voltage to give the same current as before the waste water's effect on the electrodes. The corresponding graph is shown below as well(Fig. 8). It demonstrates the comparison between the three media: NaOH, H_2 SO_4 —before and after the electrolysis of the formation water—and formation water.

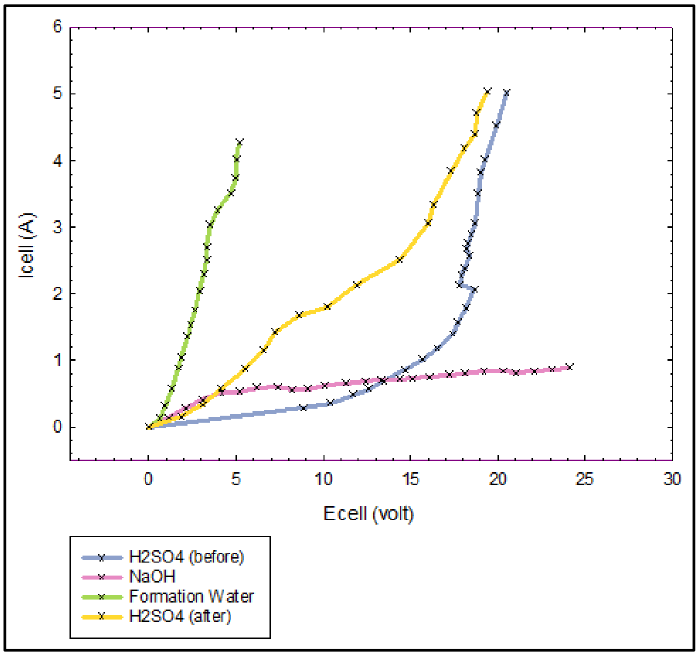

Fig. 7 Current voltage correlation obtained at two Al sheets during the electrolysis of H_2SO_4, NaOH and formation water. Note that the cathode area = 78 cm^2 while the anode area = 63 cm^2.

Formation water showed promising hydrogen evolution reaction rates (i.e., currents) that is because at the same current of 5.01 Ampere, the formation water needed only 4.02 volt while in sulfuric acid's case to reach 5.02 Ampere a cell potential of 20.5 volts were needed; That is a power saving of more than 75% is achieved in the case of using formation water as electrolyte. As for sodium hydroxide, 24.1 volt barely gave 0.89 current which is the very least of them and the very highest potential as well. This could be attributed to the extensive passivation of the Al anode during the electrolysis process.

Regarding the formation water's effect on the electrodes, the H_2 SO_4 before needed 15.67 volt to reach only 1.01 A while after the formation water's electrolysis, due to metals dissolved in it the H_2 SO_4 in the second time reached 1.15 A at 6.6 volt proving that formation water enhances the electrodes catalytic activity without the addition of any elements. Further investigations are underway to fully describe the system.

The last experiment proved that any formation water can be used for electrolysis giving high efficient hydrogen production, especially when mixed giving the highest performance with the least capacity as shown in Fig. s 9 & 10. In addition, the formation water's high salinity proved to be better providing strenuous electrolysis process. Therefore, it is safe to say that any formation water can be used for electrolysis.

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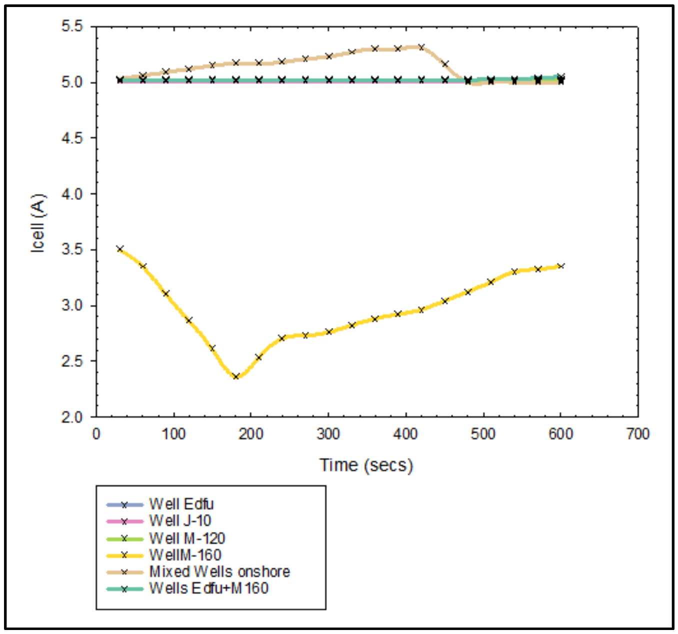

Fig. 8 Time vs Current for mixed and non-mixed well samples

As shown in Fig. 10 below, the water samples tend require almost the same amount of energy to support a current of 5 A. The values of potential decreases slightly with time.

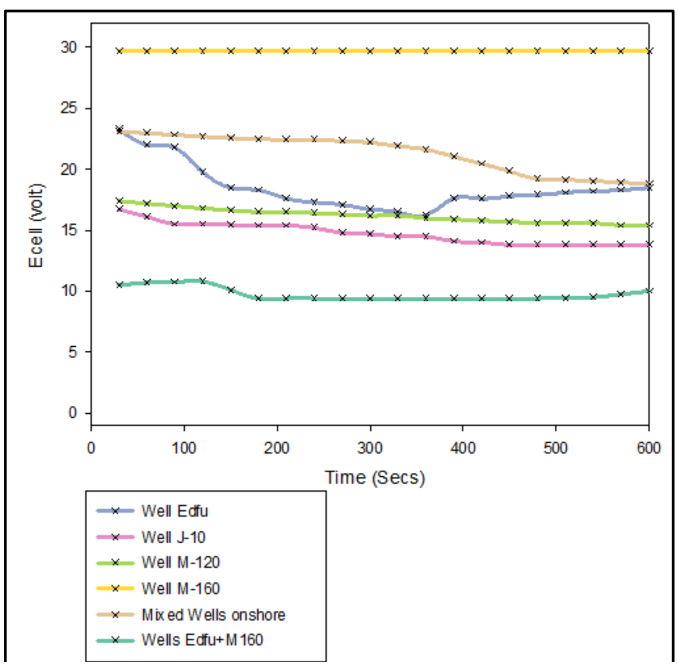

Fig. 9 Time vs Potential for mixed and non-mixed well samples

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5. CONCLUSION

In conclusion, the research has demonstrated the feasibility of using formation water from Egyptian oil and gas wells for the electrolytic production of green hydrogen. The potential of formation water as an electrolyte for hydrogen production was explored through a series of experiments, showing its capability to yield hydrogen with high efficiency. The findings indicate that formation water, with its varying salinity and composition, can indeed serve as an effective catalyst for hydrogen evolution, making it a promising resource for sustainable energy production. The investigation revealed that the use of formation water resulted in significant power savings, requiring less voltage to achieve the same current compared to conventional electrolytes. Moreover, the experiments showed that mixing different formation water samples led to improved performance, suggesting that a combination of formation waters could further enhance the efficiency of hydrogen production. Furthermore, the study highlighted the environmental benefits of utilizing formation water, especially in the context of Egypt's high water cut in oil and gas fields. By repurposing this waste stream for green hydrogen production, it not only addresses the environmental concerns associated with produced water but also contributes to the transition towards a more sustainable energy landscape. Overall, the results underscore the potential of utilizing formation water for green hydrogen production, offering a promising avenue for Egypt to diversify its energy sources and move towards a more environmentally friendly and sustainable energy future. Further exploration and development of this approach could lead to significant advancements in the field of renewable energy and contribute to global efforts in mitigating climate change. In light of these findings, it is clear that the utilization of formation water for green hydrogen production holds great promise and should be further investigated and integrated into the transition towards cleaner and more sustainable energy solutions. The impact of this research extends not only to Egypt but also to other regions facing similar challenges, offering a new perspective on repurposing waste streams for the advancement of green energy technologies.

6. REFERENCES

[1] K. A. Sanoja-López, N. S. Loor-Molina, and R. Luque, “An overview of photocatalyst eco-design and development for green hydrogen production,” Catal. Commun., no. February, p. 106859, 2024, doi: 10.1016/j.catcom.2024.106859.

[2] A. de Risi, G. Colangelo, and M. Milanese, “Advanced Technologies for Green Hydrogen Production,” Energies, vol. 16, no. 6, pp. 2–5, 2023, doi: 10.3390/en16062882.

[3] P. Stevenson, “Egypt Gas Output & LNG Exports Slump To Multi-Year Lows For 2023,” MEES. [Online]. Available: https://www.mees.com/2024/1/5/oil-gas/egypt-gas-output-lng-exports-slump-to-multi-year-lows-for-2023/3045afc0-abca-11ee-af23-8d6e15a5d6ba

[4] H. El Ghetany and M. H. El Awady, “Techno-Economic Study of the Potential for Green Hydrogen Production in Egypt,” Egypt. J. Chem., vol. 0, no. 0, pp. 0–0, 2023, doi: 10.21608/ejchem.2023.188736.7493.

[5] E. Of, R. Brine, F. O. R. Enhanced, and O. I. L. Recovery, “Patent Application Publication (10) Pub . No . : US 2019 / 0169969 A1 -,” vol. 1, 2019.

[6] Abdulrahman Abdulaziz Al-MulhemMohamed Nabil Noui-Mehidi, “WO2015013164A2.pdf.” 2017.

[7] F. Salem and T. Thiemann, “Produced Water from Oil and Gas Exploration — Problems , Solutions and Opportunities,” no. February, 2022, doi: 10.4236/jwarp.2022.142009.

[8] A. Larson, “Produced Water : Oil and Gas Terminology Glossary,” 2018.

[9] Produced Water Society, “Global Hydrocarbon Processing Applications.” [Online]. Available: https://producedwatersociety.com/

[10] K. T. Amakiri, N. A. Ogolo, A. Angelis-Dimakis, and O. Albert, “Physicochemical assessment and treatment of produced water: A case study in Niger delta Nigeria,” Pet. Res., vol. 8, no. 1, pp. 87–95, 2023, doi: 10.1016/j.ptlrs.2022.05.003.

[11] F. Dehdar, S. F. Yap, M. S. Naghavi, and M. Mahdi Dehdar, “Charting the future global status of oil and natural gas using Grey forecasting,” Institutions Econ., vol. 8, no. 3, pp. 105–125, 2016.

[12] R. Manurung, L. Putri Afisna, D. Gumara Nugrah, E. Rainal, J. Juhensen, and M. R. Mahendra, “PRODUCTION OF HYDROGEN GAS USING ELECTROLYSIS METHOD FROM WATER ELECTROLYTE WITH NaOH CATALYST,” Kurvatek, vol. 7, no. 2, pp. 45–50, 2022, doi: 10.33579/krvtk.v7i2.3162.

[13] M. H. Sellami and K. Loudiyi, “Electrolytes behavior during hydrogen production by solar energy,” Renew. Sustain. Energy Rev., vol. 70, no. December 2016, pp. 1331–1335, 2017, doi: 10.1016/j.rser.2016.12.034.

Print ISSN 2682-3993

Online ISSN 2682-4000

[14] H. Yun et al., "Simultaneous Sodium Hydroxide Production by Membrane Electrolysis and Carbon Dioxide Capture," Chem. Eng. Technol., vol. 40, no. 12, pp. 2204–2211, 2017, doi: 10.1002/ceat.201700151.

[15] W. Hiroto, M. Itsumi, S. Yusuke, and K. Hiroshi, "Sulfuric acid solution production method, and electrolysis vessel which can be used in said production method.," 2020

[16] F. Sun et al., "Energy-saving hydrogen production by chlorine-free hybrid seawater splitting coupling hydrazine degradation," Nat. Commun., vol. 12, no. 1, pp. 1–11, 2021, doi: 10.1038/s41467-021-24529-3.

[17] M.-Y. Lin, L.-W. Hourng, and K.-L. Chiou, "Parametric analysis of water electrolysis by dual electrolytes and cells," Int. J. Green Energy, vol. 16, pp. 1–6, Jan. 2019, doi: 10.1080/15435075.2018.1564139.