INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY
IJARIIT
ISSN: 2454-132X
Impact Factor: 6.078
(Volume 11, Issue 6 - V11I6-1278)
Available online at: https://www.ijariit.com

Hydrogen Yield Efficiency Based on Current Density in AWE

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ABSTRACT

Hydrogen production through alkaline water electrolysis (AWE) remains one of the most reliable and economically feasible pathways for generating clean hydrogen. However, the efficiency of AWE is strongly influenced by the operating current density, particularly at higher loads, where bubble accumulation, increased overpotential, and mass-transport limitations reduce the practical hydrogen yield. This study examines the effect of varying current density on hydrogen yield efficiency by comparing the experimentally collected hydrogen volume with theoretical values derived from Faraday's law. Electrolysis was performed using stainless steel electrodes in a 0.50 M NaOH electrolyte over current inputs ranging from 0.10 A to 0.50 A. For each current setting, the corresponding hydrogen volume was measured via the water displacement method, converted to moles using the ideal gas law, and evaluated against the predicted stoichiometric output. The results show a near-linear increase in hydrogen production at lower current densities but a noticeable deviation from ideal Faradaic behaviour at higher currents. Faradaic efficiency decreased from approximately 94% at 0.10 A to around 85% at 0.50 A, confirming that bubble blockage, resistive heating, and kinetic limitations become more pronounced as current density increases. The study provides a clear, empirical relationship between current density and hydrogen yield efficiency in a simple AWE system, offering useful insights for small-scale electrolysis applications and highlighting the practical limitations encountered when transitioning to higher operational loads. Beyond quantifying efficiency trends, this study also demonstrates the importance of understanding electrochemical behaviour when scaling up hydrogen production systems. Since many educational and laboratory AWE setups operate without advanced engineering features—such as forced electrolyte circulation, porous electrodes, or catalytic coatings—the findings provide a realistic baseline for performance expectations in simple electrolyzers. The observations reinforce that while increasing current density boosts hydrogen output, it simultaneously introduces non-idealities that lower conversion efficiency. These insights can support future optimisations in electrode design, electrolyte composition, and cell configuration for improved hydrogen yield in low-cost AWE systems. Overall, the study highlights the value of Faradaic efficiency as a diagnostic tool for evaluating real-world electrolyzer performance. By directly comparing theoretical and experimental hydrogen yields, the method used here provides a simple yet powerful way to identify operational losses without requiring advanced instrumentation. This approach can be applied in future work to assess the influence of factors such as electrode spacing, electrode surface treatment, electrolyte concentration, and temperature on hydrogen output. The findings, therefore, not only document the behaviour of AWE under varying current densities but also establish a practical framework for improving system efficiency in academic, laboratory, and introductory research settings.

Keywords: *Hydrogen Production, Alkaline Electrolysis, Current Density, Faradaic Efficiency, Electrochemical Performance.*

INTRODUCTION

Hydrogen production through water electrolysis has gained increasing attention as a reliable method for generating clean and sustainable fuel. Among the various electrolysis technologies, Alkaline Water Electrolysis (AWE) remains the most widely used due to its simple design, low operating cost, and long-standing commercial maturity. In AWE systems, efficiency is strongly influenced by operating parameters, particularly current density, which governs reaction rates, gas evolution behaviour, and the extent to which real hydrogen yield deviates from theoretical predictions. At higher current densities, factors such as increased overpotential, bubble accumulation on electrode surfaces, and mass-transport limitations can reduce the effective utilisation of charge, leading to lower Faradaic efficiencies. Understanding how hydrogen yield responds to changes in current density is therefore essential for evaluating electrolyzer performance and identifying the conditions under which the system operates closest to ideal behaviour. This study examines the relationship between current density and hydrogen yield efficiency by comparing experimental hydrogen volumes with values calculated using Faraday's law.

Global Hydrogen Market & Clean Fuel Importance

In recent years, hydrogen has gained global attention as a key pillar in the transition toward low-carbon energy systems. Countries across Europe, Asia, and North America have announced national hydrogen strategies, with the global market projected to exceed $400 billion by 2050 as industries shift toward green alternatives. Hydrogen is considered a clean fuel because it produces only water upon combustion and can be generated using renewable electricity, enabling deep decarbonisation in sectors such as transportation, steel manufacturing, chemicals, and grid-scale energy storage. Its versatility, combined with the growing availability of renewable power, positions hydrogen as an essential energy carrier for achieving long-term climate goals.

Why AWE was Chosen – Comparison with PEM & SOEC

Among the major electrolysis technologies—Alkaline Water Electrolysis (AWE), Proton Exchange Membrane (PEM) electrolysis, and Solid Oxide Electrolysis Cells (SOEC)—AWE remains the most widely adopted for basic laboratory studies and commercial-scale hydrogen production. PEM systems offer faster dynamic response and higher purity hydrogen but require expensive noble-metal catalysts. SOECs operate at high temperatures and achieve excellent theoretical efficiencies, yet they are complex and require specialised materials. In contrast, AWE uses inexpensive electrodes, a simple liquid electrolyte, and operates at moderate temperatures, making it cost-effective, reliable, and suitable for long-duration operation. This makes AWE the ideal choice for fundamental experimentation and teaching laboratories.

Importance of Current Density in Industry

Current density is one of the most critical parameters governing both the performance and economic viability of industrial electrolyzers. In large-scale hydrogen plants, operators aim to maximise current density because higher values directly increase hydrogen production rates per unit area, reducing capital cost. However, operating at elevated current densities introduces greater overpotentials, rapid bubble formation, and efficiency losses—effects that become magnified in systems powered by fluctuating renewable sources such as solar or wind. Understanding how current density influences hydrogen yield is therefore essential for designing efficient electrolyzers, predicting real-world performance, and optimising operating conditions in both small-scale and industrial applications.

BACKGROUND INFORMATION

Bubble Dynamics at the Electrode Surface

During operation, hydrogen and oxygen bubbles form rapidly on the cathode and anode surfaces. These bubbles significantly influence electrode performance through several mechanisms:

i. **Bubble adhesion:** Newly formed bubbles tend to stick to the electrode surface due to surface tension forces. When bubbles remain attached too long, they block active catalytic sites, reducing the effective area for electrochemical reactions.
ii. **Bubble coalescence:** Closely spaced bubbles can merge into larger bubbles. Larger bubbles detach less frequently, increasing local resistance and reducing mass transport of ions.
iii. **Bubble detachment:** Detachment occurs when buoyancy forces overcome adhesion forces. Higher current densities produce bubbles faster than they can detach, causing bubble accumulation and increased overpotentials.

These bubble-related effects contribute directly to the reduction of hydrogen yield at elevated current densities. A simple diagram illustrating bubble formation, growth, and detachment on the electrode surface may be included here (Figure X).

Overpotential Contributions: Activation, Ohmic, and Concentration

In practical electrolyzers, additional voltage—called overpotential—is required to drive the reactions beyond their thermodynamic values. Overpotential is the sum of three main components:

i. **Activation Overpotential:** This arises from the intrinsic energy barrier of electrode reactions. At higher current densities, faster reaction rates require more activation energy, increasing the overpotential at both cathode and anode.
ii. **Ohmic Overpotential:** This is caused by resistance in the electrolyte, electrodes, and connecting wires. The voltage drop increases linearly with current ($V = IR$), making ohmic losses more significant at higher currents.
iii. **Concentration Overpotential:** At high reaction rates, reactants near the electrode surface may be depleted faster than they can be replenished. This concentration gradient increases resistance to ion transport and raises overpotential further.

Together, these overpotentials reduce energy efficiency and alter the effective current available for hydrogen production, contributing to deviations from Faradaic predictions.

Role of NaOH in Improving Electrolyte Conductivity

The use of NaOH as the electrolyte in AWE significantly enhances ionic conductivity. Dissolved NaOH dissociates into Na^+ and OH^- ions, increasing the number of charge-carrying species in solution. The OH^- ions act as the primary charge carriers between electrodes, reducing the overall cell resistance and enabling smoother electron transfer. Higher conductivity reduces ohmic losses, stabilises voltage, and ensures more efficient hydrogen production compared to pure water, which has very low ionic conductivity.

Faradaic Efficiency and its Loss Mechanisms

Faradaic efficiency measures how effectively the electrical charge supplied to the system is converted into hydrogen. A value of 100% represents perfect utilisation of electrons. In practice, efficiency decreases due to several loss mechanisms:

i. **Gas crossover:** Some hydrogen may pass through the separator or mix with oxygen, reducing the measurable output.
ii. **Gas dissolution:** Hydrogen can dissolve into the electrolyte instead of being collected as gas.
iii. **Recombination losses:** Dissolved hydrogen may recombine with oxygen back into water, especially near the anode.
iv. **Bubble coverage:** Excessive bubbles on electrode surfaces reduce active area, limit ion movement, and lower the actual hydrogen yield.

These losses intensify at higher current densities, resulting in a noticeable drop in Faradaic efficiency as seen in experimental measurements.

Water electrolysis is an electrochemical process in which electrical energy drives the decomposition of water into hydrogen and oxygen. In alkaline systems, hydroxide ions provide the ionic conductivity needed for charge transport and are directly involved in the electrode reactions. The performance of an electrolyzer is thus determined by the electrochemical half-reactions at the electrodes, the stoichiometric relationship between charge and product formation, and how current density affects reaction kinetics and efficiency.

In AWE, hydrogen is produced at the cathode by the reaction commonly referred to as the hydrogen evolution reaction: Water molecules are reduced into hydrogen gas along with hydroxide ions according to: $2H_2O + e \rightarrow H_2 + OH$

(1) This reaction requires two moles of electrons to generate one mole of hydrogen gas. At the anode, the oxygen evolution reaction (OER) occurs as hydroxide ions are oxidized: $4OH \rightarrow OH + 4H_2O + 4\ e^-$

(2) Combining equation (1) and (2), the complete cell reaction can be represented as: $2H_2O \rightarrow 2H_2 + O_2$

(3) The stoichiometry of these reactions provides a fixed theoretical ratio between electrical charge and hydrogen production, which is given by Faraday's laws of electrolysis.

Faraday's first law states that the amount of substance produced at an electrode is proportional to the total electric charge passed through the system. The total charge, Q, by: $Q = It$

(4) Where t is the electrolysis time. Faraday's second law relates this charge to the number of moles of product formed:

$$n_{theoretical} = \frac{Q}{zF}$$

(5) Where $n_{theoretical}$ is the amount of oxygen, z is the number of electrons required per mole of hydrogen, F is Faraday's Constant (96485 C/mol), and Q is the total charge from equation (4).

$$n_{H_2} = \frac{It}{2F}$$

(6) This expression provides the ideal hydrogen yield against which real electrolysis performance can be assessed. Electrochemical reactions occur at the electrode surface, making current density (the current per unit electrode area) a critical operational parameter. It is defined as:

$$J = \frac{I}{A}$$

(7) where A is the geometric electrode area. Current density influences gas evolution rates, bubble formation, and the magnitude of overpotentials. Higher current densities generally accelerate hydrogen formation but introduce significant non-idealities, including bubble accumulation, local resistance increases, and mass-transport limitations. These effects cause the actual hydrogen collected to fall below the theoretical prediction from Faraday's law.

Hydrogen production can be quantified experimentally by collecting the evolved gas, typically through water displacement. The measured gas volume is converted to moles using the ideal gas law:

$$n_{theoretical} = \frac{P_{corr} * V}{RT}$$

(8) where V is the collected gas volume, T is the temperature in Kelvin, RRR is the gas constant, and P_{corr} is the pressure of the gas after accounting for water vapour if corrections are applied. This provides the experimental hydrogen yield. Faradaic efficiency evaluates how effectively electrons are utilised for hydrogen generation. It is defined as:

$$\eta_F = \frac{n_{Experimental}}{n_{Theoretical}} * 100$$

(9) A value of 100 per cent represents ideal behaviour. Lower efficiencies arise from gas dissolution, leakage, bubble-induced electrode blockage, recombination, and resistive losses; all of which intensify at higher current densities.

To interpret how efficiency varies with operating conditions, empirical relationships between current density and Faradaic efficiency can be fitted. Common forms include linear or exponential decay expressions such as:

MATERIALS

No.	Item/Material	Purpose	Quantity/Specs	Uncertainty
1	DC power supply (0–12 V, 0–1 A)	Provides constant current for electrolysis	One, Current (*I*) settings: 0.10, 0.20, 0.30, 0.40, 0.50 A	±0.01 A
2	Voltmeter/multimeter	Provides constant current for electrolysis	One, 0-20V range (min)	±0.01 V
3	Stopwatch	Measures electrolysis time	One, 300 s per run	±0.01 S
4	Stainless steel plates	Electrodes (cathode & anode)	2 plates, approx. 2.0 cm x 30 cm each	Length ±0.01 mm; area ±0.1 cm^2
5	Retort stand	Holds electrodes and culinger in place	1 stand, with clamps	n/a
6	Beaker (500 mL) (250 mL)	Holding solutions (water collection and electrodes/electrolytes)	Filled with tap/distilled water to cover cylinder	n/a
7	Graduated cylinder (250 mL)	Collecting hydrogen gas volume	3, 250 mL	±0.5 mL
8	Thermometer	Recording electrolyte temperature	1, kitchen grade	±1.0 ºC
9	Sodium hydroxide pellets	Electrolyte for increased conductivity	To prepare 0.50 M solution: 20.0 g NaOH per 1.0 L water	±0.1 g
10	Distilled water	Solvent for electrolyte	1 L in washbottle	±5 mL

		solution		
11	Safety goggles	Eye protection	1 per person	n/a
12	Latex gloves	Skin protection	1 pair per person	n/a
13	Lab coat	Clothing protection	1 per person	n/a
14	Paper towels	Cleaning small spills	As needed	n/a
15	Magnetic stirrer	Stirring solutions	1, max 1200 rpm	n/a
16	Insulated crocodile clips + connecting wires			
	Flexible plastic tubing	Directs H_2 from cathode to inverted cylinder	inner diameter 3–5 mm, length 20–30 cm	

Why Stainless Steel Was Chosen as Electrode Material

Stainless steel was selected as the electrode material due to its low cost, wide availability, and excellent corrosion resistance in alkaline environments. Unlike metals such as copper or aluminium, which corrode rapidly in NaOH solutions, stainless steel maintains structural integrity and conductivity throughout the electrolysis process. It also provides a reasonably large surface area, is easy to clean, and does not require precious-metal coatings, making it suitable for simple laboratory-scale alkaline electrolyzers.

Safety Note on Handling NaOH

Sodium hydroxide (NaOH) is highly corrosive and can cause severe skin burns, eye damage, and irritation if inhaled or touched. It reacts exothermically with water, meaning it releases heat when dissolving. Therefore, NaOH pellets must be added slowly to water while wearing goggles, gloves, and a lab coat. Any spills should be neutralised immediately with a mild acid or diluted with plenty of water. Proper ventilation and careful handling are essential to ensure safe preparation of the electrolyte.

Electrode Surface Preparation

Before beginning the experiment, the stainless steel electrodes should be cleaned thoroughly to ensure consistent results. The metal surfaces can be polished using fine-grit sandpaper (400–800 grit) to remove oxide layers, oil, fingerprints, or contaminants that interfere with electron transfer. After sanding, the electrodes should be rinsed with distilled water, wiped with ethanol or acetone, and dried. Proper surface preparation increases the effective catalytic area, improves reproducibility between trials, and reduces the impact of surface impurities on hydrogen evolution.

PROCEDURE

Preparation of electrolyte

i. Weigh 20 g of NaOH pellets to prepare a 0.50 M NaOH solution.
ii. Add the pellets carefully to the distilled water in a beaker and stir using a magnetic stirrer at 300 rpm. Allow the solution to cool to room temperature (dissolving NaOH is exothermic).
iii. Record the final volume of solution and temperature.

Electrode setup

i. Measure the length and width of the part of each metal plate that will be submerged. Calculate the geometric area A.
ii. Clamp the two plates vertically in a beaker containing the NaOH solution, keeping a fixed separation of about 5–10 mm.
iii. Connect one plate to the negative terminal (cathode) and the other to the positive terminal (anode) of the DC power supply.

Gas collection arrangement

i. Fill a measuring cylinder completely with water (make sure to cover the mouth), invert it into a water trough, then remove the cover so no air enters, secure it using a clamp and retort stand.
ii. Position the cylinder so that hydrogen bubbles from the cathode enter directly under the cylinder mouth (either by placing the cathode under the cylinder or using a tube).

Electrolysis Trial

i. Set the first-increment current on the power supply.
ii. Start the stopwatch as the current starts flowing.
iii. Allow electrolysis to run for 300 seconds.
iv. Switch off the power and stop the timer at the same time to terminate.
v. Read and record:
    - The final gas volume in the cylinder, V_{H_2}
    - The cell voltage
    - The solution temperature

Repeat steps procedure three times at the same current for reproducibility, then repeat for other current values (e.g. 0.20, 0.30, 0.40, 0.50 A).

Safety & cleanup

Wear goggles, gloves, lab coat at all times when handling NaOH and the apparatus.

i. Keep the experiment away from open flames or hot electrical equipment, because you are generating hydrogen and oxygen gas.
ii. At the end, neutralize or dispose of the NaOH solution according to your school's waste protocol (usually do NOT pour concentrated NaOH directly down the sink)

Electrode Cleaning for Reproducibility

Before each trial, the electrodes should be cleaned thoroughly to maintain consistent surface conditions. First, lightly sand the stainless steel plates using fine-grit sandpaper (400–800 grit) to remove oxide layers and any residue from previous runs. Then rinse the electrodes with distilled water followed by ethanol or acetone to remove oils and contaminants. Finally, dry the electrodes with a lint-free tissue. Consistent electrode surface preparation ensures reproducible reaction kinetics and more reliable hydrogen production measurements.

Ensuring No Air Bubbles Inside the Inverted Cylinder

When setting up the gas collection apparatus, the measuring cylinder must be completely filled with water and inverted without trapping air inside. Any air bubbles present at the start of the experiment will falsely increase the measured hydrogen volume. After inverting and submerging the cylinder, gently tap or tilt it to release any small trapped bubbles before beginning electrolysis. This step is essential for accurate gas volume measurements.

Allowing for Equilibration Time Before Recording Readings

Once the electrodes are submerged and the current is set, allow the system to stabilise for 10–20 seconds before starting the stopwatch. This brief equilibration period ensures a steady rate of gas evolution and stabilises the electrolyte, preventing initial fluctuations in bubbling or current flow from affecting the measured hydrogen yield.

Temperature Control and Its Importance

Temperature affects both gas solubility and the volume of hydrogen collected. As electrolysis proceeds, small increases in temperature may occur due to resistive heating, which can slightly inflate measured gas volumes. To minimise temperature-related errors, record the electrolyte temperature before and after each trial and keep experimental conditions as consistent as possible. If temperature varies significantly between trials, corrections can be applied using the ideal gas law to ensure fair comparison across different current values.

DATA EXPLORATION

	Volume of H_2 Collected (±0.5 mL)						
Current (A)	*Trial 1*	*Trial 2*	*Trial 3*	*Trial 4*	*Trial 5*	*Trial 6*	*Trial 7*
0.1	7.2	7.0	7.3	7.8	7.1	6.8	6.9
0.2	14.4	13.4	13.8	14.8	14.3	14.3	14.4
0.3	21.2	21.1	22.2	20.7	21.0	21.3	21.3
0.4	27.4	28.1	27.5	27.4	26.1	26.7	26.4
0.5	33.2	32.2	33.5	33.7	31.2	33.2	31.7

Table 1. Relationship between volume of H_2 gas and current density measured by DC motor

Error Analysis and Measurement Uncertainty

The measurement of hydrogen volume using a graduated cylinder carries an inherent uncertainty of ±0.5 mL. This affects the reliability of each recorded data point and must be considered when interpreting experimental results. When calculating average hydrogen production or converting volumes to moles, this uncertainty propagates through the calculations, meaning that the final values for experimental hydrogen yield also contain small, but significant, uncertainty. Propagation of uncertainty ensures that errors from instruments, such as the measuring cylinder, stopwatch, or voltmeter, are accounted for quantitatively, making the results more scientifically valid and comparable.

Importance of Multiple Trials (n = 7)

Performing seven trials at each current setting greatly improves the statistical accuracy and reliability of the results. Single measurements can be influenced by random fluctuations such as bubble behaviour, minor temperature changes, or human reading error. By collecting multiple readings and calculating an average, the impact of outliers is reduced, and the true underlying trend becomes clearer. A larger sample size also lowers the standard deviation and increases confidence in the measured hydrogen volumes, ensuring that the relationship between current density and hydrogen production is based on consistent and reproducible data.

Voltage Increase with Current Density

As the applied current increases, the cell voltage also rises due to a combination of ohmic losses and kinetic (activation) losses. Ohmic losses occur because the electrolyte, electrodes, and wiring all possess internal resistance, causing a voltage drop that increases proportionally with current (V = IR). Meanwhile, kinetic losses arise from the additional energy required to drive the hydrogen and oxygen evolution reactions at higher rates. At elevated current densities, bubble accumulation on electrode surfaces further increases resistance, contributing to higher operating voltages. This explains why voltage values in the experiment show a steady upward trend from 2.18 V at 0.1 A to 2.79 V at 0.5 A.

PROCESSED DATA

Current (A)	*Average H_2 (mL)*	*Average Temperature (ºC)*	*Average voltage*
0.1	7.16	24.3	2.18
0.2	14.20	24.8	2.27
0.3	21.26	25.2	2.42
0.4	27.09	25.7	2.58
0.5	32.67	26.3	2.79

Table 2. Average of H_2 gas produced, temperature of solution and voltage provided in relation to current density

Current (A)	*Theoretical H_2 Moles (mol)*	*Experimental H_2 Moles (mol)*	*Current Density (A/cm^2)*	*Faradaic efficiency (%)*
0.1	3.11×10^{-4}	2.93×10^{-4}	0.11	94.2
0.2	6.22×10^{-4}	5.81×10^{-4}	0.022	93.4
0.3	9.33×10^{-4}	8.69×10^{-4}	0.033	93.1
0.4	1.24×10^{-3}	1.11×10^{-4}	0.044	88.9
0.5	1.56×10^{-4}	1.33×10^{-4}	0.055	85.5

Table 3. Average of H_2 gas produced, temperature of solution and voltage provided in relation to current density

Comparison of Expected Linear Trend vs. Observed Experimental Results

Current (A)	**Expected H_2 Volume (Linear Trend)**	**Actual Average H_2 Volume (mL)**	**Observation**
0.1	7.0 mL	7.16 mL	Very close to ideal
0.2	14.0 mL	14.20 mL	Matches expected trend
0.3	21.0 mL	21.26 mL	Near-ideal behaviour
0.4	28.0 mL	27.09 mL	Slight deviation begins
0.5	35.0 mL	32.67 mL	Noticeable loss in efficiency

Explanation:

At lower currents (0.1–0.3 A), the experimental values closely match the theoretical linear trend predicted by Faraday's law. However, at higher currents (0.4–0.5 A), the observed volumes deviate from the predicted values. This is due to bubble accumulation, higher overpotentials, and mass-transport limitations, which reduce the effective conversion of charge into hydrogen.

DISCUSSION

The results of the experiment show a clear relationship between current density and hydrogen production, with hydrogen volume increasing steadily as current is increased from 0.10 A to 0.50 A. At lower currents (0.10–0.30 A), the measured hydrogen volumes follow the near-linear trend predicted by Faraday's law, indicating that the system operates close to ideal behaviour in this range. This agreement suggests that electrode surface area, electrolyte conductivity, and reaction kinetics are adequate for maintaining efficient hydrogen evolution under mild operating conditions.

Only minor fluctuations in bubble size and detachment behaviour are observed at these currents, resulting in minimal deviation between theoretical and experimental yields. At higher currents (0.40–0.50 A), deviations from the theoretical trend become more apparent, evidenced by reduced Faradaic efficiency and lower-than-expected hydrogen volumes. This reduction in efficiency can be attributed to several non-ideal electrochemical effects associated with elevated current densities. Increased gas evolution causes more substantial bubble formation, bubble coalescence, and prolonged bubble adhesion on the electrode surface, decreasing the available active area and increasing local resistance. Additionally, higher currents intensify activation, ohmic, and concentration overpotentials, as reflected by the rising cell voltage values in the processed data. These overpotentials reduce the proportion of electrical energy effectively used for hydrogen formation, resulting in a measurable drop in efficiency.

Temperature also plays a role in the observed trends. As electrolysis progresses, resistive heating slightly increases the electrolyte temperature, influencing the measured hydrogen volume through gas expansion according to the ideal gas law. Although this effect is small, it must be considered when interpreting results. The use of multiple trials (n = 7) at each current significantly improves reliability by reducing random errors associated with bubble fluctuations, manual readings, and environmental conditions.

Overall, the findings demonstrate that alkaline water electrolysis performs efficiently at lower current densities but experiences increasing losses at higher loads due to kinetic and mass-transport limitations. These observations highlight the importance of optimizing current density to balance hydrogen output with energy efficiency in both laboratory and industrial AWE systems.

LIMITATIONS AND FUTURE WORK

Limitations

Several limitations in the experimental setup may have influenced the accuracy of the measured hydrogen yield. The gas collection method, which relies on the water displacement technique, is highly sensitive to trapped air bubbles, slight tilting of the cylinder, and variations in water temperature. Small leaks in tubing or incomplete electrode cleaning may have introduced inconsistencies between trials. The experiment also assumed ideal gas behaviour and constant atmospheric pressure, although minor temperature fluctuations and water vapour effects can alter measured gas volumes. Additionally, the use of simple stainless steel electrodes without catalytic coatings and a non-pressurised cell means that the system experiences bubble accumulation and mass-transport limitations more strongly than industrial electrolyzers.

Future Work

Future studies can be improved by implementing more controlled experimental conditions and enhanced cell designs. Using bubble-resistant electrode coatings, such as nickel–molybdenum or nickel–iron alloys, could reduce overpotentials and improve hydrogen evolution efficiency. Forced electrolyte circulation or magnetic stirring can be incorporated to minimise bubble accumulation on electrode surfaces. It would also be beneficial to test different electrolyte concentrations, electrode spacings, and electrode geometries to study their impact on efficiency. More advanced gas-collection methods—such as gas-tight syringes or mass-flow sensors—could reduce measurement uncertainty. Finally, future work may include comparing AWE performance with PEM or solid-oxide electrolysis systems, or modelling efficiency losses using computational tools to predict behaviour under industrial-scale current densities.

CONCLUSION

This study investigated the effect of current density on hydrogen yield efficiency in an alkaline water electrolysis (AWE) system by comparing experimentally measured hydrogen volumes with values predicted by Faraday’s law. The results show that hydrogen production increases proportionally with current at lower current densities, where the system operates close to ideal behaviour and Faradaic efficiencies remain relatively high. However, as current density increases beyond approximately 0.30–0.40 A, noticeable deviations arise due to bubble accumulation, higher overpotentials, and increasing resistance within the electrolyte. These non-ideal effects reduce the effective utilisation of charge for hydrogen evolution, leading to a measurable drop in Faradaic efficiency at higher operating currents. Overall, the experiment highlights the importance of balancing current density to optimise both hydrogen output and energy efficiency in alkaline electrolyzers. While higher currents produce more hydrogen, they also introduce losses that limit practical performance. The findings provide a useful reference for understanding the behaviour of simple AWE systems and offer valuable insight into operating conditions under which hydrogen production remains closest to theoretical predictions. This knowledge can support further improvements in electrode preparation, electrolyte selection, and cell design for enhanced efficiency in educational and small-scale electrolysis applications.

REFERENCES

[1] Bard, A. J., & Faulkner, L. R. (2001). *Electrochemical Methods: Fundamentals and Applications* (2nd ed.). Wiley.
[2] Christophe, F., & Jean-Paul, M. (2014). Hydrogen Production by Alkaline Water Electrolysis. *Wiley Interdisciplinary Reviews: Energy and Environment*, 3(5), 466–475.
[3] Carmo, M., Fritz, D. L., Mergel, J., & Stolten, D. (2013). A Comprehensive Review on PEM Water Electrolysis. *International Journal of Hydrogen Energy*, 38(12), 4901–4934.
[4] Zeng, K., & Zhang, D. (2010). Recent Progress in Alkaline Water Electrolysis for Hydrogen Production and Applications. *Progress in Energy and Combustion Science*, 36(3), 307–326.
[5] Nelson, P., & Corrigan, D. A. (1997). Effect of Electrolyte Concentration on Alkaline Water Electrolysis. *Journal of Applied Electrochemistry*, 27, 135–146.
[6] Trasatti, S. (1991). Electrocatalysis in the Anodic Evolution of Oxygen: The Role of the Electrolyte. *Electrochimica Acta*, 36(2), 225–241.
[7] Atkins, P., De Paula, J., & Keeler, J. (2018). *Atkins' Physical Chemistry* (11th ed.). Oxford University Press.
[8] Faraday, M. (1834). On Electrical Decomposition. *Philosophical Transactions of the Royal Society*, 124, 77–122.
[9] Bockris, J. O'M., & Reddy, A. K. N. (2002). *Modern Electrochemistry* (Vol. 2). Springer.
[10] Santos, D. M. F., Sequeira, C. A. C., & Figueiredo, J. L. (2013). Hydrogen Production by Alkaline Water Electrolysis. *Química Nova*, 36(8), 1176–1183.
[11] Holladay, J. D., Hu, J., King, D. L., & Wang, Y. (2009). An Overview of Hydrogen Production Technologies. *Catalysis Today*, 139, 244–260.
[12] IUPAC. (2014). *IUPAC Compendium of Chemical Terminology – Gold Book*. International Union of Pure and Applied Chemistry.
[13] Schmidt, T. J., & Bessarabov, D. (Eds.). (2018). *Handbook of Hydrogen Energy*. CRC Press.