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Effect of Electrode Type and Current Strength on the Mass of Substance Reduced at the Cathode in the Electrolysis Process

Jam'an Fahmi[1], Dwi Sapri Ramadhan[1], Dian Wardana[1], Wulan Dwi Safitri[1], Moondra Zubir[1], Nurdin Siregar[2], Riska Greselia Manullang[3], Novitri Yolanda Sagala[3], Desy Meriani Br Sipahutar[3]

[1] *Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, Medan 20221, Indonesia*
[2] *Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, Medan 20221, Indonesia*
[3] *Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, Medan 20221, Indonesia*
**Corresponding author: jamanfahmi@unimed.ac.id*

ABSTRACT

This study investigates the effect of electrode type and current strength on the mass of hydrogen gas produced at the cathode during the electrolysis of sodium chloride solution. A simulation based on Faraday's law was conducted using three electrode materials—carbon, copper, and zinc—under controlled current settings of 0.10 A, 0.20 A, and 0.30 A for a fixed electrolysis duration of 30 minutes. Current efficiency values were assigned to each electrode to model realistic performance differences, with copper exhibiting the highest efficiency, followed by zinc and carbon. The results show that increasing the current leads to a linear rise in the mass of hydrogen produced for all electrode types, confirming the proportional relationship between electric charge and cathodic reduction predicted by Faraday's law. Additionally, copper electrodes produced the highest hydrogen yield at all current levels, while carbon generated the lowest, indicating that electrode characteristics influence electrochemical efficiency. Overall, the findings demonstrate that current strength is the dominant factor determining the mass of reduced species at the cathode, whereas electrode material provides a secondary yet significant contribution to electrolysis effectiveness.

Keywords: electrolysis, electrode materials, current strength, hydrogen production

1. INTRODUCTION

Electrolysis is an important electrochemical process widely applied across various industrial fields, including metal electrodeposition, material purification, hydrogen production, and the treatment of wastewater containing heavy metals. Fundamentally, electrolysis involves redox reactions driven by direct electric current, causing ions in an electrolyte solution to undergo reduction or oxidation at the electrode surfaces. Several parameters affect the efficiency and outcomes of electrolysis, among which the type of electrode material and

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the applied current strength play crucial roles in determining the rate of cathodic reduction, the morphology of metal deposits, and the overall process efficiency.

The choice of electrode material significantly influences the electrochemical performance of an electrolytic system. Studies on brine electrolysis demonstrate that variations in electrode materials such as stainless steel, aluminium, and copper lead to substantial differences in the amount of hydrogen gas generated at the cathode, reflecting variations in electrocatalytic activity and electrode stability.[1,2] Research on seawater electrolysis further supports this observation, showing that electrode materials—including graphite and various commercial metals—strongly affect current stability, product yield, and corrosion behaviour during electrochemical reactions.[3,4] These findings highlight that intrinsic properties of electrode materials, such as conductivity, corrosion resistance, and ion affinity, directly influence the mass of substances reduced at the cathode.

In addition to electrode type, current strength is a key parameter that affects both the amount and quality of deposited substances at the cathode. According to Faraday's law, the mass of reduced material is directly proportional to the total electric charge passed through the system; thus, increasing the current generally increases the deposited mass. This relationship is demonstrated in copper electrodeposition, where higher applied potentials (correlating with increased current) accelerate the deposition rate of metallic copper, although excessively high potentials may produce poor-quality deposits characterized by rough or burnt surfaces.[1,5] Similarly, electrolysis-based removal of Cu ions from wastewater shows that increasing current strength from 1 A to 5 A significantly enhances removal efficiency, achieving up to 99.94% reduction within 180 minutes.[5,6–8]

The effects of current strength are also prominent in the electrodeposition of metals and alloys. Research on zinc and other alloy systems indicates that high current densities may reduce deposition efficiency due to competing side reactions, such as hydrogen evolution and the formation of passivation layers that impede further ion reduction at the cathode.[9,10] Conversely, other studies report improved deposition efficiency with increasing current density up to an optimal threshold, beyond which deposit instability or rapid nucleation negatively affects coating quality. [6,2,10]

Although many studies have independently examined the effects of electrode material and current strength, investigations linking both variables to the mass of substance reduced at the cathode as a direct indicator of reduction efficiency remain limited. Understanding this relationship is essential for optimizing electrolysis processes across both industrial and laboratory contexts. Therefore, the present study aims to analyze how variations in electrode type and current strength influence the mass of substances reduced at the cathode, drawing upon electrochemical principles and relevant empirical findings reported in the literature.

2. EXPERIMENTAL

2.1. Chemicals and Equipment

Electrodes: Carbon (graphite) rods, Copper (Cu) plates (0.5 × 4 cm) and Zinc (Zn) plates (0.5 × 4 cm). Electrolyte: 200 mL of aqueous NaCl solution (0.5 M). Power Supply: Adjustable DC power supply capable of delivering 0–1 A current, Measuring Instruments: Digital multimeter (for current verification), Analytical balance (±0.1 mg). Other equipment: Beaker glass (250 mL), electrode holders, cables, and clamps.

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2.2. Research Methods

This research uses an experiment-based quantitative method, collecting data based on experimental results. Experiment-based quantitative research methods are systematic and rigorous research methods to test hypotheses or research problems. The steps taken in experiment-based quantitative research methods include approach and type of research, population and sample, research instruments, data collection, and data analysis. This quantitative method, the author is the instrument in the research, and the analysis is carried out continuously from the beginning of the research to data analysis. Conducting direct experiments on the object of study according to the scope of research and toeri as supporting research based on the scope of discussion.

2.3. Research Procedure

2.3.1 Electrode Preparation

Each electrode (carbon, copper, and zinc) was cleaned using distilled water, wiped with ethanol, and dried prior to use. The dimensions and immersion depth (2 cm) were kept constant to ensure comparable surface areas.

2.3.2 Electrolysis Procedure

Electrolysis experiments were performed in a 250 mL beaker containing 200 mL NaCl solution. Two identical electrodes (same material) were positioned vertically with a 2 cm separation distance. The electrodes were connected to a DC power supply in which the cathode was designated as the electrode where reduction occurred. For each electrode type, electrolysis was carried out at three current settings: 0.10 A; 0.20 A; 0.30 A. The current was controlled using the power supply and verified with a multimeter. Each electrolysis run was conducted for a fixed duration of 30 minutes (1800 seconds). After electrolysis, the mass of hydrogen produced at the cathode was calculated using Faraday's law based on the measured current and time.

2.3.3 Faraday Simulation and Efficiency Assumptions

To model realistic differences among electrode materials, current efficiencies) were assigned as follows: Carbon: 0.75, Copper: 0.90, Zinc: 0.85. These values represent the fraction of electrical charge effectively contributing to hydrogen evolution at the cathode.

3. RESULTS AND DISCUSSION

3.1. Effect of electrode type on the mass of substance reduced at the cathode

The simulation results for the effect of electrode type on the mass of hydrogen gas produced at the cathode are presented in figure 1 below. At a fixed current of 0.20 A and an electrolysis time of 30 minutes, the mass of H_2 formed at the cathode is 0.0028 g for carbon electrodes, 0.0034 g for copper electrodes, and 0.0032 g for zinc electrodes. These data show that, under identical operating conditions, the copper electrode produces the highest mass of hydrogen, followed by zinc and then carbon.

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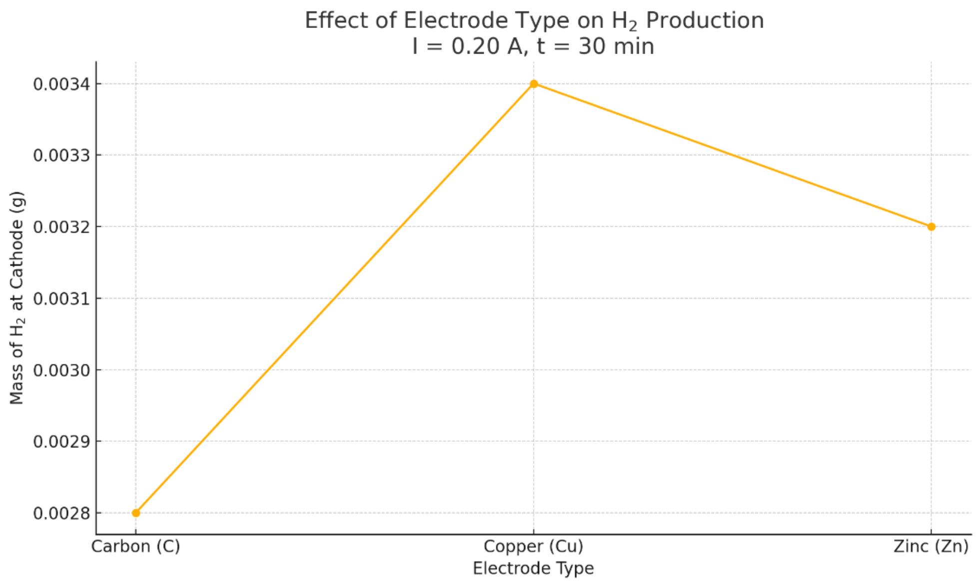

Figure 1. Effect of electrode type on the mass of H_2 produced at the cathode

In this simulation, the differences among electrodes originate from the assumed current efficiency (η) for the hydrogen evolution reaction. Copper is assigned the highest efficiency due to its relatively low overpotential for hydrogen evolution and stable conductive surface, while carbon is assumed to have the lowest efficiency because part of the current may be consumed in side processes or distributed over a less active surface.[12] As a consequence, although the total electric charge passed through the cell is the same for all electrode types, the effective charge used specifically for hydrogen evolution is different, resulting in variations in the mass of H_2 at the cathode.[4, 13, 14]

These findings are in line with electrochemical principles and literature reports indicating that electrode material strongly influences the kinetics of cathodic reactions, including hydrogen evolution, through factors such as overpotential, surface morphology, and corrosion stability. More active electrodes with lower overpotentials and better catalytic properties tend to exhibit higher faradaic efficiency toward the desired reduction reaction, which in this case is the formation of H_2 from water reduction.

3.2. Effect of current strength on the mass of substance reduced at the cathode

The influence of current strength on the mass of hydrogen produced at the cathode for different electrode types is summarized in figures 2–4. For all electrodes, an increase in current from 0.10 A to 0.30 A at a constant electrolysis time of 30 minutes leads to a proportional increase in the mass of H_2 formed.

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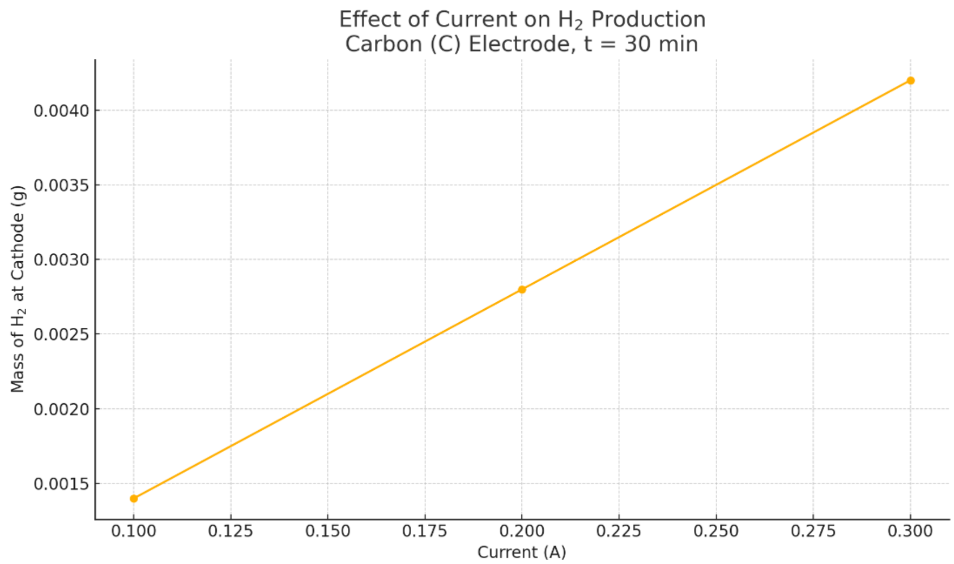

Figure 2. Effect of current strength on the mass of H_2 produced at the cathode using a carbon (C) electrode (t = 30 min)

The graph for the carbon electrode shows a nearly perfect linear increase in the mass of H_2 produced at the cathode as the current increases from 0.10 A to 0.30 A. At 0.10 A, the mass of hydrogen is approximately 0.0014 g, which doubles to about 0.0028 g at 0.20 A and further increases to 0.0042 g at 0.30 A. This linear trend confirms Faraday's law of electrolysis, indicating that the mass of the reduced species is directly proportional to the electric charge passed through the system. Because the assumed current efficiency for the carbon electrode is relatively low ($\eta = 0.75$), the absolute amount of H_2 produced is smaller than for the copper and zinc electrodes at the same current.

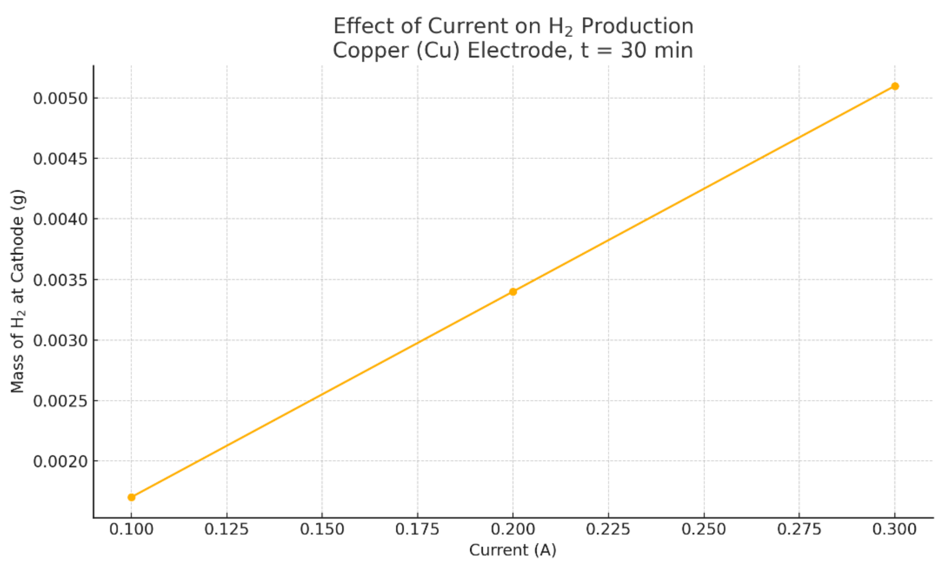

Figure 3. Effect of current strength on the mass of H_2 produced at the cathode using a copper (Cu) electrode (t = 30 min)

The graph for the copper electrode also exhibits a clear linear relationship between the applied current and the mass of H_2 generated at the cathode. The mass increases from about 0.0017 g at 0.10 A to 0.0034 g at

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0.20 A and reaches approximately 0.0051 g at 0.30 A. Compared with the carbon electrode, the slope of the line is steeper, reflecting the higher current efficiency assumed for copper (η = 0.90). This indicates that a larger fraction of the electrical charge contributes effectively to the hydrogen evolution reaction. Consequently, copper produces the highest mass of H_2 among the three electrode materials at any given current.

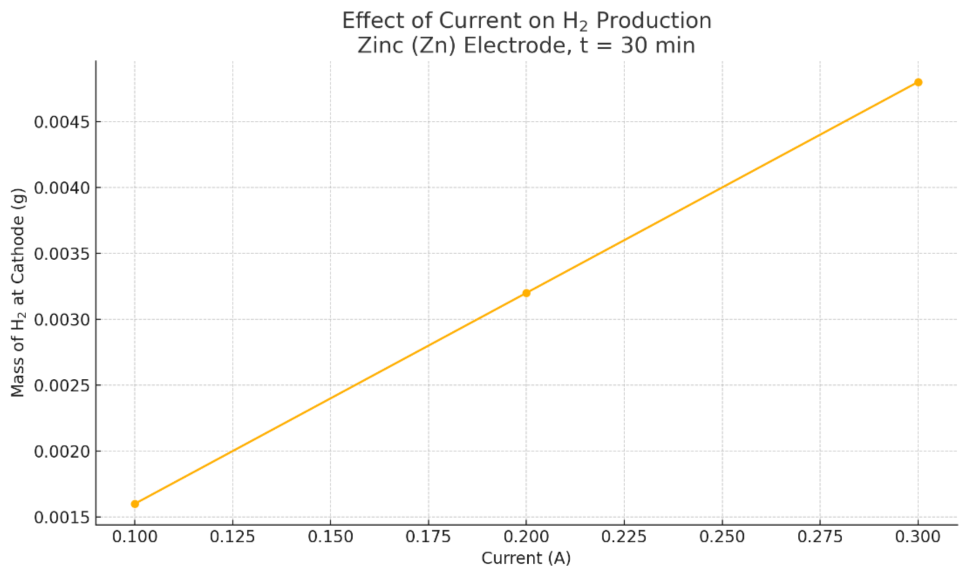

Figure 4. Effect of current strength on the mass of H_2 produced at the cathode using a zinc (Zn) electrode (t = 30 min)

For the zinc electrode, the graph again shows a linear increase in hydrogen production with increasing current. The mass of H_2 rises from around 0.0016 g at 0.10 A to 0.0032 g at 0.20 A and 0.0048 g at 0.30 A. The slope of the line lies between copper and carbon, which is consistent with the intermediate efficiency value assigned to zinc (η = 0.85). This confirms that, while current strength is the dominant factor controlling the mass of hydrogen produced, the electrode material modulates the overall yield through its current efficiency.

The nearly linear relationship between current and mass of hydrogen is consistent with Faraday's law of electrolysis, which states that the mass of substance produced at an electrode is directly proportional to the total electric charge passed through the electrolyte. [11,15] At a given current, copper consistently yields a slightly higher mass of H_2 than zinc and carbon, again reflecting the higher current efficiency assumed for this electrode. Nonetheless, for each electrode type, the dominant factor controlling the number of reduced species is the magnitude of the current rather than the electrode material. This is expected, because the electric charge ($Q = I \cdot t$) directly determines the theoretical amount of product that can be formed, provided that side reactions are minimal and current efficiency is sufficiently high.[15]

Overall, the simulation clearly supports the conclusion that the mass of substance reduced at the cathode is directly proportional to the current strength and is also influenced by the nature of the electrode material through its effect on current efficiency. These results can be used as a theoretically consistent basis to redesign laboratory experiments on brine electrolysis, using realistic current values and physically meaningful relationships between current, electrode type, and mass of product formed.

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4. CONCLUSION

The results of this study demonstrate that the mass of hydrogen gas produced at the cathode during electrolysis is primarily determined by the strength of the applied current and secondarily influenced by the type of electrode used. Increasing the current from 0.10 A to 0.30 A consistently led to a proportional rise in hydrogen production for all electrode types, confirming Faraday's law that links the number of reduced species to the total electric charge passed through the system. Meanwhile, differences in electrode material affected the overall hydrogen yield through variations in current efficiency, with copper producing the highest mass of H_2 due to its superior catalytic properties, followed by zinc and carbon. These findings highlight that although current strength is the dominant factor governing cathodic reduction, electrode characteristics also play a meaningful role in optimizing electrolysis performance.

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