The Cost-Effectiveness and Efficiency of Spin-Coated Carbon Quantum Dots on a Rudimentary Electrolytic Cell

Karla Madrigal

English Department, Texas A&M International University

ENGL 2311: Technical Communication

[Professor's Name, I redacted for privacy]

April 20, 2024

Abstract

This experiment focuses on the efficiency that spin-coated carbon quantum dots have on water-splitting electrodes for hydrogen gas production. This efficiency can be applied to the field of fuel cells, which use hydrogen gas to make emission-free energy. Improving the hydrogen evolution reaction (HER) in non platinum group metals is a focus of electrolyzer technology and hydrogen production, and this experiment aims to improve HER using the highly conductive and easily accessible carbon quantum dots. The study focuses on measuring resistance of various cathode configurations and grams of hydrogen gas produced from various trials using nickel-based cathodes: an unmodified cathode, a spin-coated cathode, a jagged cathode, and a spin-coated and jagged cathode. While it was predicted based on preliminary research that a spin-coated and jagged Ni-based cathode would perform the most effectively due to its aerophobic qualities and enhanced conductivity, a flat CQD-coated cathode outperformed the rest of the cathode configurations.

Keywords: *Carbon Quantum Dots*, *Fuel Cells, Hydrogen Evolution Reaction (HER), Electrolysis, Hydrogen Production, Nickel, Bubble-forming.*

The Cost-Effectiveness and Efficiency of Spin-Coated Carbon Quantum Dots on a Rudimentary Electrolytic Cell

Hydrogen electrolysis has been researched for decades as a clean and theoretically 100% efficient method of producing hydrogen gas for hydrogen fuel cells (Ahad, 2023, p. 4). For many researchers, the topic of interest revolves around improving the hydrogen evolution reaction (HER), or the reaction that separates hydrogen from water molecules and forms hydrogen gas. Improving the efficiency of HER is mostly centered around the make and structure of the electrode, which has been proven most efficient when based on platinum group metals (PGM) (Ampurdanés, 2019, pp. 162). However, platinum is expensive, not only to acquire but also to maintain, due to degradation. In contrast, materials like carbon and nickel are becoming increasingly appealing to researchers due to their accessibility and stability as catalysts. Han et al., in particular, studied the effectiveness of a nickel-based cathode 3-D printed with spiky structures to deter gas bubbles from forming (2024). Additionally, the applications of carbon quantum dots (CQDs) and other nanoparticles in electrochemistry and photoelectrolysis have shown potential in challenging PGM catalysts (Kuo, 2024 pp. 1103). Based on the research, the most successful cathode configuration in this trial would be a nickel cathode with an aerophobic surface coated with carbon quantum dots.

Methods and Materials

Preparation of Carbon Quantum Dots

For the microemulsion of carbon quantum dots (CQDs), the researcher prepared 0.059 L of 0.83M acetic acid (white vinegar), 15 g of glucose($C_6H_{12}O_6$), 0.24 L of water, and several pieces of microwave-resistant glassware to house the solution while in the microwave. The first step is to dissolve the .83M acetic acid solution and glucose into the water, and then microwave the solution for 5 minutes. Next, after the solution has been cooled, the researcher needs to slowly add baking soda ($NaHCO_3$) to neutralize the acetic acid. After another 5 minutes in the microwave, there should be a concentrated solution of CQDs. Quantum dots are known for their luminescence as electrons in their outermost shell jump to more excited states in the presence of ultraviolet (UV) light, so pointing a UV light at the solution to observe the luminescence is a way of verifying the creation of quantum dots.

Preparation of Electrochemical Cell

Preparation of Electrolyte and Gas Collection

The cells were constructed with 200 mL of water in a beaker, with two glass tubes housing the electrodes face down. With a marker, the glass tubes were marked at the water level of the beaker, with the intention of observing the water level dropping below the line, indicating that hydrogen gas was being produced.

Preparation of Electrodes

The researchers purchased two nickel electrodes online, and separated them into 4 nickel strips in total: Nickel Anode (NA), Nickel Control Cathode (NCC), Nickel Flat CQD Cathode (NFCQDC), and Nickel Grooved Cathode (NGC). NA would be used as an anode for the oxygen evolution reaction (OER). and not be modified for the entirety of the experiment to avoid interference with the data, meanwhile the NCC would not be modified, but instead replaced

Process

At each test, before adding the electrodes to the cell, the electrodes' resistance was measured in Ohms. Each test would last 4 minutes, and there was an observation in the increase or decrease of gas volume. After each test, an additional line was drawn at the current water level, then the nickel electrode would be swapped with the next one. The NA would also be sandpapered down in order to refresh the material from any chemical reaction that occurred on the surface of the anode. Finally, after each trial, the height of the decrease in water level was measured, and the formula to calculate the volume of a cylinder was applied to derive the volume of hydrogen gas created. With the Ideal Gas Law equation, it is possible to calculate the moles of hydrogen produced. Multiplying this number by 2.02, or the atomic mass of hydrogen gas, returns the mass of hydrogen gas in grams.

Results

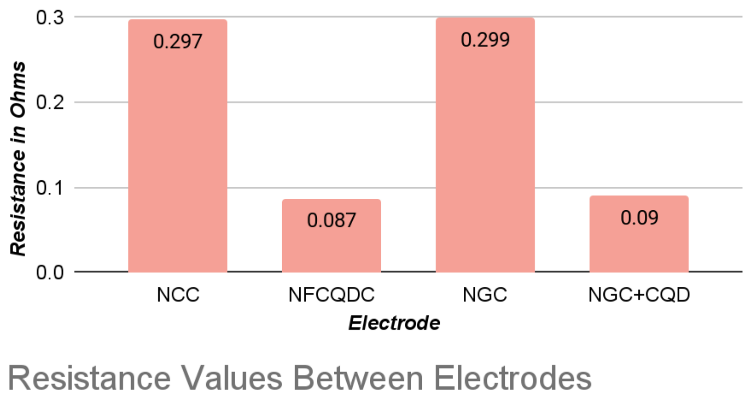

Figure 1: A multimeter measured the resistance, in Ohms, of the electrodes. NCC: 0.297 Ohms, NFCQDC: 0.087 Ohms, NGC: 0.093 Ohms, and NGC+CQD: 0.09 Ohms.

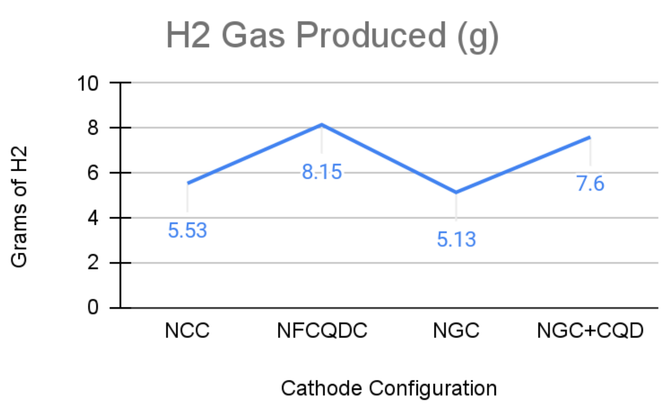

Figure 2: Based on the Ideal Gas Law: PV÷RT = n, the mass of H2 gas produced, in grams.

Analysis

Across both Figures 1 and 2, the NCC performed with a significantly lower efficiency than that of the rest of the cathodes. The NFCQDC produced the most hydrogen gas within four minutes and had the least amount of resistance when measured with a multimeter. All 3 of the modified electrodes saw a dramatic increase in hydrogen production, but among these, the NGC stands out because it was measured to have the highest resistance by the multimeter.

Discussion

As previously stated in hypothesis, it was the researcher's belief that the NGC + CQD cathode would work best, because not only does it possess the higher conductivity from the CQDs, but the jagged and rough surface could prevent the bubbles from forming on the cathode. In actuality, while the CQDs do significantly boost the conductivity and effectiveness in both configurations that include the CQDs, the jaggedness and grooves actually hindered the performance across the board. While it seems counter-intuitive, given that the research supports not just uneven and sharp structures (Han et al., 2024), but also heterogeneous structures (Kuo 2024), it is plausible that the lack of proper equipment created some undesirable traits in the samples. Besides nickel-based electrodes, cobalt-based electrodes, such as cobalt oxide, have had lots of attention in scholarly journals, namely because of its molecular structures (Ampurdanés et al., 2019). It would be worth investigating and experimenting with not only the effectiveness of different molecular structures, but also other nanoparticles as well. Cobalt oxide is also regarded as not just a strong HER electrode, but also a competitive oxygen evolution reaction (OER) electrode. Another test to consider in future iterations of the electrolyzer would be improving the OER, and determining whether an improvement in OER correlates to an improved HER. At the end of the day, water-splitting and efficient electrolyzer designs is also relevant to the subfield of

Unitised Hydrogen Fuel Cells (UHFCS), or fuel cells that can act as both electrolyzers and fuel cells depending on the mode (Paul et al. 2017). Understanding what makes successful catalysts for not just the HER reaction, but also the redox reaction between oxygen and hydrogen, is critical for the makings of a successful UHFC.

References

Ahad, M. T., Bhuiyan, M. M. H., Sakib, A. N., Becerril Corral, A., & Siddique, Z. (2023). An Overview of Challenges for the Future of Hydrogen. Materials (1996-1944), 16(20), 6680. https://doi.org/10.3390/ma16206680

Ampurdanés, J., Chourashiya, M., & Urakawa, A. (2019). Cobalt oxide-based materials as non-PGM catalyst for HER in PEM electrolysis and in situ XAS characterization of its functional state. Catalysis Today, 336, 161–168. https://doi.org/10.1016/j.cattod.2018.12.033

Han, Z., Zhao, H., Peng, C., Fan, C., Wang, G., Zhang, J., & Tang, Z. (2024). 3D-printed pyramid nickel-based electrode enabling directional bubble traffic and electrolyte flow for efficient hydrogen evolution. International Journal of Hydrogen Energy, 64, 476–486. https://doi.org/10.1016/j.ijhydene.2024.03.264

Kuo, T.-R., Chiou, Y.-T., Huang, H.-W., Chutima Kongvarhodom, Muhammad Saukani, Sibidou Yougbaré, Chen, H.-M., & Lin, L.-Y. (2024). Heterojunction and co-catalyst engineering of bismuth vanadate by nickel molybdenum oxide and carbon quantum dot decorations for photoelectrochemical water splitting. *International Journal of Hydrogen Energy*, *51*, 1099–1108. https://doi.org/10.1016/j.ijhydene.2023.10.344

Paul, B., & Andrews, J. (2017). PEM unitised reversible/regenerative hydrogen fuel cell systems: State of the art and technical challenges. Renewable & Sustainable Energy Reviews, 79, 585–599. https://doi.org/10.1016/j.rser.2017.05.112

Wang, S. J., Zhang, Z. Y., Tan, Y., Liang, K. X., & Zhang, S. H. (2023). Review on the characteristics of existing hydrogen energy storage technologies. Energy Sources Part A:

Recovery, Utilization & Environmental Effects, 45(1), 985–1006.

https://doi.org/10.1080/15567036.2023.2175938