Performance Optimization of Dry HHO Cells: A Comparative Experimental Review of Electrolyte Selection and Cell Configuration

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***Abstract*—The continuous reliance on fossil fuels for transportation and power generation has resulted in severe environmental degradation, necessitating the development of cleaner and sustainable energy alternatives. Hydrogen has emerged as a promising energy carrier due to its high energy density and environmentally benign combustion characteristics. Among the various hydrogen generation methods, Dry HHO (oxy-hydrogen) cells have gained increasing attention due to their compact structure, improved safety, and enhanced efficiency compared to conventional wet electrolysis systems. This research paper presents a comparative experimental review and design optimization study of Dry HHO cells, focusing on electrolyte performance and cell configuration. The analysis is strictly based on two experimental investigations: Almassri et al. (2022) and Sivakumar et al. (2021). The performance of Ammonia Hydroxide (NH_4OH), Sodium Hydroxide (NaOH), and Potassium Hydroxide (KOH) electrolytes is evaluated in terms of hydrogen production rate, energy consumption, and material durability. The findings indicate that although NH_4OH demonstrates high hydrogen productivity, its severe corrosive behavior limits its long-term applicability. NaOH, on the other hand, offers faster gas generation with improved system stability, making it a more suitable electrolyte for practical Dry HHO cell applications.**

Keywords- (Dry HHO cell; Hydrogen production; Water electrolysis; Electrolyte optimization; Sodium hydroxide; Potassium hydroxide; Ammonia hydroxide; Stainless steel electrodes; Oxy-hydrogen gas; Renewable energy systems; Cell configuration; Electrochemical efficiency)

1. INTRODUCTION

The rapid growth in global energy demand, combined with escalating environmental concerns, has intensified research efforts toward alternative and renewable energy technologies. Conventional fossil fuel combustion is a primary contributor to greenhouse gas emissions, air pollution, and climate change. In this context, hydrogen is widely recognized as a clean and efficient energy carrier capable of supporting sustainable energy systems.

Hydrogen can be produced through several methods, including steam methane reforming, thermochemical cycles, and water electrolysis. Among these, water electrolysis is particularly attractive when coupled with renewable energy sources, as it enables carbon-free hydrogen production. HHO generators, which produce a mixture of hydrogen and oxygen gases through electrolysis, have been extensively studied for on-demand hydrogen generation.

HHO cells are generally categorized into wet and dry configurations. Wet cells involve complete immersion of electrodes in the electrolyte, resulting in increased electrolyte volume, higher system weight, and greater risks of leakage and parasitic current losses. Dry HHO cells, in contrast, utilize stacked electrode plates separated by non-conductive gaskets, allowing the electrolyte to contact only the active electrode surfaces. This configuration significantly reduces electrolyte volume, improves sealing reliability, minimizes corrosion at plate edges, and enhances overall system compactness.

Due to these advantages, Dry HHO cells are increasingly being explored for vehicular and small-scale energy applications. However, system efficiency is highly dependent on electrolyte selection, electrode material, and cell geometry. This paper aims to comparatively analyze these parameters by synthesizing experimental findings from two recent studies.

II. WORKING PRINCIPLE OF A DRY HHO CELL

In a Dry HHO cell, water electrolysis occurs when a direct current is applied across stainless steel electrode plates submerged partially in an alkaline electrolyte. The electrolyte increases the ionic conductivity of water, enabling efficient charge transfer between electrodes. Hydrogen gas is generated at the cathode, while oxygen gas evolves at the anode. The gases collectively form oxy-hydrogen (HHO), which can be utilized directly as a supplementary fuel.

The Dry cell configuration ensures that only the active faces of the electrodes participate in electrochemical reactions, while rubber or neoprene gaskets prevent short-circuiting and electrolyte leakage.

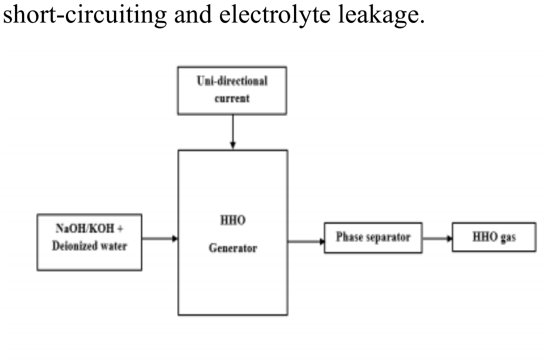

Figure 4. Schematic representation of HHO gas production.

Schematic representation of HHO gas Production

III. LITERATURE REVIEW AND EXPERIMENTAL BASIS

3.1 Dry HHO Cell Design Using Ammonia Hydroxide (Almassri et al., 2022)

Almassri et al. [1] conducted an experimental study on the design and performance of a Dry HHO cell intended for hydrogen production through electrolysis. The system consisted of 19 hexagonal electrode plates fabricated from 316L stainless steel, selected for its mechanical strength and corrosion resistance. The plates were arranged in a Dry cell configuration using insulating spacers and sealing materials to prevent electrolyte leakage. The cell was powered using a 12 V DC electrical supply, representative of automotive battery systems.

A key feature of this study was the selection of Ammonia Hydroxide (NH_4OH) as the electrolyte. The experimental results demonstrated a high rate of hydrogen generation, indicating strong electrochemical activity and favorable ionic conductivity. Based on measured electrical input and gas output, the specific energy consumption was calculated to be approximately 70.56 MJ per kilogram of hydrogen produced.

Despite the promising productivity, prolonged experimentation revealed a major limitation. The NH_4OH electrolyte caused severe corrosion of the stainless steel electrode surfaces, leading to material degradation, surface pitting, and reduced operational lifespan. The authors concluded that although NH_4OH enhances hydrogen production, its aggressive chemical behavior significantly compromises system durability and safety.

3.2 Brown Gas Generation Using NaOH and KOH (Sivakumar et al., 2021)

Sivakumar et al. [2] experimentally investigated the production of brown gas using a Dry HHO generator based on electrochemical decomposition. Their system employed 13 flat plates of 316 stainless steel, assembled using neoprene rubber gaskets to maintain electrical insulation and mechanical sealing.

The primary objective of this study was to compare the performance of Sodium Hydroxide (NaOH) and Potassium Hydroxide (KOH) electrolytes under similar operating conditions. Gas production rates were measured experimentally by recording the time required to generate a fixed volume of gas.

The results showed that NaOH achieved 1 liter of gas production in an average time of 53 seconds, whereas KOH required approximately 80 seconds. This demonstrated a clear performance advantage for NaOH in terms of gas generation rate. Additionally, the study reported that gas output increased with electrolyte concentration up to an optimal molarity, beyond which performance declined due to increased solution resistance and thermal losses.

Importantly, no excessive corrosion or material degradation was reported during the experiments, indicating that both NaOH and KOH are compatible with stainless steel electrodes under controlled operating conditions.

IV. COMPARATIVE ANALYSIS AND DISCUSSION

4.1 Electrolyte Performance Comparison

The experimental findings from the two studies highlight a critical trade-off between hydrogen productivity and material durability. NH_4OH, as reported by Almassri et al. [1], provides high hydrogen output but introduces severe corrosion-related challenges. In contrast, NaOH and KOH, as examined by Sivakumar et al. [2], offer stable and repeatable gas generation with significantly reduced corrosion risks.

NaOH demonstrated superior performance compared to KOH by achieving faster gas production at similar operating conditions. From a practical and safety-oriented perspective, NaOH represents a more suitable electrolyte for long-term Dry HHO cell operation, despite the higher instantaneous productivity observed with NH_4OH.

4.2 Electrode Material Validation

Both studies independently confirm the suitability of 316/316L stainless steel as the preferred electrode material for Dry HHO cells. Its corrosion resistance in alkaline environments and mechanical robustness make it ideal for repeated electrochemical cycling. The corrosion observed in NH_4OH-based systems is therefore attributed primarily to electrolyte chemistry rather than electrode inadequacy.

4.3 Cell Geometry and Configuration

The hexagonal plate geometry used by Almassri et al. [1] offers improved packing efficiency and potentially more uniform current distribution. However, the rectangular plate design employed by Sivakumar et al. [2] demonstrated effective performance with simpler fabrication requirements. From a manufacturing and scalability standpoint, conventional flat plate geometries may be more economically viable.

V. CONCLUSION

This study presents a comprehensive comparative analysis of Dry HHO cell efficiency based strictly on experimental findings from two peer-reviewed investigations. While Ammonia Hydroxide exhibits high hydrogen production capability, its severe corrosive effects significantly limit its applicability in practical systems. Sodium Hydroxide, in comparison, provides faster gas generation than Potassium Hydroxide while maintaining system stability and material integrity.

Based on the synthesized experimental evidence, the optimal Dry HHO cell configuration consists of 316L stainless steel plates operating with a NaOH electrolyte. This combination offers a balanced compromise between efficiency, durability, and operational safety. Future research should focus on surface coatings or advanced materials capable of mitigating corrosion effects, potentially enabling the use of high-productivity electrolytes such as NH_4OH without compromising system lifespan.

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