Hawai‘i Natural Energy Institute Research Highlights

Electrochemical Power Systems

Proton Exchange Membrane Fuel Cell Producing Hydrogen Peroxide

<u>OBJECTIVE AND SIGNIFICANCE</u>: Hydrogen peroxide is widely useful to many industries, as well as the military, as an environmentally friendly disinfectant and liquid oxidant for air-independent fuel cell applications. The main method for hydrogen peroxide production today: an anthraquinone-oxidation process, is energy-intensive, expensive, produces waste that negatively impacts the environment, and is not easily scalable, leading to the transport of dilute solutions at high cost to minimize safety concerns. The objective of this project is modify a proton exchange membrane fuel cell (PEMFC) to develop an alternative, electrochemical method for synthesizing hydrogen peroxide that also produces energy, eliminates waste by producing aqueous solutions of varied hydrogen peroxide concentrations, and is scalable to address the specific needs of these various industries and communities.

<u>BACKGROUND</u>: Hydrogen peroxide is considered among the world’s top 100 most important chemicals as it is very versatile and is mainly an eco-friendly disinfectant. Today, over 95% of hydrogen peroxide is produced from an anthraquinone-oxidation process. This process is very costly, mainly due to the fact that it can only economically work at large-scale. Further, it is a batch process that requires further separation and dilution processes, which also necessitate enormous amounts of energy to conduct. These dilution processes are vital as a safety measure to transport hydrogen peroxide over a range of distances due to its explosive nature as an oxidant. The substantial risks associated with the transportation of hydrogen peroxide alone produces a major need for scalable, onsite production of this chemical. If successful, onsite production of hydrogen peroxide would also provide the means for wastewater treatment in rural communities.

Hydrogen peroxide can be synthesized electrochemically from hydrogen and oxygen in a fuel cell utilizing the 2-electron (e^-) pathway of the oxygen reduction reaction (ORR) (Equation 1). Most polymer electrolyte (PEM) fuel cell research involves the $4e^-$ pathway of the ORR, or complete reduction of oxygen which produces water and power (Equation 2).

$$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2 \quad \text{(Equation 1)}$$
$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad \text{(Equation 2)}$$

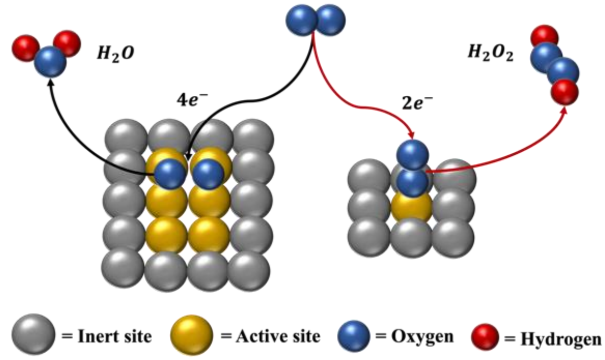

Figure 1. $2e^-$ and $4e^-$ pathways for the ORR.

<u>PROJECT STATUS/RESULTS</u>: The experimental plan and detailed procedures developed for a selective catalyst for the $2e^-$ pathway (further referred to as the “nano-dispersed supported-catalyst” or NDSC) was implemented and verified experimentally in a rotating ring/disk electrode (RRDE) setup. Results have shown that the modified NDSC is stable for a minimum of 22 hours under harsh experimental conditions.

Polarization curves were measured for both the ring and disk currents produced during experimentation with the NDSC. Hydrogen peroxide and water are generated at the disk whereas hydrogen peroxide is selectively detected at the ring. Ring current data versus time and disk potential from both the unmodified and modified NDSC are presented in Figure 2.

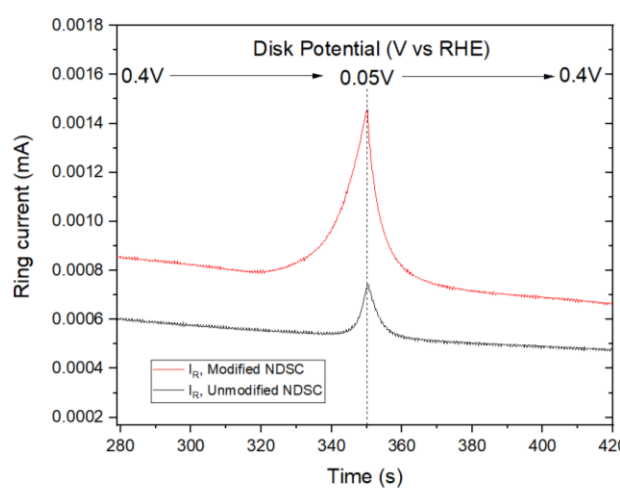

Figure 2. Ring current versus time and disk potential (0.05-0.4V vs RHE) for unmodified and modified NDSC indicating a significant increase at low disk-potentials (peak region).

The larger peak produced in the ring current for the modified NDSC (red) compared to that of the unmodified NDSC (black) at a low disk-potential (0.05V vs. the Reversible Hydrogen Electrode (RHE)) indicates that the catalyst modification is beneficial with an increase exceeding 100%. It is noted that the ring signal indirectly shows the presence of hydrogen peroxide at the ring electrode.

Preliminary hydrogen peroxide detection tests by colorimetry were performed to directly confirm the presence of hydrogen peroxide produced at the disk. Figure 3 shows the result of a colorimetric test, which confirmed the presence of approximately 3 mg/L hydrogen peroxide within the bulk solution after completion of experimental procedures.

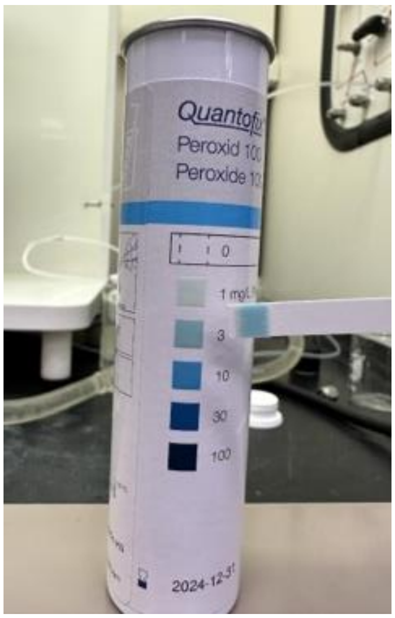

Figure 3. Colorimetric test strip indicating the positive detection of hydrogen peroxide after insertion into the bulk solution (post-production test).

HNEI is developing a quantitative potentiometric titration technique for a more precise detection of hydrogen peroxide in the bulk solution after experimentation with modified NDSCs. HNEI will complete long-term RRDE experiments under a range of conditions aimed at maximizing the hydrogen peroxide yield and characterizing catalyst stability. Finally, experiments will be conducted in a single, 50 cm^2 PEMFC specifically modified (including changes in both operating conditions and hardware design) to simultaneously maximize peroxide yield and minimize peroxide decomposition within the cell. Other performance metrics will also be monitored during these tests, including exhaust composition and cell power for optimization of hydrogen peroxide production and electrical power.

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