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The Remediation of Wastewater Using a Novel Microbial Fuel Cell with Optimized Electricity Generation and an Algae Bioreactor

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Abstract- The USA generates the maximum amount of wastewater per capita across the world, and according to the EPA, approximately $25 billion is annually spent on its treatment. In addition to the high costs, high residues of nitrogen and phosphorus are found in the remediated clean water. The purpose of this study was to create a scalable, novel microbial fuel cell (MFC)/algae bioreactor that would be more efficient in pollutant removal as well as energy consumption than current aeration technologies. The MFC consists of two chambers (cathode and anode) separated by a Nafion membrane. The control treatment, aeration, and MFC took 11 days, 3 days, and 0.9 days, respectively to remediate the water (90% dissolved oxygen increase). Additionally, the MFC was able to generate electricity at a sustainable voltage (0.62 V max). Anabaena biomass increase in the algae bioreactor effectively reduced nitrate levels. As shown in this study, MFC treatment holds promise for a more electrically efficient, time efficient and cost-efficient method for treating wastewater.

I. INTRODUCTION

3% of the United States' electrical load is due to wastewater treatment, which is equivalent to the electricity use of 9.6 million households [1]. The cost and electrical load of treating wastewater is largely due to the aeration technology as it consumes 45-75% of wastewater treatment plant costs [2]. Aeration reactors treat wastewater by bringing the pollutants in contact with air, causing biodegradation of the contaminants. To solve the problem of energy efficiency, microbial fuel cells (MFCs) were used to treat wastewater, as MFCs are devices that use bacteria as catalysts to oxidize organic and inorganic matter and generate current through the transfer of electrons from anode to cathode [3]. Although MFCs have been studied for many years, they have not been put into practical use due to hindering points such as cost and durability, with materials like the forward osmosis membrane requiring very specific storage conditions and carbon paper electrodes being too flimsy.

This study created an optimized design of the most commercially viable materials to construct the MFC. However, MFCs are not completely efficient in removing nitrates and phosphates from wastewater. These pollutants are linked to zones of eutrophication and hypoxia, or "dead zones" where life cannot be sustained due to reduced oxygen levels because of algal blooms and excess nutrient deposits[4]. Dissolved oxygen is an important factor to measure water quality as it directly indicates an aquatic resource's ability to support aquatic life. To further remove nitrates from the water, algae treatment of the water was undertaken as algae contain a high affinity transport system NrtABCD permease, which allows nitrate to enter the algae and be converted into ammonium, which reduces pollutant levels in the cleaned wastewater [5].

So, the purpose of this study was to engineer a novel, scalable, cost-efficient, and time efficient MFC with optimized electricity generation and enhanced pollutant removal with an algae bioreactor, whose efficiency should be higher than current aeration and control treatments.

II. METHODS

In phase one, the control, aeration, and MFC were run until a 90% increase in dissolved oxygen was observed. The control treatment consisted of still artificial wastewater, made according to the OPEC formula, and the aeration reactor consisted of artificial wastewater circulated by an aquarium diffuser. *E. coli* K-12 (Carolina Biological) served as the exoelectrogenic microbial agent for the MFC (figure 1), which was constructed by joining two, 300mL plastic containers together with a Nafion membrane. The anode compartment consisted of carbon felt electrode and was fed wastewater solution inoculated with 15 colonies of *E. coli* K-12. The cathode compartment consisted of carbon cloth electrode with platinum as catalysts and 5% sodium chloride as a draw solution. Dissolved oxygen (DO) and electricity generation were measured using a Vernier dissolved oxygen probe and Vernier energy sensors, respectively.

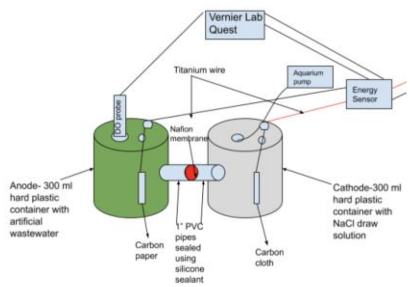

Figure 1: Schematic of MFC *(by authors)*

Figure 2: Algae bioreactor setup *(by authors)*

In phase 2, an algae bioreactor was constructed using plastic water bottles containing *Anabaena* algae solution (Carolina Biological), plus the remediated wastewater from phase one (figure 2) to further remediate nitrates via biomass increase over one week.

III. RESULTS/DISCUSSION

The purpose of this study was to determine the efficiency of a novel MFC to treat wastewater in terms of electricity generation and pollutant removal. The control, aeration, and MFC reactor took 11 days, 3 days, and 0.9 days, respectively, to observe a 90% increase in dissolved oxygen levels (figure 3). This increase indicated that enough oxygen had reentered the water to combat the effects of hypoxia and eutrophication. The MFC remediated the wastewater significantly faster than both the control and aeration, due to the Nafion membrane, which filtered out particulates. This membrane, in addition to the *E. coli* K-12, transferred the hydrogen ions to the cathode to combine with the oxygen molecules, facilitating the transfer of oxygen from the air to the water, increasing the DO in the anode chamber.

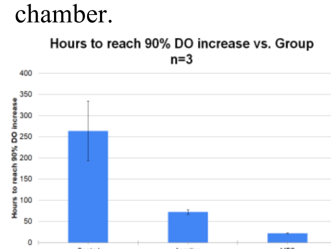

Figure 3: The amount of time, in hours, it took the Control reactor, Aeration reactor, and Microbial Fuel Cell to reach a 90% increase in DO from the initial readings. *(graph by authors)*

The MFC group showed the capability of producing an increased voltage of 0.126V on average (figure 4), proving *E. coli* K-12 to be a valid exoelectrogenic microbial agent which concurs with Sugnaux et. al (2013) [6] as it created an electrical current between the anode and cathode, by oxidizing the organic substrate of the wastewater. The wastewater in the anode chamber of the MFC is oxidized by the *E. coli* K-12 into carbon dioxide and hydrogen ions. The hydrogen ions pass through the membrane to the cathode chamber, where it combines with oxygen molecules from the air to produce pure water molecules. The overall reaction ends up converting the organic substrate and oxygen into carbon dioxide, pure water, and electricity.

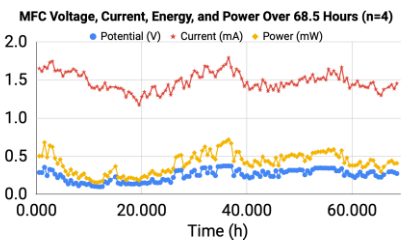

Figure 4: Novel MFC testing over 68.5 hours for variables including voltage (blue), current (red), and power (yellow). All variables experienced fluctuation, reaching a maximum at around hour 35 of operation. *(graph by authors)*

The average efficiency of the MFC was 75% which is comparably larger than the standard 40% efficiency of aeration reactors, as aeration requires inputted power from an aquarium pump, which is lost as thermal energy to the environment. Additionally, it does not produce any power of its own. However, the MFC used the energy from the aquarium pump, while also generating its own power. At hour 35 of (figure 5), a 135% efficiency was observed, meaning the MFC was producing more power than it consumed.

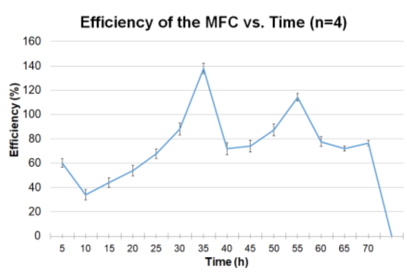

Figure 5: The efficiency of the MFC system as time increased from 0 to 70 hours. Energy efficiency was calculated using the equation: P_{output}/P_{input}. *(graph by authors)*

The microbial fuel cell is 42.72% cost efficient while the aeration reactor is 29.48% cost efficient (figure 6). The MFC cost $10.68 to construct while the aeration reactor cost $17.69. The increased cost efficiency of the MFC is attributed to carbon felt electrode and commercially viable Nafion membrane used in this device. The MFC is a more practical instrument to use in wastewater treatment, as it can help reduce electricity costs, and save money spent in the water sector, while also producing a greater power efficiency.

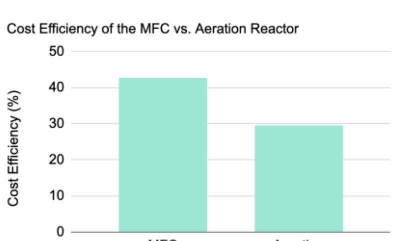

Figure 6: Cost efficiency (%) of the Microbial Fuel Cell compared to that of the Aeration Reactor. *(graph by authors)*

On day one of testing the algae bioreactor, nitrate levels began at 75mg/L, and decreased to 23.5mg/L after the full seven-day period (figure 7). This decrease was due to the growth of algal biomass in the water as algae used the enzyme nitrogenase to convert nitrates into atmospheric nitrogen by consuming the pollutant. The reduced nitrate level achieved by the bioreactor may be suitable for other aquatic species, such as fish, to live in, as the nitrate safe limit for such species is 25mg/L [7].

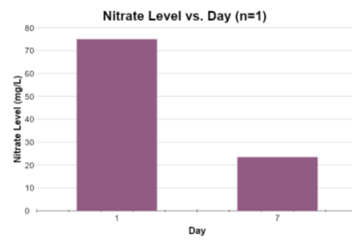

Figure 7: Nitrate removal by the algae bioreactor over a span of 7 days. 10 mg/L of nitrate is considered a safe drinking water standard [7]. *(graph by authors)*

IV. Conclusions

The alternative hypothesis was accepted as the rate of the remediation of wastewater (90% DO increase) was significant in the MFC as compared to the control group and aeration group. The MFC design was able to produce electricity indicating a preservation of energy through wastewater treatment. As a result, the MFC indicated a higher energy efficiency in treating wastewater as compared to current aeration technologies. In the future, a larger scale model of the MFC can be tested to observe the efficacy of this prototype design at the industrial level. This novel MFC has a patent pending (application number: 62987455). Moreover, the electrodes and Nafion membrane used were determined to be the most cost and energy efficient as well as readily available. Hence, this design is scalable, commercially viable and capable of being used in industry which reduces the burden on fossil fuels, reduces the time taken to remediate wastewater, and mitigates the increased electricity consumption projection over the following decades.

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