Enhanced MFC Performance Using Vertically Oriented Graphite Electrodes for Voltage generation and Pollution Removal

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KEYWORDS

Microbial fuel cell, Domestic Wastewater, Bioreactors, Graphite Electrodes, Voltage Generation, Pollution Removal, Sustainable Treatment

ABSTRACT

The need for sustainable solutions is highlighted by the growing energy requirements for treating household wastewater (DWW) and the depletion of fossil resources. In order to accomplish simultaneous wastewater treatment and electricity generation, this study investigates the integration of bioreactors with an emphasis on material efficiency. Significant pollutant removal and bioelectricity production were accomplished by the reactor by utilising graphite electrodes, which have high conductivity and durability. The experimental design examined how electrode location and aeration affected performance indicators. The results showed that, thanks to better electron transfer kinetics, aeration greatly increased voltage generation and pollutant elimination efficiency. In order to optimise bioreactor performance and open the door for scalable, energy-efficient wastewater treatment systems, this work highlights the crucial role that materials play.

1. Introduction

Globally, the treatment of domestic wastewater (DWW) requires a lot of energy, and with the exhaustion of fossil fuel resources, the price of energy is likely to increase [1]. One novel method towards improving the economic and energy efficiency of wastewater treatment plants is the conversion of the chemical energy stored within the organic content within DWW into electrical power. Untreated wastewater made up of organic and mineral trash biodegrades and can lead to water hardness and pollution, according to Zhang et al. (2018) [2]. Domestic Wastewater is divided into Black water from the kitchen and toilet with high levels of organic pollutants, usually above 10,000 mg/L[8]. Grey Water mostly washroom and laundry room wastewater with little organic content (400–1000 mg/L) [7].

Bioreactors have also shown very potential as green alternatives for wastewater treatment. They make very good use of the microbial process to produce bioelectricity while treating wastewater with the help of certain materials such as electrodes for the transfer of electrons. The efficiency of the reactor usually depends upon the materials used. For instance, graphite electrodes have also been extensively explored as they are economical, robust, and conductive when used within the context of microbial fuel cells (MFCs), which facilitate the generation of electricity and the removal of pollutants [3]. The scalability and the losses within the system also rely upon materials such as membranes, catalytic layers, and reactor structural elements [6].

Method

This involved designing and fabricating a bioreactor for the dual purpose of domestic wastewater treatment and power production. Domestic wastewater was collected from a domestic sewage treatment plant (STP) with a population base of approximately 1600 residents. Grab sampling was employed for the collection of representative samples. The wastewater was tested immediately for preliminary parameters like pH, COD, BOD, turbidity, and ammonia content for establishing the baseline characteristics.

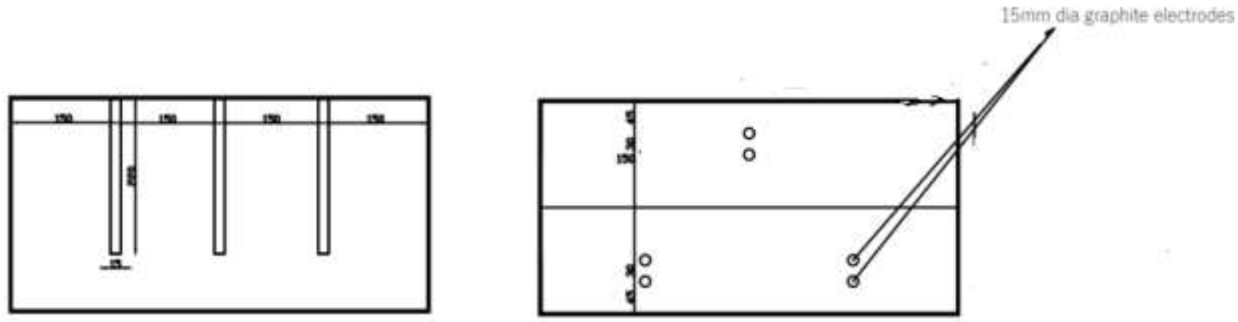


Figure 1: Schematic Diagram of Reactor Setup with 15mm Diameter Graphite Electrodes

The bioreactor was constructed using acrylic sheets with dimensions of 0.6 m × 0.3 m × 0.35 m. Graphite electrodes were installed strategically in series and parallel configurations for voltage optimization. The reactor also consisted of aeration tubes for enhanced microbial action and a collection reservoir for the proper distribution of the flow during the process.

For the experimental setup, the wastewater was pretreated with debris removal and pumped into the reactor with 100 ml/min and 500 ml/min controlled flow rates. The experiments were performed under aerated and non-aerated modes with a maintained hydraulic retention time (HRT) of 60 minutes. The voltage produced was measured every 5 minutes with the aid of a multimeter, and the effluent was analyzed for the final wastewater properties. Treatment efficiency was tracked with reference to the removal of prominent parameters such as COD, BOD, and ammonia.

Statistical techniques including correlation and regression were employed to study the correlation between the wastewater parameters and the yield of bioelectricity. Additionally, the Wastewater Quality Index (WWQI) was calculated using the Canadian Water Quality Index (CWQI) method to classify the treated wastewater and determine the pollution intensity.

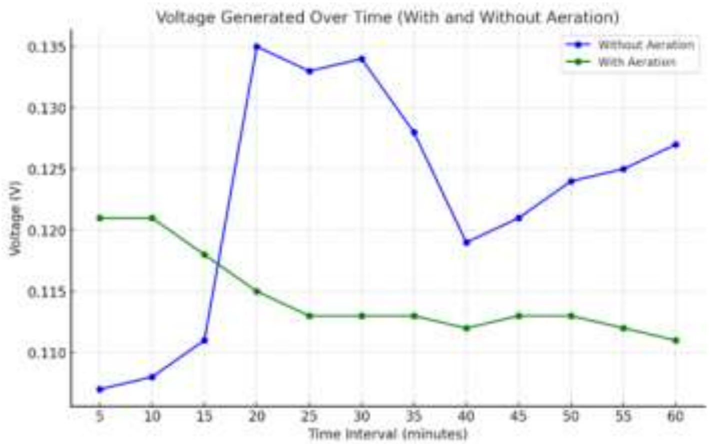
2. Findings and Discussions

The bioreactor demonstrated significant efficiency in wastewater treatment, with aeration playing a crucial role. Table 1 highlights marked reductions in turbidity and total suspended solids (TSS) , with TSS decreasing from 1214 mg/L initially to 16.7 mg/L with aeration. Organic pollutants, measured by COD and BOD, dropped significantly, with COD reducing from 1440 mg/L to 248 mg/L and BOD from 560 mg/L to 74 mg/L under aerated conditions.

Table 1: Domestic Wastewater Analysis for Flow Rate 100 ml/min (3 Pairs of Electrodes Connected in Series)

Sl.no	Parameters with units	Initial	Without aeration	With aeration
1	pH value @25°C	7.5	7.5	7.4
2	Turbidity, NTU	65	63	18.3
3	Total Suspended Solids, @105°C mg/L	1214	74.8	16.7
4	Chemical Oxygen Demand, mg/L	1440	728	248
5	Ammonical Nitrogen as NH3-N, mg/L	20.7	7.8	3.9
6	Chloride as Cl, mg/L	244	220	200
7	Sulphate as SO4, mg/L	55.3	55.2	60.2
8	Total hardness as CaCO3, mg/L	540	532	532
9	Calcium as Ca, mg/L	88	86.4	83.2
10	Magnesium as Mg, mg/L	77.7	68	66.5
11	Nitrate as NO3, mg/L	13.7	1.6	0.7
12	Nitrite, mg/L	15.1	3.3	1.6
13	Total dissolved solids, @1800C mg/L	555	426	430
14	Biochemical oxygen demand mg/L (3days at 27 °C)	560	170	74
15	Dissolved oxygen	0.18	2.6	3.8
16	Phenolic compounds	ND	ND	ND

Nutrient removal was also enhanced. Ammonical nitrogen decreased from 20.7 mg/L to 3.9 mg/L, and nitrate levels dropped from 13.7 mg/L to 0.7 mg/L with aeration, indicating efficient nitrogen cycling. Dissolved oxygen (DO) levels increased from 0.18 mg/L to 3.8 mg/L, supporting microbial activity. Meanwhile, parameters like hardness, chloride, and sulphate remained relatively stable, showing limited interaction with the treatment process.The wastewater analysis highlights the effectiveness of the treatment process, particularly with aeration. Turbidity reduced significantly from 65 NTU to 31.5 NTU, and total suspended solids (TSS) decreased from 1214 mg/L to 55.4 mg/L with aeration, reflecting enhanced particle and solids removal. Chemical oxygen demand (COD) and biochemical oxygen demand (BOD) showed substantial reductions, from 1440 mg/L to 132 mg/L and 560 mg/L to 70 mg/L, respectively, indicating efficient organic pollutant degradation



Graph 1: Voltage Comparison: With and Without Aeration at 100ml/min flowrate

The graph 1 illustrates voltage generation trends over time for microbial fuel cells operated with and without aeration. In the non-aerated system, voltage steadily increased from 0.07 V at 5 minutes to 0.101 V at 65 minutes, indicating stable microbial activity under anaerobic conditions. This trend reflects a conducive environment for electron transfer, leading to gradual voltage buildup.

In contrast, the aerated system showed higher initial voltage at 0.121 V, which gradually declined to 0.111 V by 60 minutes. This reduction suggests that while aeration enhances oxygen availability and supports aerobic microbial processes, it may reduce electron transfer efficiency, resulting in lower sustained voltage.

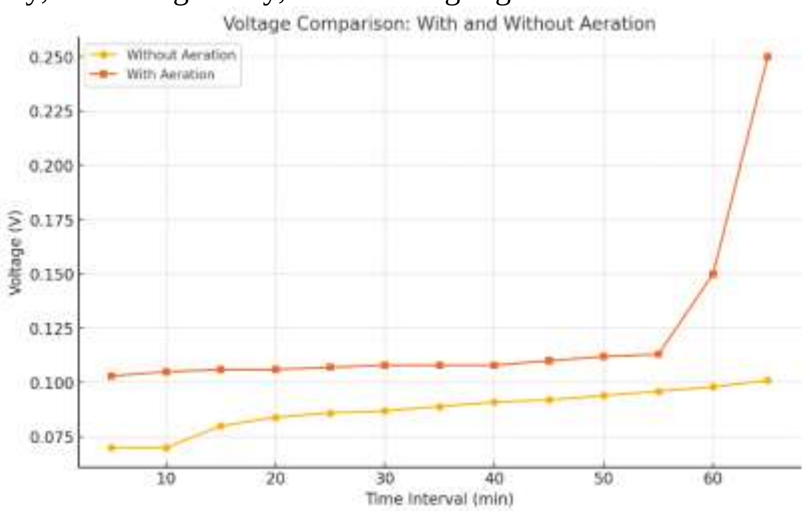
Overall, the absence of aeration provided a more stable voltage increase, while aeration boosted initial performance but led to voltage stabilization or decline. These findings highlight the trade-off between energy generation and wastewater treatment efficiency, with aeration favouring treatment processes at the expense of sustained voltage output.

Table 2: Domestic Wastewater Analysis for Flow Rate 500 ml/min (3 Pairs of Electrodes Connected in Series)

Sl.no	Parameters with units	Initial	Without aeration	With aeration
1	pH value @25℃	7.5	7.5	7.6
2	Turbidity, NTU	65	47	31.5
3	Total Suspended Solids, @105℃ mg/L	1214	110.3	55.4
4	Chemical Oxygen Demand, mg/L	1440	232	132
5	Ammonical Nitrogen as NH_3-N, mg/L	20.7	11.6	10.5
6	Chloride as Cl, mg/L	244	235	225
7	Sulphate as SO4, mg/L	55.3	49.7	33.7
8	Total hardness as CaCO3, mg/L	540	536	527
9	Calcium as Ca, mg/L	88	63.2	52.4
10	Magnesium as Mg, mg/L	77.7	31.1	3.8
11	Nitrate as NO3, mg/L	13.7	13.7	11.8

12	Nitrite, mg/L	15.1	14.1	13.9
13	Total dissolved solids, @1800C mg/L	555	520	434
14	Biochemical oxygen demand mg/L (3days at 27 ℃)	560	79	70
15	Dissolved oxygen	0.18	2.6	2.71
16	Phenolic compounds	ND	ND	ND

Table 2 Nutrient removal with 500ml/min flow rate, with ammonical nitrogen decreasing from 20.7 mg/L to 10.5 mg/L, and nitrate showing a modest decline. Dissolved oxygen (DO) levels rose from 0.18 mg/L to 2.71 mg/L, supporting aerobic microbial activity. Parameters like sulphate and magnesium showed notable reductions due to precipitation, while chloride and hardness remained relatively stable. The results underscore the significant impact of aeration in improving treatment efficiency, enhancing clarity, and reducing organic and nutrient loads in the effluent.



Graph 2: Voltage Comparison: With and Without Aeration at 500ml/min flowrate

Graph 2 demonstrates the significant influence of aeration on voltage generation in microbial fuel cells (MFCs). A steady and progressive increase was seen with the voltage output without aeration from 0.07V after 5 minutes to 0.101V after 65 minutes. The aerated system had a starting voltage of 0.103V and showed a steep increase thereafter with a value of 0.25V after 65 minutes. Enhanced performance in the aerated setup can be attributed to the greater availability of oxygen, which boosts the cathodic reaction and efficiency of electron transfer. The non-aerated arrangement with anaerobic conditions recorded slower voltage rise due to the limited electron acceptors. The findings demonstrate the importance of aeration in the optimization of MFC performance, particularly where elevated voltage is required.

However, it is essential to consider the trade-offs between the increased efficiency and the increased operating expenses associated with aeration. Further studies with the incorporation of gas composition and flow rate would provide further understanding into the interaction between the transfer of mass, the function of the microbes, and the yield of energy within MFCs. The study identifies the potential for aeration as a vital parameter for enhancing the performance of MFC systems for sustainable power and wastewater treatment.

3. Conclusion

This study brings into focus the possibility of bioreactors' use for the recovery of energy and the treatment of domestic wastewater. With their capability to produce power and remove impurities with such high efficiency, graphite electrodes are prime candidates for green usage. With better cathodic reaction and electron transfer, aeration is now a critical component for the improvement of reactor performance. Scalability issues still exist, though, and further reactor design and material selection optimisation is required. This study emphasises how incorporating cutting-edge materials into bioreactors might help solve the world's wastewater treatment problems and promote renewable energy sources.

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