Optimization of Substrates for the Production of Energy fromWastewater through the Utilization of Microbial Fuel Cells (MFCs)

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Abstract: Currently, microbial fuel cells (MFC) provide viable options for both generating power and treating wastewater. A microbial fuel cell (MFC) is a cutting-edge technology that offers an efficient solution to the problems presented by costly and ecologically damaging energy generation systems reliant on fossil fuels. This study involved the creation of a dual-phase microbial fuel cell (MFC) and the subsequent conduction of experiments in two distinct stages. The initial stage of the experiment was the use of home sewage and dairy effluent, without the addition of any substrate. The second part of the experiment involved the use of residential sewage and dairy effluent, with sodium acetate serving as the substrate. An analysis was conducted on the physiochemical parameters of wastewater in both stages, including color, odour, pH, COD, BOD, TDS, and TSS. The experimental run yielded removal efficiencies of 83.4% for COD and 64.8% for BOD in dairy effluent, 78.4% for COD and 60.4% for BOD in domestic sewage with substrate addition, 75.5% for COD and 53.6% for BOD in dairy effluent, and 63.1% for COD and 58.1% for BOD in domestic wastewater without substrate addition. The voltage produced in the initial phase, in the absence of substrate, during the treatment of household and dairy wastewater was 702.2 mV and 738.5 mV, respectively. During the second phase, the voltage created for treating household wastewater was 725.4 mV, whereas for dairy wastewater it was 753.2 mV. The voltage produced during the treatment of dairy effluent is higher in both stages of the experimental trial. The study showed that organic matter in dairy wastewater degraded more efficiently and produced a higher quantity of electrons compared to household wastewater organic matter.

Keywords: Microbial, Fuel cell, Energy production, Sustainable, Wastewater.

I. INTRODUCTION

The growing global population requires a proportional increase in water demand. Over the past century, the rate of water consumption has been increasing at a pace that is more than double the rate of population growth. The increase in water use has resulted in a proportional increase in the production of wastewater and, as a result, a corresponding increase in the demand for treatment. As a result, it has been noted that modern wastewater treatment systems currently make up approximately 3% of the electricity consumption in wealthy nations [5]. Due to the ongoing increase in the world's population and the limited availability of water resources, it is becoming increasingly important to find more reliable and cost-effective ways to handle wastewater. To guarantee both water and energy security [7], it is essential to develop innovative treatment techniques that can offset the significant energy costs.

Wastewater treatment facilities (WWTPs) are widely employed in different towns and businesses to reduce the pollution of water bodies caused by harmful wastewater. Rhoads et.al, 2005, emphasized that most WWTPs were built with a focus on meeting specified effluent efficiency standards, without sufficiently considering energy requirements. They underscored the fact that this is a domain that requires enhancement. However, the energy efficiency of wastewater treatment plants (WWTPs) is currently receiving attention because of the importance of renewable water and energy sources, as well as the carbon emissions that come with them, in the context of urban growth.

Moreover, the growing recognition of climate-related issues has resulted in a greater emphasis on energy conservation, improvements in energy efficiency, and the quest of renewable energy sources as major goals in the field of global sustainable development. The connection between water and energy is illustrated by the wastewater treatment plant (WWTP) [3]. Improving water quality in most wastewater treatment plants (WWTPs) requires a significant amount of energy. Municipalities regard WWTPs as the main independent consumers of energy. Several crucial steps in a wastewater treatment plant (WWTP), such as the gathering and transportation of wastewater, physical and chemical

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treatment, biological treatment, sludge treatment, and eventual release, require significant energy input. In a traditional wastewater treatment plant (WWTP), energy consumption represents 25-40% of the total operating costs. Moreover, the global concern also stems from the greenhouse gas emissions produced by energy use in WWTPs.

Microbial fuel cells (MFCs) have emerged as a promising technology in recent years, but they also pose significant challenges. Microbial fuel cells (MFCs) play a role in energy exchange, with energy that can be extracted or used as electricity [10]. A microbial fuel cell (MFC) is a bio-electrochemical system (BES) that uses the metabolic activity of microorganisms to convert biomass into energy [14, 15]. Microbial fuel cells (MFCs) are considered as a highly promising and sustainable technology to meet the huge energy demand. It specializes in using wastewater as energy to generate electricity while cleaning wastewater. This can reduce operating costs associated with wastewater treatment plants [6].

A microbial fuel cell (MFC) is a compact device that uses the energy potential of bacteria by using their metabolism in the anaerobic oxidation process to generate electricity from biomass. Microbial fuel cells (MFCs) have been recognized as a promising tool to produce bioenergy from wastewater during wastewater treatment, thus the costs associated with wastewater treatment are always present [4]. The basic structure of the microbial fuel cell (MFC) includes a proton exchange membrane (PEM) anode in the anode chamber and a cathode in the cathode chamber. Microbial fuel cells (MFCs) operate by using biocatalysts to catalyze the oxidation of organic substrates in the anode chamber. This process produces protons, electrons and carbon dioxide (CO2) [13].

While the anode transfers electricity from outside to the cathode, protons are transferred from the anode chamber to the cathode chamber through the proton exchange membrane (PEM). At the cathode, electrons engage in a chemical reaction with protons and oxygen, leading to the creation of water [8]. The electricity produced by microbial fuel cells (MFCs) using wastewater is of high purity and can be directly utilized without any modification. Just like hydrogen and methane produced by anaerobic digestion, anaerobic waste does not require any extra purification, separation, or conversion processes. MFC technology is environmentally sustainable, as it can function in many environmental conditions and produce power without generating pollution [9, 12]. Despite its ability to efficiently treat wastewater and generate electricity, MFC technology faces challenges when it comes to implementing it in real-world applications or marketing beyond laboratory settings. Microbial fuel cells (MFCs) have several challenges that hinder their direct field applications. These challenges include the expenses associated with electrode materials, the need for precious metal catalysts, limited performance, low power densities, and the high cost of proton exchange membranes (PEMs) [1].

This study aims to assess the efficiency of small-scale microbial fuel cells (MFCs) in treating domestic wastewater collected from a primary settling tank of a wastewater treatment plant (WWTP) and dairy effluent received from Dudhsagar dairy. The developing MFC was equipped with a cathodic and anodic chamber, which were connected by a graphite rod electrode and a salt bridge.

II. MATERIALS & METHODOLOGY

A. Sample Collection and it's characterization

The wastewater samples, each with a volume of 10 liters, were obtained from the Pirana sewage treatment plant located in Ahmedabad, Gujarat, India, and dairy wastewater was collected from Dudhsagar Dairy in the Mehsana district. The physiochemical features were initially assessed and documented. Colour, odour, pH, Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), and Total Suspended Solids (TSS) were assessed using a standardized approach [2].

B. Microbial fuel cells reactor and experimental setup

A microbial fuel cell comprises an anodic and cathodic container. Figures 1 and 2 illustrate the layout of the microbial fuel cell (MFC). The electrode used in this study is a cylindrical graphite structure. The graphite rod is suspended using copper wire as a conductor to facilitate the movement of electrons from the anode to the cathode. The salt bridge is made of a 20 cm long PVC pipe with a diameter of 2.5 cm, containing 5% agar and 1 M KCl. The salt bridge enables the movement of electrons from the anode to the cathode. Connect the anode to the multimeter and record the cathode voltage. A multimeter must be connected to the anode and cathode to measure the voltage and current generated during the process.

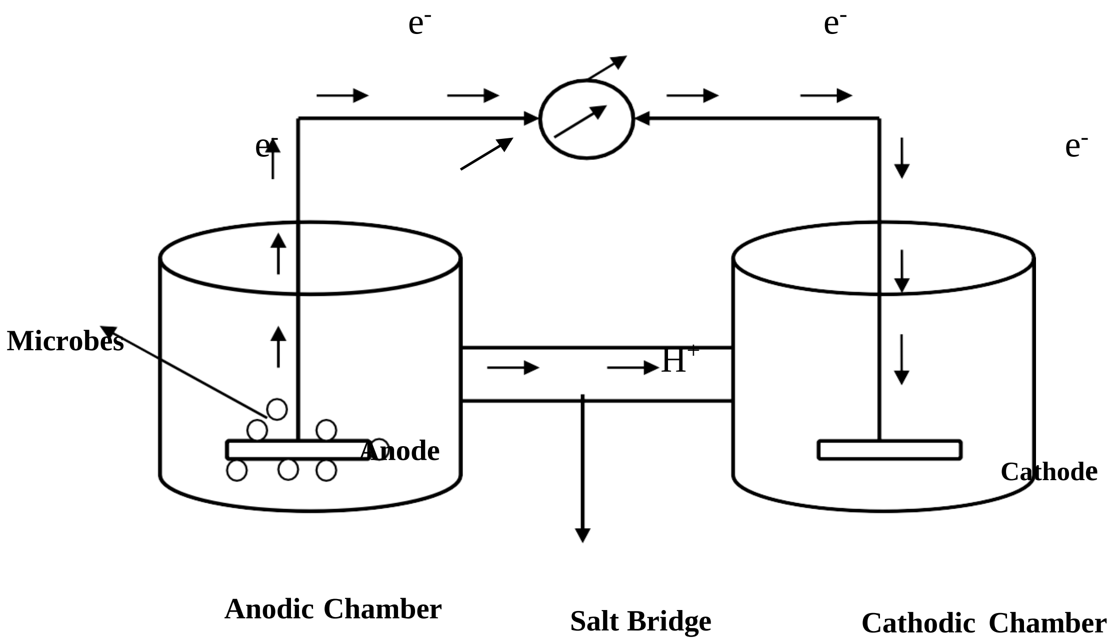

Fig. 1 Schematic Diagram of Dual-Chamber Microbial Fuel Cell

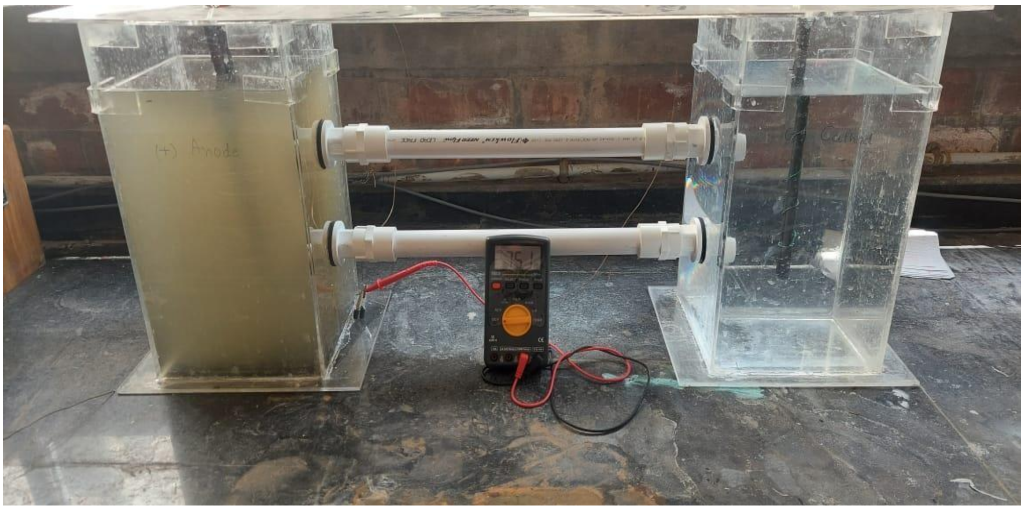

Fig. 2 Experimental MFC setup

The experiment was carried out in two stages, specifically the first stage and the second stage, with domestic sewage and wastewater as the main products. In the first stage, the microbial fuel cell operates without a substrate. In the second step, sodium acetate substrate was added at a concentration of 2 g per liter of sample. A decomposer that metabolizes the organic compounds often found in sludge and wastewater. The experimental methodology consisted of analyzing many parameters, including pH, colour, odour, COD, BOD, TDS, and TSS. These parameters were measured both before and after operating the microbial fuel cell model that was constructed. The variables of voltage, current density, and power density were calculated, compared, and analyzed over a period of time.

III. RESULTS AND DISCUSSION

A. Physiochemical analysis

An initial analysis was conducted on the physiochemical parameters of the domestic wastewater, which was then treated utilizing a built microbial fuel cell (MFC). Table 1 presents the physiochemical characteristics of household wastewater and dairy wastewater before and after treatment using a microbial fuel cell (MFC) with and without the inclusion of any substrate. The pH of untreated domestic wastewater is 6.3. After undergoing treatment, the pH level rose to 6.7, indicating that the use of microbial fuel cell (MFC) treatment successfully changed the acidic properties of the effluent, resulting in a more neutral condition. MFC significantly eliminates BOD and COD throughout the treatment process. The BOD removal rates ranged from 60.4% to 64.8%, while the COD removal rates were between 78.4% and 83.4% for domestic and dairy wastewater treated using sodium acetate substrate as tabulated in Table I. The BOD removal rates were 58.1% and 53.6% for domestic and dairy wastewater, respectively, without the addition of any. Similarly, the COD removal rates were 63.1% and 75.5% for domestic and dairy wastewater, respectively, without the usage of any substrate as tabulated in Table II. The evaluation of total dissolved solids (TDS) in the effluent showed removal rates of 56.8%, 53.8%, 77.4%, and 69.4% for domestic with and without substrate addition and dairy wastewater with and without substrate respectively. The Total Suspended Solids (TSS) exhibited removal rates of 55.1%, 45.7%, 69.7%, and 67.5% for domestic wastewater with and without substrate addition, and dairy wastewater with and without substrate addition respectively.

TABLE I:

CHARACTERISTICS OF DOMESTIC AND DAIRY WASTEWATER WITH SUBSTRATE ADDITION

Parameters	**Domestic Wastewater**			**Dairy Wastewater**		
	Initial Result	**Final Result with Substrate**	**Removal Efficiency (%)**	**Initial Result**	**Final Result with Substrate**	**Removal Efficiency (%)**
Colour	Light green	Black	---	Milky white	Milky white	---
pH	6.3	6.5	---	6.8	6.9	---
COD (mg/L)	830	180	78.4 %	3830	636	83.4 %
BOD (mg/L)	310	123	60.4 %	1480	522	64.8 %
TDS (mg/L)	670	290	56.8 %	5880	1330	77.4 %
TSS (mg/L)	285	128	55.1 %	1135	345	69.7 %

TABLE II:

CHARACTERISTICS OF DOMESTIC AND DAIRY WASTEWATER WITHOUT SUBSTRATE ADDITION

Parameters	**Domestic Wastewater**			**Dairy Wastewater**		
	Initial Result	**Final Result with Substrate**	**Removal Efficiency (%)**	**Initial Result**	**Final Result with Substrate**	**Removal Efficiency (%)**
Colour	Light green	Black	---	Milky white	Milky white	---
pH	6.3	6.7	---	6.8	6.9	---
COD (mg/L)	830	307	63.1 %	3830	942	75.5 %
BOD (mg/L)	310	130	58.1 %	1480	687	53.6 %
TDS (mg/L)	670	310	53.8 %	5880	1800	69.4 %
TSS (mg/L)	285	155	45.7 %	1135	370	67.5 %

B. MFC analysis

In the initial phase of the experiment, a saltwater solution was used as the cathode, and bacteria served as the anode to decompose organic substances. The multimeter was used to measure the daily current and voltage produced by the microbial fuel cell (MFC) over a period of about 25 days. The variables - voltage, power, and current - have been quantified, and a graph is being generated for thorough analysis (Figure 3 and 4). The graph shows the relationship between voltage and the growth curve of the microorganism during the exponential phase. As the system enters the stationary phase due to the depletion of nutrients in the anodic chamber, the voltage stabilizes and remains steady. The mean voltage measured for domestic wastewater was 473.06 mV and 505.95 mV for dairy wastewater in the absence of substrate. However, with the presence of substrate, the mean voltage increased to 496.13 mV for domestic wastewater and 523.57 mV for dairy wastewater. The electricity generated during the treatment of dairy effluent was higher in both phases of the trial run, indicating the successful decomposition of organic substances found in the dairy wastewater by the organism.

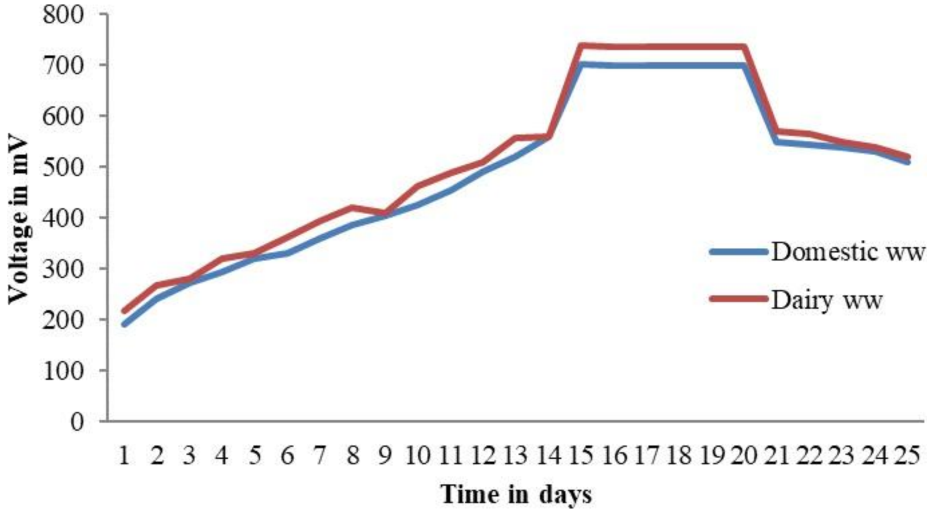

Fig. 3 Production of Voltage from sludge with respect to time

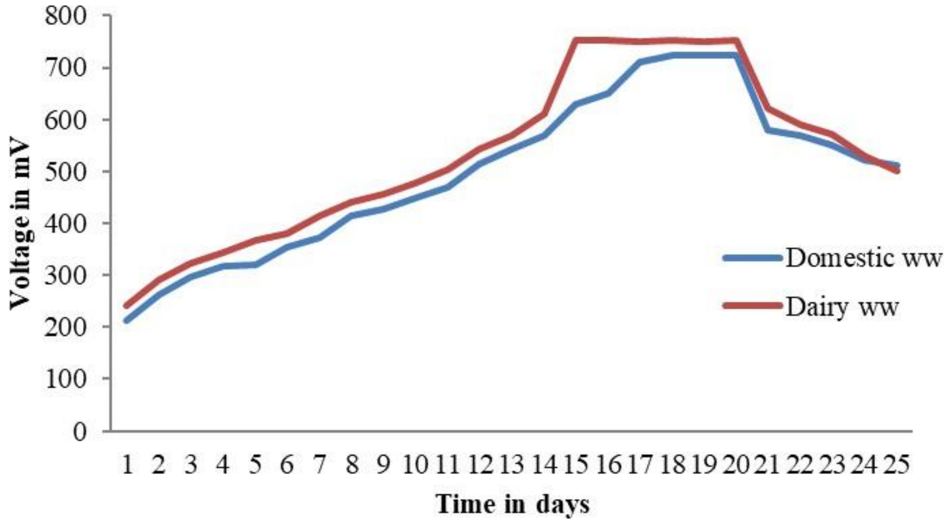

Fig. 4 Production of Current from sludge with respect to time

IV. CONCLUSION

Researchers around the world have been increasingly interested in using microbial fuel cells (MFCs) for energy generation. The results of the trial run in the microbial fuel cell (MFC) showed that the power output significantly increased in the second phase, attributed to the inclusion of a mediator. This mediator molecule facilitated the transport of electrons generated within the bacteria to the anode through a redox process, thus enhancing power generation. The treatment technique efficiently reduced the levels of COD, BOD, TDS, and TSS in both stages of the experimental runs, indicating effective treatment of dairy and household wastewater. The data indicates that the microorganism effectively breaks down organic compounds in dairy wastewater and produces a higher quantity of electrons compared to domestic wastewater.

The choice of microbe and electrode significantly impacts the cost and efficiency of microbial fuel cells (MFCs). Specific microorganisms and advanced electrode materials can greatly influence the overall cost-effectiveness of MFCs.

For example, optimizing microorganisms to enhance electron production and selecting electrodes that improve electron transfer can reduce material costs and increase energy yields. In this study, sensors used for monitoring cost around Rs. 3000, adding to the overall expense of the system. Therefore, thorough research on optimizing microorganisms and developing novel electrodes is crucial to minimize the complexity of rate-limiting processes, thus contributing to improved current performance. By optimizing microorganisms and creating unique electrodes, the commercial application of microbial fuel cells (MFCs) can be significantly enhanced, offering a potential option for generating cost-effective bioelectricity. Future studies should focus on detailed cost analysis and the economic impact of various microbial and electrode configurations to further justify the commercial viability of MFCs.

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DECLARATIONS

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2. The authors confirm that there are no conflicts of interest.

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