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SUSTAINABLE ELECTRICITY GENERATION FROM TANNERY WASTEWATER USING MICROBIAL FUEL CELLS

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ABSTRACT

Using tannery effluent as a starting point, this research explores the possibility of microbial fuel cells (MFCs) producing energy and treating wastewater. Physicochemical parameters including pH, COD, BOD, TSS, and TDS were measured in wastewater samples taken from an Indian tannery. As inoculum for MFCs, three bacterial strains—BS1, BS2, and BS3—that are resistant to tannery conditions were extracted from tannery waste soil. In contrast to monoculture isolates and activated sludge, MFCs inoculated with mixed microbial consortia generated a greater current of 10.38mA, according to the study's optimization of growth parameters for the isolated strains. Additionally, mixed consortia outperformed other configurations with a COD elimination efficiency of 94.3%. While mechanistic research could benefit from monocultures, large-scale applications might be better served by mixed microbial consortia.

Keywords: Electricity, Microbial fuel cells, Bacterial strains, Tannery wastewater

I. INTRODUCTION

The hunt for renewable energy sources is more important than ever before in light of the growing environmental consciousness and the accompanying increase in the world's energy consumption. The potential of microbial fuel cells (MFCs) to produce energy from organic waste materials has made them one of the most talked-about new technologies in recent years. The effluent from tanneries is rich in organic compounds and, if not handled correctly, may cause significant harm to the environment; nonetheless, it is also a potential feedstock for MFCs. Using tannery wastewater to generate power, MFCs solve waste management problems and contribute to clean energy generation, making them an important part of sustainable development as a whole. One of the most well-known causes of excessively contaminated wastewater is the leather tanning industry. Organic pollutants, heavy metals (such as chromium), and dangerous compounds are all part of tannery effluents, which, if discharged into the environment, may severely pollute soil and water supplies. Traditional treatment technologies also struggle with tannery effluent due to its high levels of biological oxygen demand (BOD) and chemical oxygen demand (COD). This is especially problematic in areas with a high concentration of tanneries since it endangers human and environmental health. In this case, microbial fuel cells have a lot of potential as an innovative approach to effectively deal with these wastewater issues.

Microorganisms play a key role in the operation of microbial fuel cells, which transform the chemical energy present in organic materials into electrical energy. Bacteria inside the fuel cell decompose organic substances in the wastewater, which in turn releases electrons that pass via an external circuit, producing energy. Merge fuel cells (MFCs) are attractive because they can treat wastewater and generate electricity at the same time, which makes them a more environmentally friendly option than traditional wastewater treatment systems. Bacteria aid in environmental cleanup by reducing levels of hazardous contaminants in wastewater and producing energy as they break down organic debris. Because of its high organic content, wastewater from tanning operations is an ideal candidate for use in microbial fuel cells. Bacteria in MFCs may generate energy from tannery effluents because of the abundance of organic molecules in these waste streams. Concurrently, MFCs lessen the wastewater's organic load, which in turn lowers the levels of chemical oxygen demand (COD) and biological oxygen demand (BOD). Industries that are both energy-intensive and subject to strict environmental emission regulations might benefit from this procedure as it helps clean the wastewater while also producing electricity. This eco-friendly method might be very helpful for tanning companies, which require a lot of energy, as it could turn their waste into electricity.

Nevertheless, in order for microbial fuel cells to be practical for widespread use, a number of obstacles must be overcome. A major obstacle is that tannery effluent contains harmful compounds including sulfides and chromium, which may inhibit microbial activity and lower the MFC's overall effectiveness. Problems with toxicity may reduce bacteria's efficiency in decomposing organic materials, which in turn affects power production. The electrode materials used in MFCs are expensive and not very long-lasting, which is another reason why they haven't caught on commercially yet. Improving performance and minimizing costs requires refining the materials and design of the MFC's electrodes, which are crucial components. Still, investigations into microbial fuel cell technology are continuing, and the results thus far are encouraging. More efficient and scalable MFC systems are on the horizon, thanks to efforts to make bacteria more resistant to harmful substances, produce cheaper electrode materials, and increase the efficiency of electron transmission. There is a problem and an opportunity for innovations in these areas to fully use MFCs in businesses like leather tanning, which generates significant quantities of wastewater. The use of microbial fuel cells to generate electricity from tannery wastewater has the potential to revolutionize waste management and make it an integral part of energy production, leading to more sustainable and efficient industrial operations.

II. REVIEW OF LITERATURE

Elabed, Alae et al., (2019) When compared to more traditional approaches, treating tannery effluent in bioelectrochemical systems (BESs) is seen as a viable, cost-effective, and environmentally friendly option. Two different tests were conducted under identical working circumstances (temperature 30 ± 0.1 °C, acidophilic microenvironment pH 4.5, constant voltage − 0.2 V/ECS) to clarify the divergence in producing an effective microbial anode from raw and processed tannery wastewater. The poisonous nature of the tannery effluent prevented the detection of any microbiological activity in the reactor that was run with raw tanneries. The reactor's capacity to generate bioelectricity on-site while simultaneously treating wastewater was proved by its use of tannery effluent that underwent electrochemical pretreatment. With the complete elimination of chromium and the removal of 90% of chemical oxygen demand, 84% of biological oxygen demand (BOD_5), and 96% of sulfate, a maximum current density of 11.2 A/m^2 was achieved. In order to treat tannery wastewater efficiently, this research demonstrates the use of electrochemical pretreatment in conjunction with BESs and high current recovery.

Bose, Debajyoti et al., (2018) The five main elements that determine the performance of microbial fuel cells are the following: pH, concentration, temperature, and the kind of electrodes used. By optimizing for these five factors, the current study explains how energy recovery from wastewater operations have become more efficient as a whole. The rate of substrate depletion and microbial growth are both based on monod kinetics, which is relevant to this optimization. Research using pure microbial cultures and experiments using undefined mixed microorganisms have shown different results when it comes to energy recovery from wastewater sources. As the cost of materials has decreased, the demand for electricity has increased globally, and the net CO_2 emissions from power plants has decreased, there has been a surge in research into the use of microbial reactors to harness energy. The article goes on to talk about the electrogenic reactor systems' future possibilities, including how they can work with anaerobic digesters and other wastewater treatment sources, and how they can improve energy security, which is related to economic stability. By effectively removing COD (Chemical Oxygen Demand), treating industrial and household wastewater with microbial reserves may greatly advance wastewater treatment infrastructure and produce a value-added product called bioelectricity. Copyright 2018 by the Society of Chemical Industry and John Wiley & Sons, Ltd.

Singh, Har et al., (2018). An innovative technology that tackles the threefold issues of pollution-generating, high-cost, and fossil fuel-based energy generation is a microbial fuel cell (MFC). An innovative approach to treating wastewater while also producing electricity is on the horizon. It may be able to produce bio-electricity by feeding microorganisms wastewater. Additionally, MFCs have potential uses in desalination, bio-hydrogen generation, biosensing, bioremediation, and carbon capture. The primary emphasis of this study is on MFC-integrated bio-electricity generation and wastewater treatment. Also covered are the several types of MFC designs, electrode materials, critical process parameters (such as pH and temperature), and the most up-to-date technology for integrating MFCs with natural bodies of water (hybrid MFCs). Engineers and scientists now have a fresh perspective thanks to this technology, which shows promise for a more environmentally friendly world.

Singh, Abhilasha. (2014) Regular biological treatment procedures have a hard time dealing with the toxic chemical composition of tannery effluent. The organic compounds in tannery effluent may be broken down by microbes that are already present in the wastewater if given the right circumstances. Here we report the isolation and characterization of three tannery-tolerant bacterial electrogenic strains (BS1, BS2, and BS3) from soil polluted with tannery waste. Various microbial fuel cells were used to clean wastewater from tanneries using either pure or mixed consortia of three bacterial strains. For the purpose of this comparative study, we treated the tannery effluent with an artificial microbial consortium (activated sludge inoculum) and compared it to untreated wastewater, which included solely bacteria found in the natural environment. For the best outcomes, use a mix of electrogenic strains in a consortium. In only 30 days of operation, we were able to achieve a current of up to 10.38mA and a reduction of 94.3 percent of Chemical Oxygen Demand (COD).

III. MATERIALS AND METHODS

Wastewater Sample

The waste water from an Indian tannery was collected. The tanning process was completed by taking spot samples, which were then kept at 4°C. Chemical and physical tests included color, COD, and BOD in addition to pH, TDS, and TSS. Microbial fuel cells (MFCs) employed plain tannery effluent as its inoculum, unless otherwise noted. At 30°C and pH 7.0, the experiments used diluted wastewater.

Bacterial Strains

The soil used for tannery waste disposal was cultured using an enrichment process in order to extract bacteria that are resistant to tannery conditions. Glucose and nutritional supplements were added to thioglycollate medium, which the bacteria were cultivated in. The morphology, Gram-staining, and biochemical tests were used to identify the strains, which were then called BS1, BS2, and BS3.

MFC Construction and Operation

The MFCs were constructed from 1000 ml of glass, with graphite serving as the cathode and ordinary carbon paper as the anode, with a proton exchange membrane between the two. The anode chamber was kept under anaerobic conditions, while the cathode chamber was filled with phosphate buffer at a pH of 7.0. After being infected with different combinations, MFCs were operated in fed-batch mode for 30 days per cycle. Power density, current, potential, and COD elimination efficiency were used to quantify performance.

Analytical Methods

Using a digital multimeter, we measured the current and potential, and then we estimated the power using the formula P=IV. Dichromate oxidation and manometric respirometry were used to assess COD and BOD5, respectively. Three MFCs were used to average the results.

IV. RESULTS AND DISCUSSION

Growth optimization of bacterial isolates

Isolated bacterial strains were subjected to optimization tests to identify growth factors and achieve a greater biomass production while being cultured on a shaker at 120 rpm. We chose three strains from the nine that were isolated based on how well they grew in the modified medium. The parameters that were optimized were inoculum concentration, temperature, pH, and agitation. The samples were taken at predetermined intervals, and the Spectrophotometer (Shimadzu Scientific Instruments) was used to record the absorbance at 600 nm in order to track the development of the biomass. A growth curve was generated by plotting the absorbance values against time (not shown). Table 1 displays the optimum growth conditions for a selection of bacterial strains.

Table 1: Optimization of Growth Conditions for Bacterial Isolates

Bacterial Strain	Inoculum conc. (v/v)	Temperature (oC)	pH	Agitation rate (rpm)
BS1	5%	34	8.2	150
BS2	8%	36	7.7	150

BS3	6%	37	7.4	120

Characterization of tannery wastewater

Table 2 displays the properties of the wastewaters. Due to the extraordinarily high concentration of hazardous materials in the wastewater, this research demonstrated that tannery process wastewater is one of the main sources of environmental contaminants. Many more studies have found the same thing.

Table 2: Analysis of Tannery Wastewater Composition

S. No.	Parameters	Units	Value
1	pH	-	7.9
2	COD	mg/L	2536
3	BOD	mg/L	1529
4	TSS	mg/L	3254.6
5	TDS	mg/L	16831.3
6	Odor	-	Foul
7	Color	-	Brownish

Electricity generation

Using tannery wastewater as anolyte in MFCs caused a lag phase followed by a slow increase in current. The presence of components that are readily degradable, which were consumed by microbes in the wastewater, is likely responsible for the initial rise in current. The current outputs started to drop as these biodegradable substrates were used up.

In the meanwhile, we saw decreased efficiency due to the ongoing deterioration of complicated components. A significant decrease in the current prompted the addition of fresh feed. Under anaerobic conditions, the inoculum was let one hour to settle before 300 mL of exhausted feed was replenished with new feed. After each feeding session, the anode chamber was sparged with oxygen-free N2 gas for four minutes to keep the microenvironment anaerobic. Adding more feed resulted in a constant rise in current generation.

Upon achieving a consistent voltage, current was detected in several resistors. Claiming normal fuel cell behavior, a declining current trend was found with a rise in resistance. There was a lower power density for higher resistance. Lower resistance was determined to have a faster rate of substrate oxidation by microorganisms compared to higher resistance. Fig. 1 shows that the plain wastewater sample had the worst current generation response. This sample had a longer lag period and reached 3.86 mA on the 5th day, but after many fluctuations, it reached a peak value of 8.54 mA on the 25th day, ruling it out as a viable option for electricity generation. Improved response, shorter lag time, and peak values of 9.35mA, 9.53mA, 9.11mA, and 9.49mA on the 26th, 25th, 20th, and 15th days of operation were seen in samples containing monotype isolates BS1, BS2, and BS3 and activated sludge inoculum, respectively.

Compared to MFCs operating with plain wastewater, MFCs inoculated with monotype isolates, and MFCs injected with activated sludge, mixed microbial flora MFCs shown a considerably better response to current generation. When compared to systems that operated on plain wastewater, BS1, BS2, BS3, and foreign inoculum, the average peak current produced by mixed microbial consortia was 10.38 mA on the 16th day, which was about 21.5, 10.0, 8.0, 12.0, and 10% greater. Mixed microbial consortia showed a much more current output than any monoculture, even though it required a long time to establish stable microbial consortia and provide a consistent current response (0.97mA for two days).

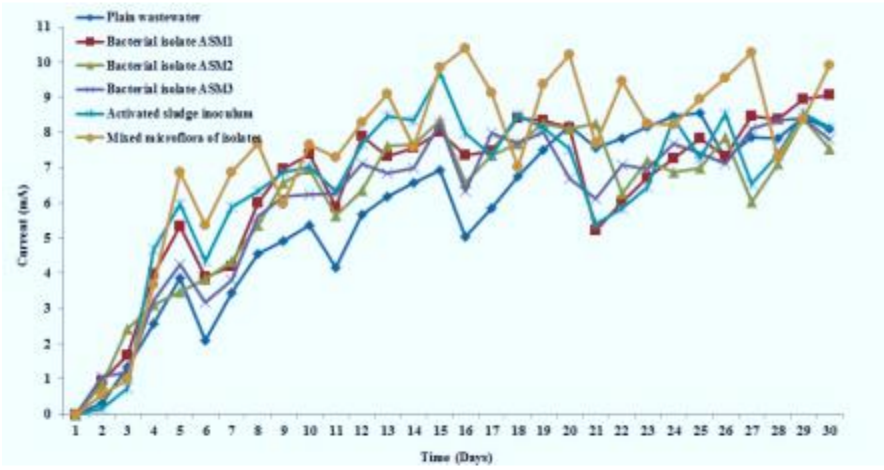

Figure 1: Current Generation in MFCs Using Various Inoculums and Wastewater

On top of that, even though the current response was reduced after adding newly supplied electron providers, mixed bacterial communities exhibited remarkable stability by swiftly re-establishing the earlier current (with significant drops on the 9th, 14th, 18th, 21st, and 28th days, with values of 5.96, 7.60,7.02,7.68, and 7.38mA, and subsequent regains on the 10th, 15th, 18th, 21st, and 29th days, with values of 7.66, 9.83, 9.36, 9.44, and 8.36mA, respectively). In contrast to mixed microflora, activated sludge inocula required a longer adaptation period (0.75mA in 2 days) and produced worse outcomes following feed replacement on every occasion. On the other hand, MFCs infected with monocultures (BS1, BS2, and BS3) produced currents of up to 0.94, 0.85, and 1.08 mA in 24 hours, respectively, and initially had a substantially greater response. Nevertheless, after replacing the wastewater in the overall operation, the current response was reduced to 9.35, 9.53, and 9.11mA.

These findings provided evidence that an established mixed culture could effectively cleanse tannery effluent and produce power. Consistent with previous research, these findings... Although mixed microbial consortia are often considered to have more potential for large-scale applications, monoculture may serve as an excellent model for mechanistic investigations.

Figure 2 shows the efficacy of COD removal for all samples. On the 30th day of operation, samples running on plain wastewater, BS1, BS2, BS3, activated sludge inocula, and mixed microflora showed COD removal efficiencies of 83.4 percent, 87.8 percent, 86.3 percent, and 94.3 percent, respectively. Based on these findings, it seems that the microbial fuel cell was the medium of choice for the electrochemically active bacteria's propagation, whereas the wastewater had a smaller proportion of these bacteria. Almost all organic pollutants in wastewater were eliminated by microbes grown for 30 days in a microbial fuel cell, which also generated power.

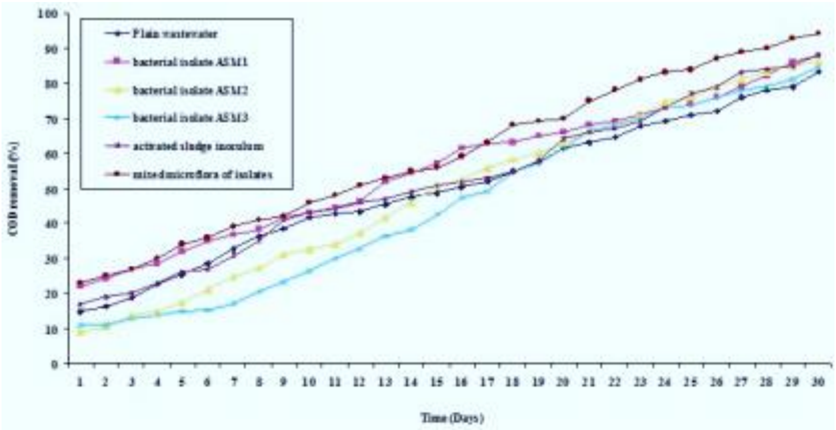

Figure 2: COD Removal Efficiency in MFCs Using Various Inoculums and Wastewater

V. CONCLUSION

The use of microbial fuel cells (MFCs) to cleanse wastewater and generate electricity is an attractive and long-term solution to two pressing problems. Using tannery effluent, which is abundant in organic compounds, MFCs may transform polluting pollutants into clean power. Not only does it lessen the negative effects of industrial waste on the environment, but it also offers an alternative energy source, which helps meet the increasing need for renewable electricity throughout the world. Utilizing MFC technology in the leather tanning sector has the potential to transform wastewater management, transforming a major source of pollution into a useful asset. Improving the technology's scalability and efficiency will need tackling obstacles such harmful compounds in tannery effluents and the requirement for cost-effective components in MFCs. The current limitations of MFCs in industrial applications are anticipated to be solved by ongoing research and technical developments. Microbial fuel cells, which may produce energy from tannery effluent, are an important step toward more sustainable manufacturing processes; doing so has financial and ecological advantages. More efficient waste management systems and greener energy generation might be possible in the future thanks to MFCs.

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