OPTIMIZATION OF COSMETIC INDUSTRIAL WASTEWATER TREATMENT AND POWER GENERATION USING HALOPHILIC MICROBIAL FUEL CELLS

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Abstract - This study aims to test microbial fuel cell (MFC) technology in treating cosmetic industrial wastewater, meanwhile generating electrical energy. The current study applied an Air cathode, (ACMFC) reactor fitted with platinum-coated carbon cloth and carbon fiber brush was used to study the effectiveness of cosmetic wastewater treatment and energy produced by halophilic bacteria. Cosmetic industrial wastewater was obtained from a cosmetic industry in Jeddah, Saudi Arabia, and halophilic bacteria from a desalination plant located in Jeddah, Saudi Arabia.

The analysis was conducted at various organic loads. (OL) 0.5, 1, 1.5, 2 and 2.5 g COD/L. Initial TCOD (Total Chemical Oxygen Demand) removal efficiency at 0.5 g COD/L was 85 % with 179 mW/m2 power density. Increment in OL to 1 and 1. 5 g COD/L recorded 89 % and 91 % TCOD removal with corresponding power densities of 256 and 310 mW/m2 in ACMFC operated. Further increase in the OL to 2.5 g COD/L revealed a decrease in the TCOD reduction and energy production. The maximum electricity of 910 mV with a power density of 425 mW/m2 at 2 g COD/L and 94% TCOD removal. Columbic efficiency was 55% at 0.5 g COD/L and declined to 18% at 2.5 g COD/L OL. A maximum TSS removal of 80 % was attained at 2 g COD/L OL in ACMFC. The study revealed 2 g COD/L as the optimized OL for the potential treatment of cosmetic industrial wastewater and energy production.

Analysis of the bacterial community performed with samples from the anode and sludge region revealed the presence of halophilic bacteria strains such as Thiobacillus, Acinetobacter, Geobacillus, Ochrobactrum, Stenotrophomonas, Comamonas, Sulfuricaulis, Pseudomonas, and Microbacterium. Consequently, the phylogenetic analysis of the anodic and sludge samples detailed the presence of halophilic bacterial strains.

Thus, the present study concludes the efficiency of ACMFC with halophilic strains to treat cosmetic wastewater and is recommended to be employed in the wastewater treatment of the cosmetic industry.

Keywords - MFC, ACMFC, Cosmetic Wastewater, COD Removal.

I. INTRODUCTION

The challenges that the world faces and caused by the human being irresponsible practices put us in front of environmental, economic, and social challenges that previous generations did not see, including the sharp increase in population, excessive consumption of natural resources, competition in the waste of water, and food, and the wealth of the earth, waste production, urban sprawl, deforestation, overfished, and transportation. Have been linked to environmental issues like air and water pollution increases, climate change, acid rain, ozone depletion, lowered biodiversity, melting of polar ice caps, and ocean acidification. This puts future generations in danger in that they may not guarantee decent levels of living if our lifestyle continues. Through our actions, we are destroying habitats and endangering the lives of future generations [1], [2].

On a Globally, sewage, agricultural, and industrial waste enter the world's water every day. It also disrupts the marine ecosystem. Regarding environmental pollution, the release of untreated effluent wastewater that is rich in organic compounds into water resources leads to marine water pollution. This can cause eutrophication and coastal pollution, the increased growth of plankton results in the depletion of oxygen in water sources, killing living organisms in the water and has a damaging effect on the surrounding agricultural land. Furthermore, as beaches and lakes become contaminated, they present risks to human health such as exposure to viruses from sewage or chemicals from industrial plants [2].

Globally, many countries have implemented legislation to ensure that wastewater meets certain standards which will eliminate any risk to the surrounding environment and its inhabitants. Wastewater is collected from several domestic and industrial sources, and it must be treated before it can be released safely into the environment without any detrimental effects to surrounding ecosystems [3]. However, inadequate management of treatment of the wastewater causes severe environmental harms to the air, water, and soil, for example, eutrophication, deficiency in the quality of water drinking, and unpleasant odors. Therefore, advanced treatment technologies that are efficient in the treatment of these effluents are essential to achieve the more stringent regulations concerning industrial wastewaters [4].

One of the major environmental and economic concerns is the cosmetic industry [5], as it generates a large amount of wastewater. This wastewater includes

high concentrations of organic matter, and a range of suspended solids, oils, metals, and detergents [5], it is also characterized by relatively high COD values [6]. The wastewaters produced by hair care products manufacturers usually exhibit high chemical oxygen demand (COD), because they contain compounds such as surfactants, dyes, natural oils, and fragrances, some of which are inadequately biodegradable and may be toxic, hence these wastewaters must be treated before discharged. Despite treatment wastewater, the remaining toxicity may negatively affect receiving water quality and may be harmful to aquatic life, therefore, wastewater treatment systems must be efficiently operated and optimized for the reduction or elimination of toxicity to satisfactory levels [2]. Therefore, establishing effective treatment of cosmetic industrial wastewater is a serious and crucial issue that must be addressed to sustain the industry.

It is common knowledge that the increase in energy demand throughout the world is because of global industrialization and economic growth, however, it cannot be indefinitely sustained by traditional fossil fuels as in past centuries. Bearing this in mind, other cleaner alternatives that are renewable such as wind power, and solar energy could be potential energy sources in the future [7]. According to reference [8], the world is striving for a sustainable source of energy as an alternative to fossil-fuels and nuclear technology.

Microbial fuel cells (MFCs) are an emerging technology, with the advantage of power generation, although the quantity of power is low. Nonetheless, in the case of industrial wastewater treatment, the vast capacity means that the resulting power potential will be high. Particularly for applications using high-concentration wastewater streams, such as industrial wastewater [4]. For instance, reference [9] in advocating the use of MFCs, states that the treatment of 1000 tons of wastewater, would result in releasing of approximately 1500 tons of greenhouse gases, using traditional technologies. He argues that alternative technologies such as MFCs will facilitate the reduction of the greenhouse effects significantly. Unlike traditional fossil fuels, the electricity produced using MFCs is clean, renewable and zero-polluting. On a large scale, the application of MFC technology removes concerns about greenhouse gas emissions.

This study was based on an evaluation of the probability of applying MFCs technology for the removal of residual organic pollutants present in cosmetic wastewater, and the removal of COD. It also explores the concept that MFCs are efficient as a means of both treating wastewater and generating electricity simultaneously in a sustainable manner [10]. Following on from the discussion above, the main objective of the present study is to treat the cosmetic industrial wastewater using microbial fuel cells (MFCs) with electricity generation. The sub-goals of the study are:

1) The enrichment of the bacterial consortium from brine water samples from the desalination plant (Saline Water Conversion Company), Jeddah, Saudi Arabia.
2) The acclimatization of air cathode MFC to treat the cosmetic industrial wastewater and produce electricity.
3) Operating the air cathode MFC at different organic loading and optimization of reactor conditions.
4) Determining the effects of salinity on treatment of cosmetic industrial wastewater under optimized condition Identifying the bacterial community in the electrode responsible for wastewater treatment and electricity production by molecular techniques.

Note: The brine water sample will be inoculated in mineral salt medium with 4% salinity for enrichment of halophilic consortium. This enriched consortium will be used in air cathode MFC to treat the cosmetic wastewater. The cosmetic wastewater will be collected from Al Mahajar industrial city.

II. MATERIALS AND METHODS

The sample was collected from the wastewater cosmetic industry, Jeddah, Saudi Arabia. The reactor was designed in the Center of Excellence in Environmental Studies (CEES), King Abdulaziz University (KAU), Jeddah, and fabricated locally. The configuration of the electrode in the reactor is detailed below as stated by reference [11].

MFC Reactor Design and Operation

The volume of the reactor is 260 mL, where the anode material was a carbon brush with twisted titanium wire steam (15 x 7 x 5 cm) and the cathode was a platinum catalyst coated on carbon cloth. The anode projected surface was 138 cm2 and the cathode was 15.9 cm2. Before starting the reactor, a leak test was performed using distilled water to seal the leakage in the reactor. After successful leak testing the connections were made based on the experimental set-up as detailed. The anode region of the reactor consisted of the carbon brush. The PTFE and Pt-coated carbon cloth was used as the cathode and connected to a multi-meter for measuring the power generation. The pH meter present inside the reactor was used to provide power generation details to evaluate the complete power density. Sludge samples collected from domestic/industrial effluent treatment plants were used in the reactor to a volume of 30- 40mLwas added before starting up the reaction to stop the methane formation because the methane gas would encumber the production of electricity [12]. Cosmetic

wastewater (200 - 220 mL) was loaded inside the reactor till the bottleneck and sealed airtight, with a cork which was then wrapped in parafilm tape to ensure complete air tightness.

The acclimatization phase is set up for 15 days. Normally, the inoculum takes 24–72 h to acclimatize so the microbials get acclimatized to the new environment and utilize substrate for the current generation. During the acclimatization phase, the substrate and the inoculum were introduced in the AC-MFC (Air Cathode Microbial Fuel Cells) without any external resistance (OCV). When an open circuit voltage of 180 mV was attained, then the reactor (Figure 1) was changed to the closed-circuit mode CCV (Close Circuit Volt). The operation of MFC was continued until the voltage and current density reached a stable condition. After the reactor has steady state, the assessment of biochemical and electrochemical parameters by varying the OLR periodically the samples were withdrawn from the reactor using a syringe.

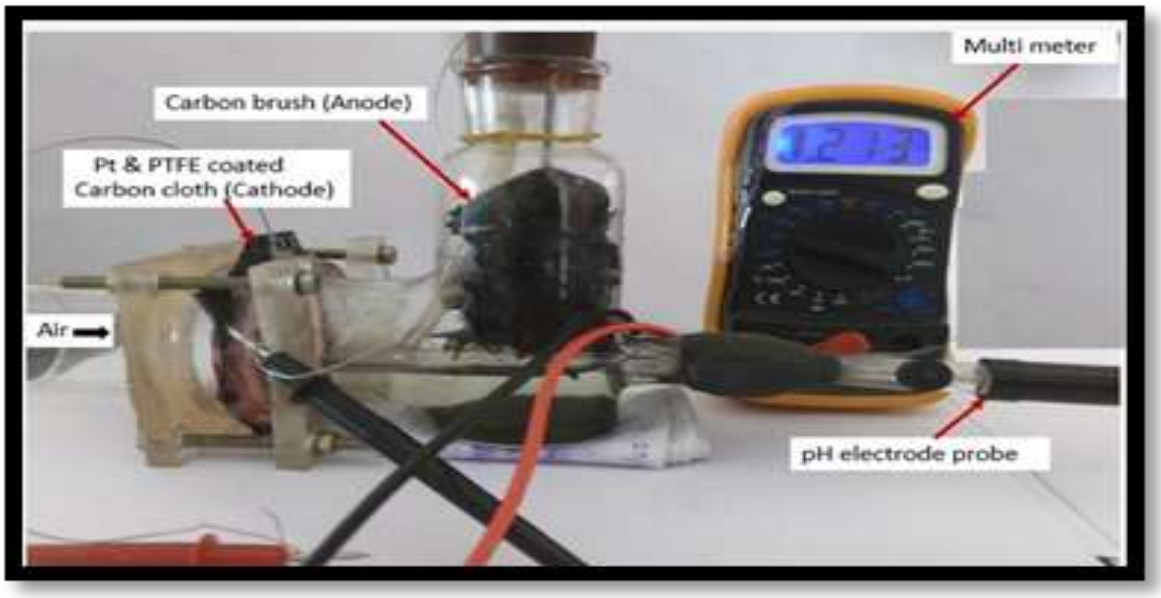


Figure (1). Schematic Representation of AC-MFC Design.

Analysis of Wastewater Parameters
1- COD (Chemical Oxygen Demand) Analysis
COD (mg/L) = (B - S) M x 8000 / V

Where,
B - Blank
S - Sample
M - Molarity of B and S
V – Sample Volume
(APHA, 2005).2- Total Suspended Solid (TSS) Analysis
TSS = (A-B) x 1000000 /V
Where,
A - Weight of filter paper + Sample after drying105oC
B - Initial weight of filter paper
V - Sample volume
Measurements and Calculations
A digital multimeter was used to measure current and power generation in a single chamber air cathode MFC for each organic load, and evaluated based on the following equations:

$$I = E / R \quad (1)$$
$$P = IxE \quad (2)$$

Where,
I = current (A),
E = voltage (V),
R = external resistance (Ω),
P = Power (W).
Reference [12].
Furthermore, power density and current density were analyzed based on the cathode projected surface area [13]. The external resistance ranging between 100 – 16000 Ω was used to plot the polarization curve. The ratio between coulombs recovered to total coulombs in the substrate is the Coulombic Efficiency (CE). The coulombic efficiency was calculated for fed-batch cycle based on the following equation as reference [12].

$$CE = 8I\ tb / F\ van\ \Delta COD \quad (3)$$

Where,
8 is a constant,
I = current (A),
tb = time period (s)
F = Faraday number (C/mol),
Van = volume of anode (L),
ΔCOD = COD removal (g / L).

When the MFC reached a steady state condition in each organic load, the polarization curve was plotted by changing various external resistances.

III. RESULRTS

Chemical and Electro Parameters

This study was conducted using single chamber air cathode MFC in the processing of cosmetic wastewater. The aim was to evaluate the performance of a device at several organic loads (OL) such as 0.5, 1.0, 1.5, 2, and 2.5 g COD/L. The COD and SCOD removal efficiency of the AC-MFC were evaluated in addition to assessing the level of power generation, coulombic efficiency, and total suspended solids. (Table.1) represents the results of varying OLR with Chemical and Electro Parameters.

Organic Load (gCOD/L)	TCOD removal efficiency (%)	SCOD removal efficiency (%)	Voltage (mV)	Power density (mW/m^2)	Coulombic efficiency (%)	TSS removal efficiency (%)
0.5	85	82	670	179	55	57
1	89	87	766	256	45	67
1.5	91	89	844	310	36	75
2	94	90	910	425	24	80
2.5	75	71	746	236	18	62

Table (1). The Relationship Between Chemical and Electro Parameters.

1- TCOD and SCOD Removal

The maximum TCOD removal efficiency of 94% was attained with an OL of 2g COD/L. Subsequently, upon increasing the OL to 2.5g COD/L the removal efficiency decreased to 75% (Figure 2).

The optimum TCOD and SCOD removal in the anode chamber was achieved with the use of electrogenic bacteria and non-electrogenic bacteria. Furthermore, the adsorption of organic matter and biofilm development on the surface of the anode electrode and the presence of the cathode electrode PTFE coated, possibly contributed significantly to the high level of COD removal.

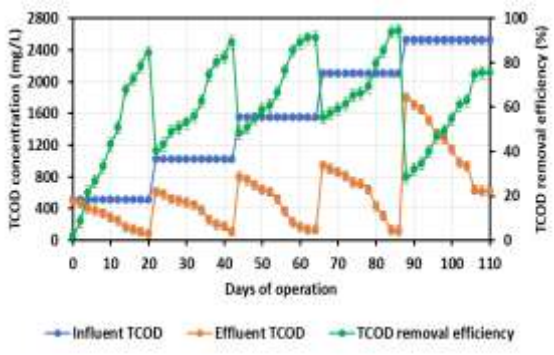


Figure (2). TCOD Removal in AC-MFC Operated With Cosmetic Industrial Wastewater.

Regarding the SCOD removal at varying OL, the trend observed was quite like that of the TCOD removal. The optimum SCOD removal efficiency of 90% was logged at the OL of 2g COD/L as illustrated in (Figure 3). However, the additional incremental increase in the OL level to 2.5g COD/L resulted in a decrease in the SCOD removal efficiency, to 71%. This decrease may have been due to the presence of methanogenic organisms.

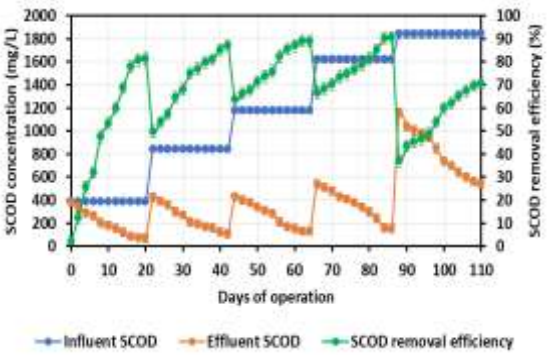


Figure (3). SCOD Removal in ACMFC Operated With Cosmetic Industrial Wastewater.

2- Power Generation

The power generated by the MFC is entirely dependent on the loading rate of the wastewater. During the treatment of the cosmetic wastewater

employing single chamber air cathode MFC, the polarization curves as shown in (Figure 4) and (Figure 5) were produced. External resistances within the range 100 Ω –16000Ω were used to create the polarization curves. At higher resistances, rapid stabilization was observed after removing the external load; however, at lower resistances stabilization was slow, replicating the characteristic behavior of a fuel cell.

In this study, a single chamber air cathode MFC reactor treating cosmetic wastewater when operated in open circuit mode for 15 days. A voltage (OCV) of 500 mV was logged at the end of open circuit mode.

It was essential to maintain the open circuit operation mode for 15 days to facilitate the stabilization of the microorganisms in the inoculums, as it takes time for the microbial to acclimatize to a new environment. Following the acclimatization phase, the circuit was closed, and the cosmetic wastewater was pumped to specify OL in the air cathode MFC.

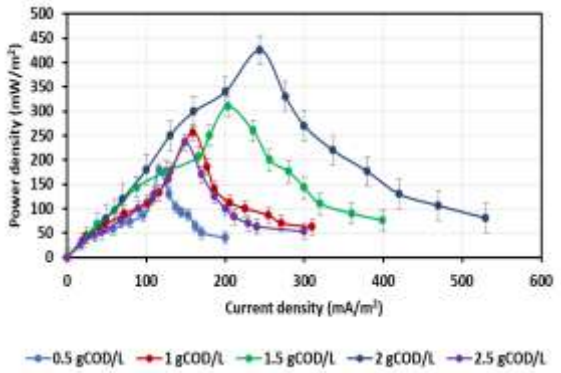


Figure (4). Polarizations of MFC Using Cosmetic Industrial Wastewater As Feedstock Power Density Vs Current Density.

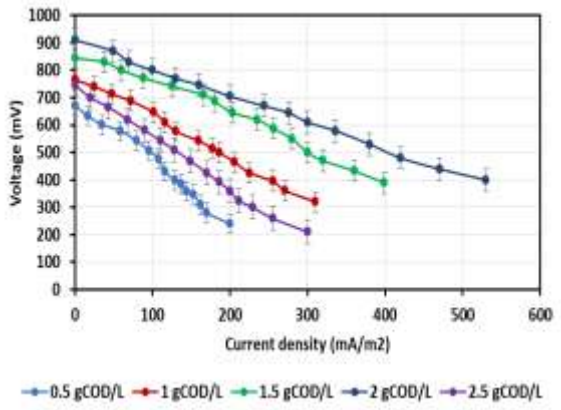


Figure (5). Polarizations of MFC Using Cosmetic Industrial Wastewater As Feedstock Voltage Vs Current Density.

3- Coulombic Efficiency

It was observed in (Figure 6) that the coulombic efficiency in the air cathode MFC decreased as the electrogenic bacteria and the bacteria-induced in the anode, saturating its surface competed. In other words, as the OL increased the coulombic efficiency decreased, therefore the coulombic efficiency was higher when the OL was low. A coulombic efficiency of 55% was the highest achieved while using the lowest OL of 0.5g COD/L. When the OL is low, methane production by utilizing the substrate is reduced, thus the coulombic efficiency increases.

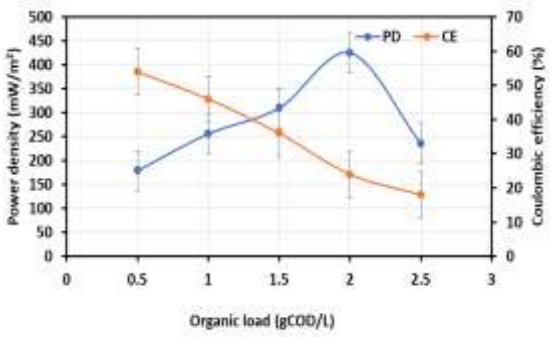


Figure (6). Coulombic Efficiency of The AC-MFC During The Treatment Of Cosmetic Industrial Wastewater.

4- Total Suspended Solids (TSS)

It was observed that the intermediate product produced from the fermentable organic matter present in the wastewater, accumulated at higher OL inducing a toxic effect on the microorganisms. Thus, the removal efficiency was adversely affected; it decreased, and the biomass was reduced, allowing the effluent TSS concentration to increase. The effluent TSS concentration was minimal, when the OL of 2g COD/L was used, achieving optimal removal efficiency, there was no loss of biomass (Figure 7).

5- Phylogenetic Analysis

The phylogenetic analysis was performed for samples pertained from the anode region and sludge region of the ACMFC. The bacterial strains present in the AC-MFC were identified using nucleotide sequences obtained from next-generation sequencing. The phylogenetic analysis recorded different types of bacterial strains with different percent occupancy in anode and sludge samples. As it shown in table (2 a,b)

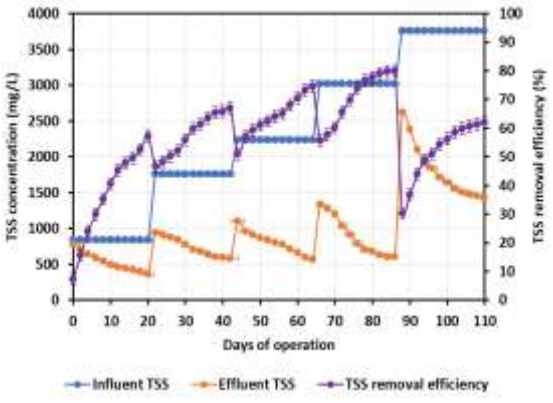


Figure (7). TSS Removal in AC-MFC Operated With Cosmetic Industrial Wastewater.

(a)

Organic Load (gCOD/L)	Sludge (%)				
Bacterial Strain	OL 0.5	OL 1	OL 1.5	OL 2	OL 2.5
Thiobacillus	20	18.6	16	13.5	15.9
Acinetobacter	10.2	11.4	12.7	13	11.8
Geobacillus	19.5	21	22.5	23.6	21.4
Ochrobactrum	19.8	20.5	21.2	26.1	23.1
Stenotrophomonas	14.9	16.6	17.3	18.5	16.8
Comamonas	2.5	1.8	1.5	1.1	2.5
Sulfuricaulis	3.6	3	2.8	2.2	3
Pseudomonas	6.5	6	5.5	2	5.5
Microbacterium	2	1.1	0.5	0	0

(b)

Organic Load (gCOD/L)	Anode (%)				
Bacterial Strain	OL 0.5	OL 1	OL 1.5	OL 2	OL 2.5
Thiobacillus	24.6	27	30.7	33	25.7
Acinetobacter	18.2	20.4	21	22.2	19.5
Geobacillus	15.2	16.1	18.1	19	14.8
Ochrobactrum	12.5	13	14.2	13.1	12.4
Stenotrophomonas	9.5	10	9.3	9	8.6
Comamonas	8.8	6	2.5	1.5	7.5
Sulfuricaulis	6.2	4.1	2.1	1.2	5.5
Pseudomonas	3.5	3	2	1	4
Microbacterium	1.5	0.4	0.1	0	0

Table (2a,b). Bacterial Community Analysis of Anodic Region and Sludge Samples At Different OL in ACMFC Operated.

IV. DISCUSSION

The current study aimed to investigate the suitable conditions for the treatment of cosmetic wastewater and to determine the energy generated in the process. A single air cathode MFC (ACMFC) was employed for the purpose and operated using organic loads ranging from 0.5 to 2.5g COD/L. The single-chamber MFC was selected rather than the dual-chambered MFCs for a multitude of reasons, namely the single chamber MFC is easier to scale up than the dual-chambere MFC, their designs are simpler and economically favorable. Generally, they are comprised of just an anode compartment and do not need aeration. The single-chamber MFC designed by reference [15] included a rectangular shape anode chamber and a cathode that was directly exposed to the air. The anode was constructed from a carbon brush without wet proofing whilst a PEM coupled with a carbon cloth electrode was used to construct the cathode [16]. Protons were transferred easily from the anolyte medium to the porous air-cathode surface [15]. As the cathode chamber was purged out, the catholyte is fed to the cathode, by squirting an electrolyte over the outer graphite sheet which prevents it from drying up. Reference [17] Created a single chamber MFC that incorporated both the anode and cathode in a single chamber. In this case, the anode was a cylindrical chamber constructed of Plexiglas with graphite rods in a circular arrangement surrounded by a cathode. The air-porous cathode consisted of a carbon/platinum catalyst/ PEM layer attached to a plastic support tube [15]. Reference [10] mentioned carbon brush produced more power than carbon paper as an electrode. Thus, in the present study, a single-chambered air cathode MFC was used with a carbon brush and carbon cloth.

1- TCOD and SCOD Removal

The AC-MFC was operated using a series of OL (Organic Loading) concentrations ranging from 0.5 to 2.5gCOD/L. The process of acclimatization has been maintained for 15 days. During this dense biomass was formed for high substrate utilization and subsequent power generation in the anode chamber [18]. During this phase, a constant low voltage was produced by the microorganisms inside the AC-MFC. Because of halted biomass on the surface of the anode electrode and the suspended microbes in the anodic chamber [18]. The microorganisms first acclimatize to the new environmental conditions, hence the initial low power production, thereafter they utilize the organic substrate, and power production increases [19].

Largely, this data indicates that both the OL and the minimum time available for the microorganisms to utilize the substrate are key factors in COD removal from cosmetic wastewater processing.

This study revealed potential COD reduction and energy production up to 2.0gCOD/L where a maximum TCOD removal of 94% was achieved. The decline in COD reduction with energy production was recorded on a further increase in organic load to 2.5gCOD/L. The high organic content in the wastewater is the probable cause of the decrease in the TCOD removal efficiency to 75% and the subsequent energy production. A high organic content could have inhibited the growth of the bacterial strains in the reactor. The decline in COD removal was because of:
i) At higher organic load (2.5gCOD/L) depletion of preservation due to mineralize the substrate by the anodic bacteria [20].
ii) With the abundance of the excess substrate, other organisms, such as methanogens, propagate rapidly and compete with electrogenic organisms in the anodic chamber, which contributes to a decrease in substrate use.

[15], [21]. Methanogens are microorganisms that turn organic matter into methane and compete for organic matter in wastewater with electrochemically active microorganisms. Consequently, the methane produced needs to be oxidized and recycled for current production, which would prevent a decrease in electron recovery [9]. Furthermore, reference [9] recorded that Methanogens can colonize biofilms, and also they have an advantage they can colonize deeper into the biofilm.

Notably, the SCOD removal efficiency followed the same pattern as the TCOD removal efficiency where 94% COD removal was recorded at 2.0gCOD/L. An additional increase in OL to 2.5 gCOD/L resulted in a decline in the treatment efficiency. In the present study, the recorded COD removal efficiencies may be due to several reasons, including:

(i)The presence of electrogenic and non-electrogenic bacteria in the anodic chamber could have contributed to maximizing TCOD and SCOD removal [12].
(ii) The existence a close association between the development of biofilms and the removal of COD as previously stated by reference [22]. In this sample (cosmetic wastewater), the forming of a thick biofilm around the anode electrode made from carbon fiber brush was observed.

2- Power Generation

MFCs generally exhibit high stability at the highest resistance, through the removal of the external load, while the stability decreases at lower resistance [23]. In the present study, the maximum power density of 425mW/m2 was recorded at the organic load of 2.0gCOD/L while linked with an external resistance of 600 Ω under closed circuit mode. On further increase in organic load to 2.5gCOD/L a decrease in the power density to 236 mW/m2 was recorded and can be explained by considering the following contributory factors:

(i) When the supply of nutrients is greater than the consumption, an imbalanced nutritional consumption rate arises and can cause substrate inhibition leading to a reduction in the rate of electron transfer, resulting in the gradual decrease in power density at high organic loading concentrations [24].
(ii) The distance between the electrodes, the substrate concentration, and the wire contacts makes MFCs susceptible to ohmic losses [25].
(iii) When the contact time to degrade the organic compounds in the wastewater is insufficient, the power production is reduced due to the high organic load. It may also be because the microorganisms readily reach the decline phase [15].

Concerning power production in MFCs, reference [20] highlighted the significant role of the substrate loading rate (wastewater) in the production. Thus, in the present study it was identified that from amongst the range of organic loading concentrations employed, 2.0gCOD/L is the optimal organic loading for probable power generation under saline conditions.

3- Coulombic Efficiency

The conversion efficiency of organic substrates into electricity facilitated by the use of bacteria through MFC operation is referred to as coulombic efficiency [26]. It is particularly significant as it is a measure of the number of coulombs recovered as electrical current and indicates the microbial fuel cell efficiency. According to reference[22] the nature of the microorganism carrying out the electrochemical reaction and the substrate used by the bacteria to generate current are the two main factors that affect the coulombic efficiency.

In the present study, the Columbic Efficiency (CE) during the initial OL of 0.5gCOD/L was 55% , thereafter the CE decreased to 45% at 1.0 gCOD/L, to 36% at 1.5 gCOD/L, to 24% at 2.0 gCOD/L and 18% at 2.5 gCOD/L under saline conditions. Although the observed decline in CE may be attributed to the adverse conditions in the anode surface, the high OL competition between the exoelectrogenic microorganisms active and other bacterial [27], other possible factors include: i) the mineralization of substrate by microorganisms by oxidation whereby Oxygen acts as an electron acceptor [24], ii) the occurrence of fermentation reactions or methanogenesis during loading of real wastewater [15], iii) The loss of electrons during substrate utilization in reactions that do not generate electricity during the application of higher external resistance [4]. Though, the low coulombic efficacy achieved during the research suggests the likelihood of the existence of methanogens [19], and diffusion of

oxygen inside an anodic chamber [13], or as suggested by reference [14] that the MFC may have attained its maximum capacity as an electricity generation device.

4- Total Suspended Solids (TSS) Removal Efficiency

The SS removal efficiency in the present study was 57% at 0.5gCOD/L, 67% at 1.0gCOD/L, 75 % at 1.5gCOD/L and 80% at 2.0gCOD/L. The SS removal efficiency increased with increasing OL, however, at the high OL of 2.5gCOD/L the SS removal efficiency decreased to 62%. The deposition of fermentative products occurs at higher OLs, thus, adversely affecting the removal of TSS, it suppresses the activity of anodophile bacteria and also reduces the pH [7]. This led to a decrease in biomass which led to a higher concentration of suspended solids in the effluent. The analysis concluded that a substantial decrease of the Suspended solids in the effluent was achieved at an optimum organic load of 2.0gCOD / L.

5- Phylogenetic Analysis

The wastewater produced in many industries is saline, like the mining and mineral industries, oil, and gas production [14], the production of dyestuffs, herbicides, fertilizers, chemicals, pesticides, the meat packing industry and some food products. The degradation of such diverse organic pollutants from industrial saline water can be achieved using halophilic microorganisms. Halophiles have good metabolic diversity including aerobic heterotrophs, denitrifiers, fermenters, oxygenic and anoxygenic phototrophs, sulfate reducers, and methanogens [21]. Since halophilic microorganisms can withstand high concentrations of salt, they have great potential to play a strategic role in environmental biotechnology in the degradation and elimination of organic pollutants from saline wastewater [3]. Although their main function was to degrade the organic matter, which provided appropriate substrates for the exoelectrogenic microorganism, subsequently the electrochemical activity increased [18]. According to reference [14] inoculation of the anode with a rich source of bacteria for example sludge or wastewater tends to generate high power densities in MFCs. Notably, to understand the electrochemical performance of specific organisms, pure cultures are more suitable, while for applications such as wastewater, mixed cultures are more suitable [20].

In the current study the diverse bacterial community was enriched, microscopic observations showed microbial population, and the microbial biofilm attached to the electrode surface has increased. The bacterial population study findings from the anode area and the sludge area are discussed below.

Bacterial Community Analysis for Anode Region Samples:

The results of the study of bacterial population samples from the anode area of the ACMFC reactor showed the existence of three strains of bacteria: Thiobacillus, Acinetobacter, and Geobacillus. At each OL the high dominance of Thiobacillus, compared to the other two bacterial strains was apparent with the maximum being at OL 2gCOD/L: Thiobacillus (33%), Acinetobacter (22.2%), and Geobacillus (19%). In each case, the dominance of each bacterial strain increased with increasing OL.

The second most dominant bacterial strain identified was Acinetobacter. Then Geobacillus is the current third dominant bacterial strain.

Interestingly in the present study the highest power production (910 mV) and presence of the bacterial strains were optimum at 2 gCOD/L OL. The Phylogenetic analysis demonstrated the existence of bacteria strains in the anode region as Thiobacillus (33%), Acinetobacter (22.2%), Geobacillus (19%) and Ochrobactrum (13.1%). There was also evidence of a meager occupancy by several other exoelectrogens which were identified, as Stenotrophomonas (10%), Comamonas (8.8%), Sulfuricaulis (6.2%), Pseudomonas (4%), and Microbacterium (1.5%).

Bacterial Community Analysis for Sludge Samples:

Phylogenetic analysis was conducted on the sludge samples, investigating the supremacy of bacterial strains. The dominant bacterial strains identified differed from the anodic sample; the most dominant was Ochrobactrum OL 2 gCOD/L (26.1%), then Geobacillus OL 2 gCOD/L (23.6%), and the third most dominant was Stenotrophomonas OL 2 gCOD/L (18.5%).

As recorded by reference [28] previously indicated that Stenotrophomonas during the treatment process, it is possible to remove due to the halophilic conditions, although this was not evident in the present study. However, the variation in the presence of the bacterial strain Thiobacillus in the sludge revealed that it decreased with increasing OL, with the minimum being at OL 2 gCOD/L (13.5%), and the maximum being at OL 0.5 gCOD/L (20%). Further, at OL 2.5 gCOD/L(15.9%) its presence again increased. A similar pattern was observed with Acinetobacter, Comamonas, Sulfuricaulis, Pseudomonas, and Microbacterium although their presence was meager.

In the consortium, the bacterial strains were identified as, Ochrobactrum and Stenotrophomonas. Previous research studies showed that Ochrobactrum species can produce electricity [16], and under saline conditions produce biosurfactants that improve bioavailability [28]. It is also possible to confirm the versatile approach of using extremophiles for the biological treatment of industrial wastewater in severe conditions. [28]

This study showed that activated sludge-inoculated ACMFC could effectively remove organic compounds

from artificial wastewater and with concomitant electricity generation. While the phylogenetic analysis of the samples from anodic and sludge regions illustrated the existence of halophilic bacteria with an extreme capacity for treating cosmetic wastewater industrial. Furthermore, exoelectrogenic activity has been shown under the saline condition for maximum production power in ACMFC.

Thus, halophilic organisms have promising potential for use in the biological and environmentally friendly, treatment of polluted wastewater.

Scalability and Practical Implications

While the results of this study demonstrate the efficacy of halophilic microbial fuel cells (MFCs) in treating cosmetic industrial wastewater under optimized laboratory conditions, the findings are primarily foundational. The small-scale reactor volume (260 mL) and the controlled experimental settings limit direct applicability to industrial operations. Scaling this system would require addressing key challenges such as material costs (e.g., platinum-coated cathodes), variability in wastewater composition, and ensuring consistent power output. Furthermore, the observed power density (425 mW/m²) indicates proof-of-concept efficiency rather than a viable energy generation solution for industrial systems. Future research should focus on larger-scale pilot studies and cost-effective reactor designs to evaluate the feasibility of implementing this technology in real-world settings. Nonetheless, this study provides a significant step toward integrating wastewater treatment and renewable energy production using extremophilic bacteria.

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