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Impact of Salt on Bioelectricity Generation in a Dual-Chambered Microbial Fuel Cell Using Sago-Processing Wastewater

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Abstract: Effect of NaCl on electricity generation, COD removal, reduction in carbohydrate and starch content in dual chambered, salt bridge Microbial Fuel Cells (MFCs) employing raw sago-processing wastewater with an organic load of 14,400 mg COD/l as substrate was evaluated. Four dual chambered MFCs were constructed and the study aimed to find out the impact of addition of NaCl which is carried out for effective MFC performance. Isolation and identification of microbes from initial influent and final effluent was performed using serial dilution, spread plate and selective agar techniques. Interestingly, it was found that the MFC in which NaCl was added to its cathode chamber was best in performance compared to other three MFCs, with a maximum voltage of 603mV and current of 6.03mA. It also documented that the maximum COD removal efficiency of 83% with a total reduction of carbohydrate and starch content from the wastewater was obtained. Utilizing sago wastewater for the production of bioelectricity from MFC technique is considered as a feasible and sustainable process.

Key words: Sago wastewater · NaCl · Conductivity · Power density · Internal resistance · COD removal

INTRODUCTION

Increasing global energy demands and over-consumption of non-renewable sources of energy have led to search and use of renewable and cost-effective sources of energy. At present, global energy requirements are mostly dependent on fossil fuels. Combustion of fossil fuels also has serious negative effects on environment due to CO_2 emission like global climate change, environmental degradation and health problems. This has intensified the search for alternatives to replace fossil fuels [1, 2]. Many researchers predict that bioelectricity could play an important role as fuel in near future. In this perspective, wastewater which contains high levels of biodegradable material has gained importance as a source of electricity generation using a Microbial Fuel Cell (MFC) [3-5]. MFC technique offers the possibility of harvesting electricity from organic waste and renewable biomass. It has been developed as a novel technique to gain energy with simultaneous wastewater treatment.

Tapioca (*Manihot esculenta*) is a crop of great economic importance, both as human food, animal feed as well as raw material for industrial products. In India, tapioca is grown over an area of about 300,000 hectares, with a production of 5,800,000 to 6,800,000 tonnes of tubers [6]. There are about 1,000 sago and starch processing factories in Salem and Namakkal districts of the Tamil Nadu state in India and it ranks second in terms of cultivation and production of tapioca and first in processing of it into sago and starch, meeting about 80% of country's demand. The amount of water used for starch processing varies, depending on the processing scale and the level of technology sophistication. Processing of one tonne of sago releases 40,000 to 50,000 litres of wastewater and it takes about 10 days for the wastewater to be treated and discharged out of the factory [7]. The release of high content of organic load along with the wastewater when stored, results in obnoxious odour, irritating colour, low pH and high BOD and COD [8]. If the wastewater is released into the environment without

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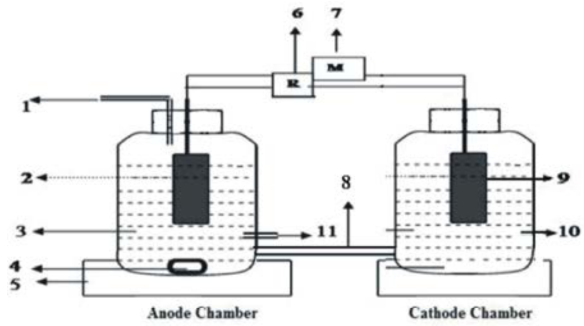
proper treatment, it alters the characters of ecosystem. Farmers using this raw wastewater for irrigation found that the growth yield and soil fertilities were reduced. Therefore it has become necessary for these units to treat the wastewater for safe discharge. Hence there is ample scope for an efficient and complete treatment system, which will ensure a safe effluent standard limit and potential energy recovery process. Most of the low cost and some conventional methods for sago processing wastewater treatment have low treatment efficiency due to high concentration of suspended solids, unextracted starch, cellulose, carbohydrates, nitrogenous compounds, cyanoglucosides and insoluble fibres present in the effluent. Conventional treatment plants are rarely operated in starch factories, probably because of requiring a high energy input. Physical treatment methods are associated with long hydraulic retention time, environmental stresses and clogging problems, wereas chemical treatment methods use expensive chemicals and the chemical sludge produced is harmful to the environment [6]. So, anaerobic technology for the treatment of wastes and wastewater is being experienced in developing countries from the beginning of this century [7]. Anaerobic treatability of sago wastewater was investigated in a laboratory using anaerobic tapered fluidized bed reactor (ATFBR) [9], hybrid reactor [10], inverse fluidized bed bioreactor [11]. Bio management methods like using a mixed inoculum of fungi (*G. putredinis, Trichoderma harzainum*), activated sludge and cow dung slurry [6], using an exotic earthworm, *Eudrilus eugeniae* [12] were also adopted for sago wastewater treatment.

Literature indicates that sago-processing wastewater has not been previously examined as a substrate for power generation in a dual-chambered MFC, though it contains a relatively high percentage of carbohydrates, cellulose, protein and nutrients, representing an important energy-rich source and is suitable for electricity generation due to the food-derived nature of organic contents in the effluent. This study is an attempt where the effect of NaCl addition has been studied in dual-chambered salt bridge MFCs and their performance has been evaluated in terms of power production, COD removal, carbohydrate and starch reduction.

MATERIALS AND METHODS

Sample Collection and Storage: Sago wastewater was collected from SPAC Tapioca Products (India) Ltd, Erode, Tamil Nadu, India. Sample collection was performed according to the standard methods [13]. The samples were stored at 4°C in the refrigerator for further analysis.



1. Inlet port
2. Anode
3. Anolyte
4. Magnetic stirrer
5. Base
6. Resistance
7. Multimeter
8. Salt Bridge
9. Cathode
10. Catholyte
11. Outlet port

Fig. 1: Schematic representation of a dual chambered, salt bridge microbial fuel cell

Microbial Fuel Cell (MFC) Configuration: Four dual chambered MFCs were designed according to the methods already proposed by Sangeetha and Muthukumar [14, 15]. Eight hard PVC bottles of equal volume (1.8 L) and with leak proof sealing were used for MFC construction. Both the cathode and the anode chambers were provided with sample inlet and outlet ports. A plastic tube (length-10 cm; dia- 2 cm) was sealed between the chambers for salt bridge construction. A salt bridge was constructed using KCl and agar. Uncoated graphite sheets with a surface area of 0.027 m^2 were used as electrodes in both the chambers of all the four MFCs and were positioned at a distance of 10cm from each other. Prior to use, the electrodes were soaked in deionised water for 24 hrs. Copper wires were used to connect the electrodes and the contact area was sealed with epoxy resin material. A digital multimeter (ORPAT ODM 100, Ajanta Limited, Morbi, Gujarat, India) was connected to the circuit to measure the potential difference between the electrodes and the current produced in the circuit. A detailed schematic representation of the experimental setup is shown in Fig. 1.

Inoculation: Anaerobic sludge that was let out from the anaerobic digesters in the effluent treatment plant (ETP) of SPAC Tapioca Products (India) Ltd was collected. The raw wastewater was inoculated with that anaerobic sludge and was used as anolyte in the anode chambers of all the MFCs. As the anaerobic sludge contains highly various bacterial consortia that consist of electrochemically active strains of bacteria [16], hence it was used for inoculation.

Table 1: Methodology adopted for the experiment

Fuel cells	MFC-1		MFC-2		MFC-3		MFC-4	
Chambers	Anode	Cathode	Anode	Cathode	Anode	Cathode	Anode	Cathode
Contents	Wastewater	Phosphate buffer solution (PBS)	Wastewater + 50mM NaCl	PBS + 50mM NaCl	Wastewater + 50mM NaCl	PBS	Wastewater	PBS + 50mM NaCl
Initial pH	5.1	7.0	5.3	5.2	5.3	5.5	5.4	5.3
Initial Conductivity (mS/cm)	3.18	4.0	13.7	17.8	13.7	4.0	3.18	17.8

Table 2: Initial Physico-chemical parameters of the anolyte used for MFC operation

Parameters	Values
pH	5.0
Temperature	30 °C
Conductivity (mS/cm)	5.7
Total Suspended Solids (mg/L)	1464
Total Dissolved Solids (mg/L)	3272
Total Solids(mg/L)	4736
Chemical Oxygen Demand (mg/L)	14,400
Biological Oxygen Demand (mg/L)	8620
Starch (mg/L)	1.53
Carbohydrates (mg/L)	40
Sulphate (mg/L)	180

MFC Operation: Table 1 illustrates the experimental arrangements followed in this study. Air was purged into the cathode compartment with aquarium aerator (Shengze Electronic Co., Ltd, Shenzhen, China) in order to supply the oxygen required for the electrochemical reaction, at a rate of one liter per min, controlled with an air flow meter (Mahavir, SN 31, Coimbatore, India). Anode chamber was covered with aluminium foil and was placed in an anodic chamber to avoid air and light intrusion into the cell. The anolyte was continuously stirred with a magnetic stirrer (Superfit Equipments, Mumbai, India) to ensure uniform suspension of organic constituents. The performance of the fuel cell was evaluated under constant substrate loading of 14,400 mg/l and operated in batch mode at an initial pH of 5.5 up to a period of 34 days. Electricity generation, COD removal rate, reduction in carbohydrates and starch were monitored during the operation.

Electrical Parameters and Power Measurements: The voltage generated in the MFCs was measured after 3 hours incubation as lag phase, using a digital multimeter connected in parallel to an external resistance of 100 Ω in the external circuit. The readings were recorded after obtaining at stabilized voltage for at least 3 minutes and the average was calculated. Current (I) and Power (W) were calculated according to Patil *et al*. [17] and Behera *et al*. [18]. Power density (mW/m^2), current density (mA/ m^2), volumetric power density (mW/m^3) and volumetric current density (mA/ m^3) were all calculated based on the procedures outlined by Venkatamohan *et al*. [19].

Quality Parameters Analyzed: The initial physico-chemical parameters for the sago wastewater were analyzed according to the standard methods [13] and are tabulated (Table 2). Starch and Carbohydrates were analysed according to Sadasivam and Manickam [20]. pH values were determined by (Susima pH Meter, India) and conductivity was measured by (ELICO-180 conductivity bridge, India). Performance of the fuel cells was evaluated by estimating the substrate (COD) removal efficiency once in three days and carbohydrates and starch removal efficiency once in five days during the experimental period.

Isolation and Identification of Bacteria: Isolation and identification of the bacteria present in the sample was carried out as per APHA [13]. Morphologically different bacterial colonies were isolated by spread plate technique and identified by biochemical methods and selective agar techniques. Selective media such as Eosin methylene blue (EMB) agar, Mannitol salt agar (MSA), *Salmonella Shigella* Agar, RS medium (Romler–Shotts Medium Base), KF– *Streptococcus* agar, MacConkey's agar were used. All media and agar used for microbiological estimations were purchased from Hi Media chemicals, Mumbai, India.

RESULTS AND DISCUSSION

Effect of NaCl on Electricity Generation: Electricity generation in MFCs is a function of various physico-chemical as well as biological parameters [21]. NaCl is generally used as the electrolyte to improve the mass transfer of charged particles and to increase the solution conductivity [22]. Electricity generation was estimated in all the four MFCs and the effect of NaCl addition was studied. The performance of the MFCs was monitored up to 34 days. The open and closed circuit voltage values generated in all the MFCs was measured and are

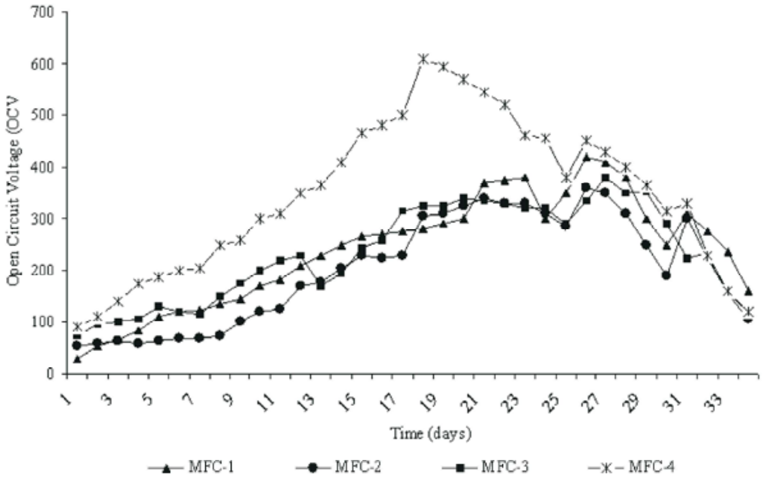


Fig. 2: Open circuit voltage generation in all the MFCs

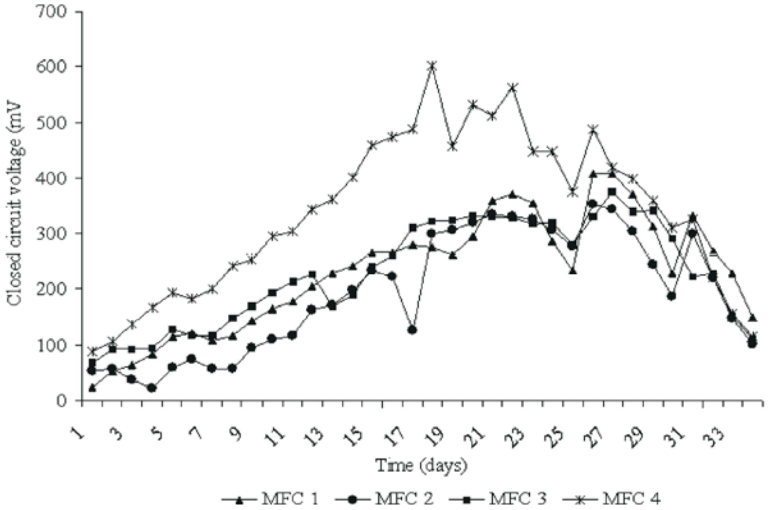


Fig. 3: Closed circuit voltage generation during the operation of fuel cells

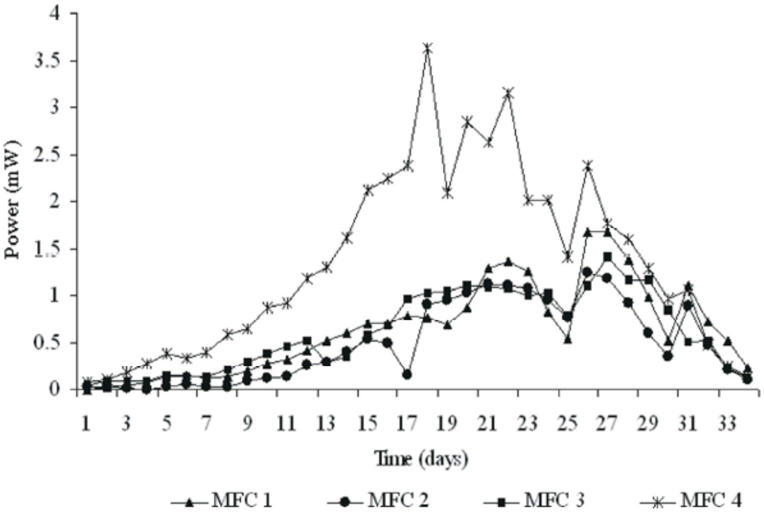
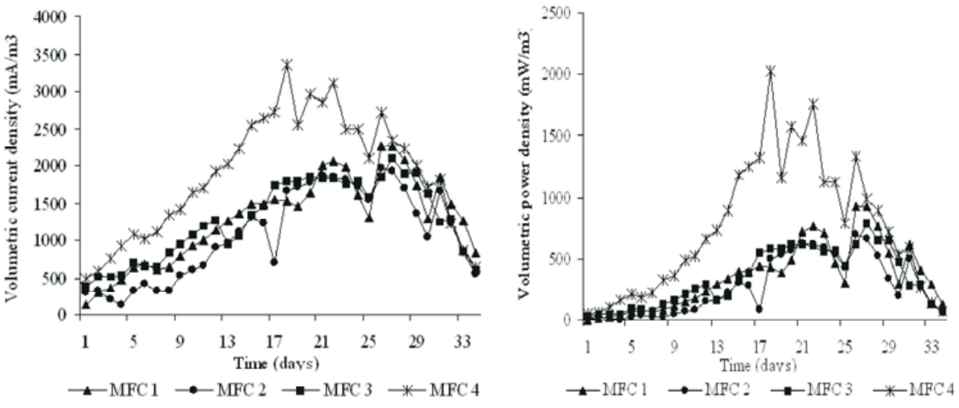


Fig. 4: Power generation during the operation of fuel cells with the function of time



(a) (b)

Fig. 5: Power details of the fuel cells (a) Volumetric current density (b) Volumetric power density

illustrated (Figs. 2 and 3). MFC- 4 documented the maximum open and closed circuit voltages of 610 mV and 603 mV on the 18th day of the experimental period. The details of power (mW) produced in the fourth MFCs are depicted (Fig. 4). Consistent increase in voltage and current output was observed in the fuel cells with exhaustion of time, accounting for a maximum power production of 3.63 mW in MFC- 4 after 17 days of start up. Power output of 1.67 mW was observed in MFC- 1 on 26th and 27th day, whereas MFC- 2 and MFC- 3 produced 1.25 mW on 26th day and 1.4 mW on 27th day, respectively. The experimental data revealed that the fuel cell with NaCl addition in its cathode chamber showed better power production than the other MFCs.

The experimental data documented the details of power generation with respect to volumetric current density (a) and volumetric power density (b) (Fig. 5). MFC-1 produced a current density of 151.4 mA/ m^2 on 26th and 27th day of experimental period where as MFC- 2 and MFC- 3 produced a current density of 130.7 and 139.2 mA/ m^2 on 26th and 27th day, respectively. In the case of MFC-4, maximum current density of 223.3 mA/ m^2 and a corresponding maximum power density of 134.6 mW/m^2 were detected on 18th day of fuel cell operation. A power density of 61.9 mW/m^2 was observed in MFC- 1 on 26th and 27th day of the experimental period, whereas MFC- 2 and MFC- 3 produced a power density of 46.1 and 52.3 mW/m^2 on 26th and 27th day, respectively. MFC-1, MFC-2 and MFC-3 generated volumetric current densities of 2272.2, 1961 and 2088.9 mA/m^3, respectively with MFC-4 documenting a maximum of 3350.0 mA/m^3. A maximum volumetric power density of 2020 mW/m^3 was noticed in MFC- 4, whereas MFC- 1, MFC- 2 and MFC- 3 produced volumetric power densities of 929.4, 692.3 and 785.4 mW/m^3, respectively. Power generation was higher in MFC- 4 compared to the other three MFCs.

The reason for increased power production in MFC- 4 may be due to the increased ionic strength of electrolyte by the addition of NaCl in cathodic chamber. Power generation was higher in MFC- 4 compared to the other three MFCs and that may be due to the increased ionic strength of electrolyte by the addition of NaCl which increases the cathodic proton transfer rate in cathodic chamber. NaCl dissociates into cations (Na^+) and anions (Cl^-) in a solution, thus increasing the number of anions and cations. This will increase the conductivity of the solution which is nothing but the ability of the ions (anions and cations) to conduct electrons (e^-) and protons (H^+). Na^+ will conduct e^-, as sodium ion is a known electron acceptor and Cl^- will conduct H^+ to the cathode electrode thus making protons and electrons available for oxygen reduction. Thus increased proton availability results in an increase in the rate of oxygen reduction, which indirectly increases the microbial and anodic activity. Similar results were reported by Gil *et al*. [22], where the cathode chamber was operated with various electrolytes like distilled water, phosphate buffer, NaCl solution and phosphate buffer. Maximum current was produced by the MFC which used phosphate buffer with NaCl solution as the catholyte. The reason is because of the combined effect of buffer and NaCl in increasing the electrical conductivity of the solution. Jang *et al*. [23] has reported that NaCl was generally used as an electrolyte to improve the mass transfer of charged particles. They observed an increase in current production from 3.5 to 4.7 mA when NaCl was added to the cathode and a maximum current of 7.7 mA was generated with continuous salt feeding.

Huang *et al*. [24] also documented a rapid increase in power density from 3.6 mW/m^2 to 9.6 mW/m^2, when the ionic strength of the catholyte was increased from 291 to 1,146 mM. The use of NaCl in the cathode might have enhanced the cathode reaction by increasing its conductivity and proton availability, thereby resulted in high power output.

Addition of NaCl to the anode chamber had a negative impact on power generation in MFC- 2 and MFC- 3, where less power output was documented compared to MFC- 1 and MFC- 4. The reason for decreased power production might be due to the fact that microorganisms in the sago wastewater are less tolerant to salt addition and their growth and multiplication was limited or attenuated by the presence of NaCl in anode chamber. All organisms with a semi permeable plasma membrane are subject to osmotic pressure, which is the effect of water moving in and out of the cell. Bacteria have a cell membrane and a cell wall and most of them thrive in a hypotonic environment, where the concentration of water outside the cell is greater than the concentration of water inside the cell. So when microbes are exposed to NaCl, the medium around it is hypertonic and it causes the microbe to dehydrate and perish. Mohan *et al*. [25] observed a similar decrease in voltage from 0.3 to 0.2 V when 15 mM NaCl was added to the anode chamber and complete inhibition of bacterial growth when the concentration was further increased to 100mM. The performance of the MFC is microbial growth dependent and addition of salt in the anode chamber is limited by the tolerance of the microorganisms to the ionic strength of the solution. Thus, decrease in the performance of MFC when NaCl was used in the anode chamber may be attributed to the effect of added salt on the growth of the organism [26]. These facts substantiate that employing NaCl exclusively in the catholyte is better than using it in the anode chamber or rendering the cathode devoid of NaCl.

Effect of NaCl on Internal Resistance: Internal resistance is the resistance inside a solution and electrons need to overcome that hindrance before passing through a circuit. Liu *et al*. [27] have reported that increasing the ionic strength of the catholyte in a MFC can remarkably increase power output due to the reduction of internal resistance. The internal resistance (R_{int}) of all the MFC's was calculated using the equation (1) according to Ieropoulos *et al*. [28, 29]

$$R_{int} = OCV/\ R_i\text{-}R_{l,} \qquad (1)$$

where,
OCV = Open Circuit Voltage (V)
R_i = Current under a load (A)
R_l = Value of the load (Ω)

The internal resistance of all the MFCs were 3kΩ before NaCl addition and it was reduced to 2KΩ (MFC- 1), 1KΩ (MFC- 2), 1KΩ (MFC- 3) and 500Ω (MFC- 4). This data revealed that NaCl addition has considerably reduced the internal resistances of the fuel cells and MFC- 4 documented maximum reduction. Low concentration of protons in the cathode raises the internal resistance of the MFC as there is a hindrance in movement of electrons from anode to the cathode chamber due to decrease in oxygen reduction at the cathode electrode and reduced anodic activity. This will eventually result in less power generation. So, addition of NaCl into the cathode will increase the proton availability, thereby decreasing the internal resistance and increasing the power generation. Therefore, internal resistance and electricity generation are inter-related and both are affected by NaCl addition. This result was supported by Liu *et al*. [27], where, the internal resistance of the cell was 161Ω and it eventually decreased to 91Ω with the addition of 100 mM NaCl. Huang e *et al*. [24], have supported the results of this study by demonstrating that the internal resistance of their MFC decreased from 2 KΩ to 900Ω, when the concentration of NaCl was gradually increased from 300 to 1200 mM. These reports have substantiated that the reduction of R_{int} was the reason for high power output in MFC- 4, where an increase in ionic strength of the catholyte improved the cathodic proton transfer rate resulting in better MFC performance.

Effect of NaCl on COD Removal: The anodic chamber of the fuel cells was monitored for substrate (COD) removal efficiency once in 72 h during the experimental period. The experimental data documented that the COD removal efficiencies were 14, 7, 18 and 27% in MFC- 1, 2, 3 and 4, respectively on 4th day of operation and a gradual increase in the efficiencies was observed during the experimental period (Fig. 6). The removal efficiencies were 75, 74, 75 and 83% in MFC- 1, 2, 3 and 4, respectively on the 34th day. MFC- 4 was observed to be the best in substrate removal compared to the other MFCs and it may be due to the increased oxidation of organics in the anode chamber. The increased proton availability in the cathode chamber after NaCl addition resulted in better oxygen reduction at the cathode which might have indirectly triggered anodic activity. The observations by Feng *et al*. [30]

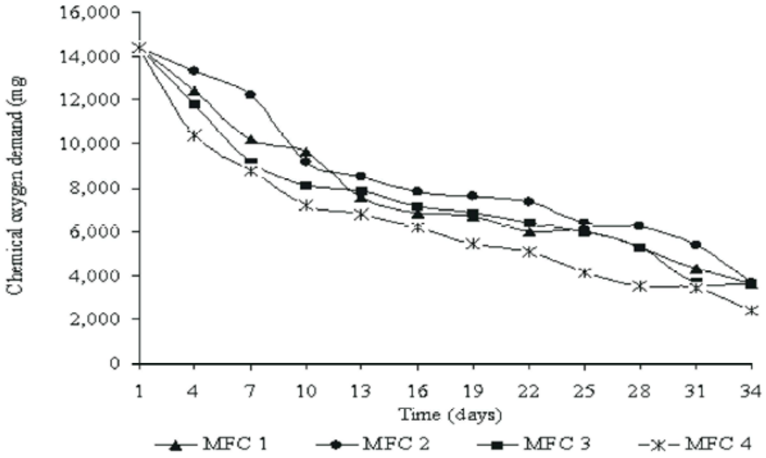


Fig. 6: COD removal efficiency over time in all the four fuel cells

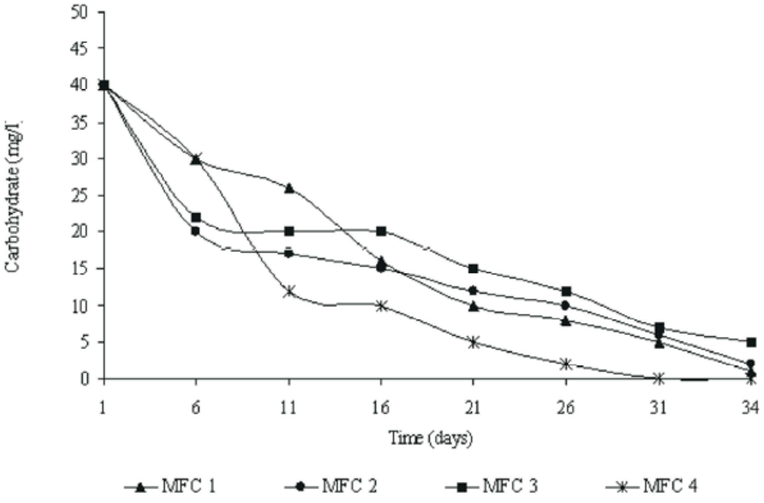


Fig. 7: Effect of salt addition on Carbohydrate reduction in MFCs

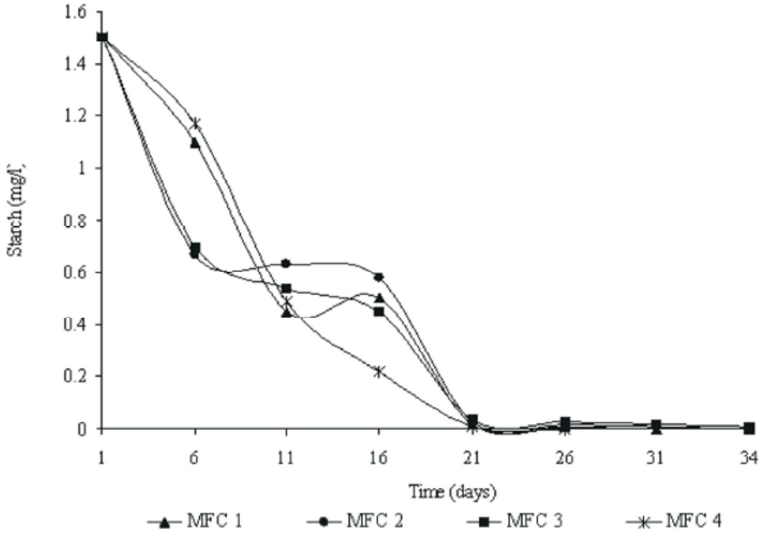


Fig. 8: Effect of salt addition on the reduction of starch in MFCs

Table 3: Physico-chemical parameters of the treated effluent from the anode of all the four MFCs

Parameters	MFC-1 (mg/L)	MFC-2 (mg/L)	MFC-3 (mg/L)	MFC-4 (mg/L)
Chemical Oxygen Demand	3,610	3,680	3,610	2,400
Carbohydrate	1	2	5	Nil
Starch	Nil	Nil	0.01	Nil

Table 4: Identification and confirmation of microbes from sago wastewater before and after MFC operation

					Carbohydrate fermentation test					IMVIC tests				
Organisms in the initial effluent	Gram's staining	Catalase test	Oxidase test	Cultural characteristics	Glucose	Sucrose	Lactose	Maltose	Mannitol	Indole	MR reaction	VP reaction	Citrate test	Urease test
Staphylococcus sps	G+ Cocci	+	-	Opaque	+	A	A	+	+	-	+	+	-	-
Streptococcus sps	Cocci+	-	-	Thin, even growth	+	A	A	A	A	-	+	-	-	-
E. coli	Rod, -	+	-	White moist. glistening	+	A+	AG	A	A	+	+	_	_	_
Proteus vulgaris	Rod -	+	-	Thin blue grey spreading growth	AG	AG+/-	-	A	A	+	+	_	_	+
Klebsiella sps	Rod -	+	_	Slimy, white, translucent growth	AG	AG	AG	A	A	-	-	+	+	+
Salmonella sps	Rod -	+	-	Soft, black colonies	AG	AG	AG	A	A	+	+	-	-	-
Micrococcus sps	Cocci +	-	-	Soft, smooth, yellow growth	-	-	-	-	-	-	-	-	+	+
Pseudomonas aeruginosa	Rod -	+	+	Abundant, thin white medium to yellow	-	-	-	-	-	-	-	-	+	-
Aeromonas sps	Rod -	+	+		A	A	-	A	A	+	-	+	+	-
Organisms in the final effluent														
E. coli	Rod, -	+	-	White moist. glistening	+	A+	AG	A	A	+	+	_	_	_
Aeromonas sps	Rod -	+	+		A	A	-	A	A	+	-	+	+	-
Streptococcus sps	Cocci+	-	-	Thin, even growth	+	A	A	A	A	-	+	-	-	-
Pseudomonas aeruginosa	Rod -	+	+	Abundant, thin white medium to yellow	-	-	-	-	-	-	-	-	+	-
Salmonella sps	Rod -	+	-	Soft, black colonies	AG	AG	AG	A	A	+	+	-	-	-

A, Acid production; G, Gas production

have supported the results of this study and they reported that the COD removal efficiency was increased from 87 to 90% when 50mM of NaCl was added into the cathode chamber. These supporting results have clearly demonstrated that highest reduction in COD was due to the effective functioning of the anode compartment of MFC 4 in response to NaCl addition.

Effect of NaCl on Carbohydrate and Starch Utilization: Carbohydrate and starch reduction were monitored once in five days during the experimental period of the MFCs. The sago wastewater had an initial carbohydrate content of 40 mg/l and an initial starch content of 1.53 mg/l. Carbohydrate reduction observed in all the MFCs was calculated and plotted (Fig. 7). MFC- 4 showed a steep reduction in carbohydrate level by reaching complete removal on the 31st day, whereas the other MFCs had residual levels of carbohydrates in their anolyte. Starch reduction during the experiment was depicted (Fig. 8). MFC- 1 and MFC- 4 portrayed a rapid reduction in starch and complete removal was observed on the 31st day. Though starch removal rate in MFC- 4 was initially less compared to other fuel cells it reached a maximum of 98% on 26th day and documented complete removal on the 31st day. It is evident from the above results that NaCl addition in the cathode chamber had a positive influence on MFC performance.

The physico-chemical parameters of final effluent from the anode chamber of all the MFCs were analyzed and are summarized in Table 3.

Microbiological Analysis: The sago wastewater was subjected to microbial analysis before and after employing it in the fuel cells and the details is shown in Table 4. A bacterial count of 176 x 10^{-6} CFU/ml was present in the initial influent and 140 x 10^{-6} CFU/ml was present in the final effluent. Microbes such as *Escherichia coli*, *Staphylococcus sps*, *Proteus vulgaris*, *Micrococci sps*, *Salmonella sps*, *Aeromonas sps*, *Streptococci sps*, *Klebsiella sps and Pseudomonas aeruginosa* were identified in the initial sample, where as microbes such as *E.coli*, *Aeromonas sps, Streptococci sps*, *Pseudomonas aeruginosa* and *Salmonella sps* were found to be dominant in the final effluent. Microbes such as *Alcaligenes, Bacillus, Corynebacterium, Micrococcus* and *Pseudomonas* sps have already been identified from sago wastewater and are reported to be starch degrading bacteria [31, 32, 33]. *Pseudomonas aeruginosa* have already been used in a dual chambered MFC, employing potato-processing wastewater sludge diluted with nutrient broth. Power production of 23.3W/m^2 was documented in the MFC [34]. Gallagher *et al.* [35] and Hernandez and Newman [36] reported that *Pseudomonas aeruginosa* produces a phenazine blue pigment called pyocyanin which functions as an extra cellular electron shuttle and is responsible for the electrochemical activity of the microbe. *Aeromonas* sps have been isolated by Pham *et al*. [37], from mediator less microbial fuel cell and their electrochemical activities have been proven by cyclic voltammetry.

CONCLUSIONS

MFC is a novel wastewater treatment process in which energy can be recovered from waste. Experiments were conducted to demonstrate the feasibility of electricity production from sago wastewater in a dual chamber, salt bridge MFC. The influence of NaCl addition on MFC performance was evaluated in terms of power generation, COD, carbohydrate and starch reduction. Better performance and stabilization tendency was found in the MFC in which NaCl was added only to its cathode chamber. A maximum voltage of 603mV, current of 6.0 mA, COD removal of 83% and a total reduction of carbohydrate and starch content was recorded in it. While our results show that power production and substrate removal is feasible for sago industry wastewater, pilot-scale and additional studies are further required for better evaluation.

REFERENCES

1. Daniel, D.K., B.D. Mankidy, K. Ambarish and R. Manogari, 2009. Construction and operation of a microbial fuel cell for electricity generation from wastewater. International Journal of Hydrogen Energy, 34(17): 7555-7560.
2. Fatemi, S., A.A. Ghoreyshi, G. Najafpour and M. Rahimnejad, 2012. Bioelectricity Generation in Mediator-Less Microbial Fuel Cell: Application of Pure and Mixed Cultures. Iranica Journal of Energy and Environment, 3(2): 104-108.
3. Wen, Q., Y. Wu, D. Cao, L. Zhao and Q. Sun, 2009. Electricity generation and modelling of microbial fuel cell from continuous beer brewery wastewater. Bioresource Technology, 100(18): 4171-4175.
4. Tardast, A., M. Rahimnejad, G. Najafpour, A.A. Ghoreyshi and H. Zare, 2012. Fabrication and operation of a Novel Membrane-less Microbial Fuel Cell as a Bioelectricity Generator. Iranica Journal of Energy and Environment, 3(5): 1-5.
5. Nimje, V.R., Y.P. Labrath and V.G. Gaikar, 2013. Development of Microbial Fuel Cell Using Distillery Spent Wash: Evaluation of Current Generation and COD Removal with Respect to pH, Iranica Journal of Energy and Environment, 4(4): 348-356.
6. Savitha, S., S. Sadhasivam, K. Swaminathan and F.H. Lin, 2009. A prototype of proposed treatment plant for sago factory effluent. Journal of Cleaner Production, 17(15): 1363-1372.
7. Saravanane, R., D.V.S. Murthy and K. Krishniah, 2001. Anaerobic treatment and biogas recovery for sago wastewater management using a fluidized bed reactor. Water Science and Technology, 44(6): 141-147.
8. Gopalakrishna, K., 2007. Performance studies of hybrid reactor for the treatment of sago wastewater. Environmental Informatics Archives, 5: 415-421.
9. Parthiban, R., P.V.R. Iyer and G. Sekaran, 2008. Anaerobic Tapered Fluidised Bed Reactor for Treatment of Sago Industry Effluent. Indian Chemical Engineer, 50(4): 323-333.
10. Rajesh Banu, J., S. Kaliappan and D. Beck, 2006. Treatment of sago wastewater using hybrid anaerobic reactor. Water Quality Research Journal of Canada, 41: 56-62.
11. Rajasimman, C. and M. Karthikeyan, 2007. Starch Wastewater Treatment in a Three Phase Fluidized Bed Bioreactor with Low Density Biomass Support. Journal of Applied Sciences and Environmental Management, 11(3): 97-102.
12. Rajesh Banu, J., I.T. Yeom, S. Esakkiraj, S. Naresh Kumar and S. Logakanthi, 2008. Biomanagement of sago-sludge using an earthworm, *Eudrilus eugeniae*. Journal of Environmental Biology, 29(2): 143-146.
13. APHA, 2005. Standard methods for the examination of water and wastewater, “21st ed. American Public Health Association, New York, USA.
14. Sangeetha, T. and M. Muthukumar, 2011. Catholyte Performance as an influencing factor on Electricity Production in a Dual-Chambered Microbial Fuel Cell employing Food Processing Wastewater. Energy Sources Part A, 33(16): 1514-1522.
15. Sangeetha, T. and M. Muthukumar, 2013. Influence of electrode material and electrode distance on bioelectricity production from sago-processing wastewater using microbial fuel cell. Environmental Progress and Sustainable Energy, 32(2): 390-395.

16. Kim, J.R., B. Min and B.E. Logan, 2005. Evaluation of procedures to acclimate a microbial fuel cell for electricity production. Applied Microbial Biotechnology, 68(1): 23-30.
17. Patil, S.A., V.P. Surakasi, S. Koul, S. Ijmulwar, A. Vivek, Y.S. Shouche and B.P. Kapadnis, 2009. Electricity generation using chocolate industry wastewater and its treatment in activated sludge based microbial fuel cell and analysis of developed microbial community in the anode chamber. Bioresource Technology, 100(21): 5132-5139.
18. Behera, M., P.S. Jana and M.M. Ghangrekar, 2010. Performance evaluation of a low cost microbial fuel cell fabricated using earthen pot with biotic and abiotic cathode. Bioresource Technology, 101(4): 1183-1189.
19. Venkata Mohan, S., C. Mohanakrishna, B.P. Reddy, R. Saravanan and P.N. Sarma, 2008. Bioelectricity generation from chemical wastewater treatment in mediatorless (anode) microbial fuel cell (MFC) using selectively enriched hydrogen producing mixed culture under acidophilic microenvironment. Biochemical Engineering Journal, 39(1): 121-130.
20. Sadasivam, S. and A. Manickam, 1996. Biochemical methods, 2nd edn, New Age International Publishers, New Delhi, India.
21. Mardanpour, M.M., M.N. Esfahany, T. Behzad, R. Sedaqatyand, F. Sharifi and F. Naderi, 2013. Factors Affecting the Performance of Single Chamber Microbial Fuel Cell Using a Novel Configuration. Iranica Journal of Energy and Environment, 4(4): 342-347.
22. Gil, G.C., I.S. Chang, B.H. Kim, M. Kim, J.K. Jang, H.S. Park and H.J. Kim, 2003. Operational parameters affecting the performance of a mediator-less microbial fuel cell. Biosensors and Bioelectronics, 18(4): 327-334.
23. Jang, J.K., T.H. Pham, I.S. Chang, K.H. Kang, H. Moon, K.S. Cho and B.H. Kim, 2004. Construction and operation of a novel mediator and membrane-less microbial fuel cell. Process Biochemistry, 39(8): 1007-1012.
24. Huang, J., B. Sun and X. Zhang, 2010. Electricity generation at high ionic strength in microbial fuel cell by a newly isolated Shewanella marisflavi EP1. Applied Microbiology and Biotechnology, 85(4): 1141-1149.
25. Mohan, Y., S. Manoj Muthukumar and D. Das, 2008. Electricity generation using microbial fuel cells. International Journal of Hydrogen Energy, 33(1): 423-426.
26. Mohan, Y. and D. Das, 2009. Effect of ionic strength, cation exchanger and inoculum age on the performance of Microbial Fuel Cells. International Journal of Hydrogen Energy, 34(17): 7542-7546.
27. Liu, H., S. Cheng and B.E. Logan, 2005. Power generation in fed-batch microbial fuel cells as a function of ionic strength, temperature and reactor configuration. Environmental Science and Technology, 39(14): 5488-5493.
28. Ieropoulos, I., J. Greenman and C. Melhuish, 2008. Microbial fuel cells based on carbon veil electrodes: Stack configuration and scalability. International Journal of Energy Research, 32(13): 1228-1240.
29. Ieropoulos, I., J. Winfield and J. Greenman, 2010. Effects of flow-rate, inoculum and time on the internal resistance of microbial fuel cells. Bioresource Technology, 101(10): 3520-3525.
30. Feng, Y., X. Wang, B.E. Logan and H. Lee, 2008. Brewery wastewater treatment using air-cathode microbial fuel cells. Applied Microbiology and Biotechnology, 78(5): 873-880.
31. Ayyasamy, P.M., R. Banuregha, G. Vivekanandhan, S. Rajakumar, R. Yasodha, S. Lee and P Lakshmanaperumalsamy, 2008. Bioremediation of sago industry effluent and its impact on seed germination (green gram and maize). World Journal of Microbiology and Biotechnology, 24(11): 2677-2684.
32. Muthukumar, M. and T. Sangeetha, 2014. Harnessing of bioenergy from a dual chambered microbial fuel cell (MFC) employing sago-processing wastewater as catholyte. International Journal of Green Energy, 11(2): 161-172.
33. Subha, B. and M. Muthukumar, 2012. Optimization of ozonation process for the reduction of excess sludge production from activated sludge process of sago industry wastewater using central composite design. The Scientific World Journal, 2012:Article ID 239271, 8 pages doi: 10.1100/2012/239271.
34. Rabaey, K., N. Boon, S.D. Siciliano, M. Verhaege and W. Verstraete, 2004. Biofuel cells select for microbial consortia that self-mediate electron transfer. Applied Environmental Microbiology, 70(9): 5373-5382.

35. Gallagher, L.A., S.L. McKnight, M.S. Kuznetsova, E.C. Pesci and C. Manoil, 2002. Functions required for extracellular quinolone signaling by *Pseudomonas aeruginosa.* Journal of Bacteriology, 184(23): 6472-6480.
36. Hernandez, M.E. and D.E. Newman, 2001. Extracellular electron transfer. Cell and Molecular Life Sciences, 58(11): 1562-1571.
37. Pham, C.A., S.J. Jung, N.T. Phung, J. Lee, I.S. Chang, B.H. Kim, H. Yi and J. Chun, 2003. A novel electrochemically active and Fe (III)-reducing bacterium phylogenetically related to *Aeromonas hydrophila,* isolated from a microbial fuel cell. FEMS Microbiology Letters, 223(1): 129-134.

Persian Abstract

چکیده

اثر نمک طعام (NaCl) بر تولید جریان الکتریسته و حذف COD همراه با کاهش نشانسته یا ترکیبات قندی در پیل سوختی میکروبی دارای پل نمکی و با استفاده از فاضلاب نشاسته ساگو، غلظت mg COD/l ۱۴۴۰۰ مورد ارزیابی قرار گرفت. این مقاله چهار MFC برای ارزیابی اثر نمک بر کارایی پیل ساخته شد. جداسازی و شناسایی میکروارگانیزمها از جریان های ورودی و خروجی با روش رقیق سازی انجام گردید. نکته جالب اینکه اثر نمک در کاتد سه پیل موجب کارایی موثر پیل سوختی میکروبی گردید. حداکثرولتاژ mV ۶۰۳ و جریان mA ۶/۰۳ بدست آمده است. حداکثر بازدهی حذف COD بمیزان۸۳٪ بوده است که خود نشانه حذف ترکیبات قندی و نشاسته فاضلاب است. استفاده از فاضلاب در MFC برای تولید جریان بیو الکتریسته توجیح اقتصادی داشته و فرایند پایدار می باشد.