# A Novel Application of Polyvinyl chloride (PVC) Waste Material as a to Replace Membrane in Microbial Fuel Cell Treating Actual Potato Chips Processing Wastewater

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## ABSTRACT

The microbial fuel cell (MFC) is a modern technique for treating wastewater, which is normally use a membrane in its conventional design. However, the cost of membrane in some countries in addition to the problems of fouling associated with some complex types of wastewaters led to search for new alternatives such waste materials.
In this study, a piece of waste PVC wall cover material was used as a separator between the anodic and cathodic compartments in a dual-chamber microbial fuel cell fueled with actual potato chips processing wastewater (PCPW). The performance of membrane-less MFC was evaluated in terms of the power generation and chemical oxygen demand (COD) removal. The results revealed that the membrane-less MFC achieved high removal efficiency of COD concentration up to 99%. The pH value was used for monitoring the performance of PVC separator and the results revealed a very good performance associated with relatively high current and power densities of 560.8 mA/m$^2$ and 181.1 mW/m$^2$, respectively obtained with relatively lower internal resistance of 45 Ω.

**Keywords:** Microbial fuel cell**;** membrane-less; Potato chips processing wastewater; PVC separator.

## 1. INTRODUCTION

The industrial effluents from food processing industry usually generated from a series of processes including; washing, cleaning, cutting, slicing, salting, frying, coating and packing. These effluents are significant sources for environmental pollution with their different levels of organic loading which could be low, medium and high level of contaminations. Food processing wastewater may contain high concentrations of several organic compounds such as starches, carbohydrates, proteins, pectin, vitamins and sugars which are responsible for high suspended solids and chemical oxygen demand (COD) [1]. These effluents are normally collected and treated in a municipal sewage treatment plant or in a special on-site installation. However, it is required more efficient treatment to assure the wastewater released is in agreeable with the Environmental Regulations [2].
One of the most worldwide spread food industries is potato chips processing industry. Wastewaters discharged from potato chips processing plants are significant sources for environmental contamination. They contains high concentrations of various organic compounds such as starches, carbohydrates, sugars, and proteins, which are responsible for the high total suspended solids (TSS), and chemical oxygen demand (COD). Potato peels residues represent the major content of potato processing wastewater [1].
Microbial fuel cell (MFC) is a developed bioelectrochemical device. It converts the chemical energy, which is presented in organic compounds, into electrical energy through using microorganisms' activities. Although there has been significant experimental development in recent years, MFC has important experimental developments [3, 4, and 5].
Electrochemically active bacteria at the bio-anode have the capability to oxidize organic matters anaerobically and transfer the released electrons to the anode electrode. In general, two steps occur; the ***1st*** step: the electron donor biochemically oxidized to electrons, protons, and $CO_2$, with electrons transferring to a specific redox component, (e.g., NAD+). The ***2nd*** step is starting when electrons transferring to the anode from NADH type redox components [6].
In the anode chamber, proton accumulation is the major problem that affects the electricity generation performance and operational stability microbial fuel cells [7]. Therefore, the majority of MFC designs required the separation of the anodic and the cathodic compartments by a separator that function as a proton exchange system. Many types of separators are used in the MFCs like: naturally separated system such as sediment MFCs or specially designed single-compartment MFCs. The most commonly separator used is the cation exchange membrane (CEM). This type of membrane like Ultrex™ has generally shows the largest stability than other types. These membranes have been reported to perform adequately for over three months [8]. On the other hand, membrane-less MFCs are more desirable in the applications when fouling or cost becomes

a critical issue. Therefore, several studies have focused on finding alternative materials such as nylon fibers, glass fibers, and ceramics or some unconventional materials which normally considered as waste such as natural rubber or laboratory gloves [9].

The selection of a separator between cathode and anode represents a choice between two opposing benefits [8]:

- High selectivity: higher protons selectivity with lower resistance to conductivity.
- High stability: robust in a nutrient rich and colloidal environment with wide range of pH values.

At a global level, Polyvinyl chloride (PVC) is one of the most commonly used thermoplastic materials in respect to the worldwide polymer consumption. PVC has become a universal polymer and demand for PVC exceeds 35 million tons per year due to particular properties inherent in the PVC i.e., its low cost and high performance, combined with the wide range of products that can be obtained from different processing conditions and techniques. Nowadays, PVC can be processed into a wide variety of short-life products, such as PVC packaging materials used in food, cleansing materials, textile, beverage packaging bottles, and medical devices, and also long-life products such as pipes, window frames, cable insulation, floors coverings, roofing sheets, etc. In recent years, the rapid growth of the PVC wastes increased the importance of recycling or reusing the PVC waste, for example, the long-life PVC products show a long service life but they will finally become waste at a certain point in time. Landfilling is one simple route for disposing of PVC wastes, which become more expensive and in many and no longer acceptable due to the increasing consumption, decrease in available landfilling areas, and potential environmental hazards associated with the chlorine content of the polymer. Recycling for PVC materials is a more suitable route, which can recover the energy and/or material content of these materials, without any special environmental problems [10].

Several materials used to separate anodic and cathodic compartments with different values of internal resistance including the use of a double-layer separators consisted of glass bead layer which supported by a glass wool layer in an up-flow dual-chambered membrane less microbial fuel cell [11], a perforated polyacrylic plate as a separator fixed between the anode and cathode [12], a salt bridge with a resistance of 125Ω [13], A carbon paper with thickness of 0.29mm with internal resistance of 300Ω [14], Two layers-separator of a glass fiber separator of 1.2 mm thick or textile (46% cellulose and 54% polyester) separator of 0.3 mm thick were placed between the anode and cathode with internal resistance of 33 Ω [15], inexpensive acrylic beads with internal resistance values of 833 and 167 Ω for MFCs inoculated with anaerobic sludge and activated sludge, respectively [16], ceramics pieces with three different wall thicknesses 2.5, 5.0 and 10 mm [17], and the two parallel upflow constructed wetland-microbial fuel cell systems, with and without glass wool [18].

As shown above, none of the previously published studies dealt with evaluating the performance of membrane-less MFC fueled with real raw potato chips industrial wastewater. This study aimed to investigate for the first time the performance of novel application of PVC wall cover as a separator between anodic and cathodic compartments in a dual chamber microbial fuel cell system.

## 2. MATERIALS AND METHODS

**Potato chips processing wastewater (substrate)**

Real samples of potato chips processing wastewater (PCPW) were continuously collected from local potato chips manufacturing plant named Salah Al-din Bakery & Pastry factory, located in Tikrit city, Iraq. The characteristics of this real PCPW are given in Table 1. Sample of PCPW is given in Fig.1.

**Table 1** Quality of the real potato chips processing wastewater (PCW)

| Constituents | Units | Average concentration |
|---|---|---|
| COD | mg/L | 7810 |
| pH | - | 5.2-5.6 |
| Total dissolved solids (TDS) | mg/L | 2930 |
| Total suspended solids (TSS) | mg/L | 2580 |
| Electrical conductivity (EC) | µS/cm | 5860 |

**Fig. 1** Sample of actual potato chips wastewater (PCW)

**Biocatalyst and magical media**

Anaerobic aged sludge with the following dominant types of bacterial species; *E-coli*, *Pseudomonas*, *Prophyromonas*, *Prevotella*, and *Dickaya Solani* was used to inoculate the MFC in this study. Initially, the biomass was anaerobically enriched and acclimated using peptone-loaded mineral salt medium that [19]. The media was prepared by dissolving in gram; 0.2 $MgSO_4.2H_2O$, 0.2 $KH_2PO_4$, 7.5 peptone powder (mixture of 5g peptone and 2.5g NaCl), and 5 yeast extract (YE) in one liter distilled water. The prepared media was autoclaved for 20 min at 121°C, then after cooled to room temperature and flushed with nitrogen to maintain anaerobic conditions. Peptone media was used as a potential source for organics and nutrients including nitrogen and phosphorous, salts, and as a base for carbohydrate fermentation media. Yeast extract is rich in vitamins especially those belonging to B-complex and is often used to supply the culture media with these supplements at a concentration of 0.3% to 0.5%. The Average concentrations of COD, EC, TDS in the prepared media were 15700 mg/L, 7990 µS/cm, and 4000 mg/L at pH 6.8.

**System configuration and operation**

A horizontal dual chamber membrane-less MFC made of Perspex material was designed, constructed and setup in this study. The MFC had a total volume of 2000 ml for each chamber. The anodic and cathodic compartments in this type of membrane-less MFC were separated by a piece of plastic waste material (Polyvinyl chloride, PVC) which normally discarded as undesirable residues resulted from cutting the PVC sheets used for covering the walls. Samples of this plastic waste material are given in Fig.2. A thin layer PVC sheet of dimensions 10 x 10 x 0.1 $cm^3$ was sandwiched between two perforated Perspex materials sheets and placed between anode and cathode chambers. The perforated sheets had 72 holes, each hole of 5 mm diameter, with total effective area of 14.14 $cm^2$.

**Fig.2** Samples of the plastic waste materials

Graphite plain electrodes were used as anodic and cathodic electrodes; each had a projected surface area of 128 $cm^2$. The anode chamber was continuously fed with actual potato chips processing wastewater (PCPW) via a peristaltic pump at a rate of 1 ml/min. Phosphate buffer saline was used as a catholyte and continuously sparged with an air pump at a rate of 10 ml/min. The membrane-less MFC was preceded by holding-neutralization tank and primary sedimentation tank as a primary treatment unit as given in Fig. 3.

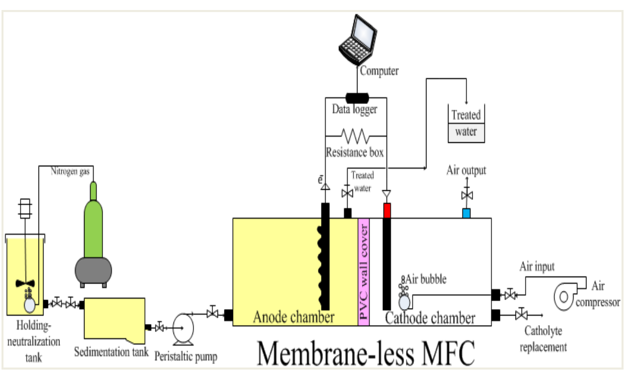


**Fig. 3** membrane-less complete system

**Electrical measurements and analytical Analyses**

Voltage data logger (model: Lascar EL-USB-3, USA) and Multimeter (model MT1233C, pro'skit, Taiwan) with accuracy of 0.001 mV were used for continuously voltage monitoring. The average voltage value for each day was calculated and then converted to power according to $P = I * V$, where $P$ is the power, $I$ is the current, and $V$ is the voltage. Then, the power was calculated as a function of the total volume of the anodic chamber. The system was operated with external load of 100Ω. The chemical oxygen demand (COD) concentrations were determined on daily basis by using COD reactor (model RD 125, Lovibond, Germany) and COD analyzer (model MD 200 COD vario, Lovibond, Germany). Dissolved oxygen (DO), pH, TDS, TSS and EC were also daily measured according to the procedure reported in the *Standard Methods* [20].

## 3. RESULTS AND DISCUSSION

**Chemical oxygen demand (COD) removal**

The membrane less-MFC was continuously operated for 30 days and fueled with PCPW to investigate and evaluate its performance. The profile of COD removal in membrane less-MFC is given in Fig.4. As shown in this figure, a rapid removal of COD removal was observed at the first day with a slight fluctuation during the first week, and then an observable increase in COD removal efficiency was clearly noticed followed by achieving a steady state conditions after almost two weeks with maximum COD removal efficiency of 99.9%.

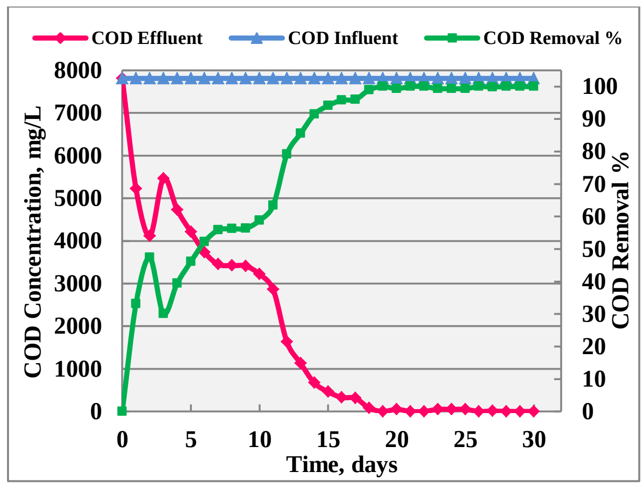


**Fig.4** Profile COD removal in membrane less-MFC

**Current and power generation**

As presented in Fig.5, the current and power started to generate in MFC at the first operation day with rapid increase achieving a steady state conditions at the eighth day and maintained stable until the end of 30 days of continuous operation period with constant values of 1750 $mA/m^3$ and 612.5 $mW/m^3$ for current generation and power generation, respectively. These data were recorded for a closed circuit at 100Ω external resistant.

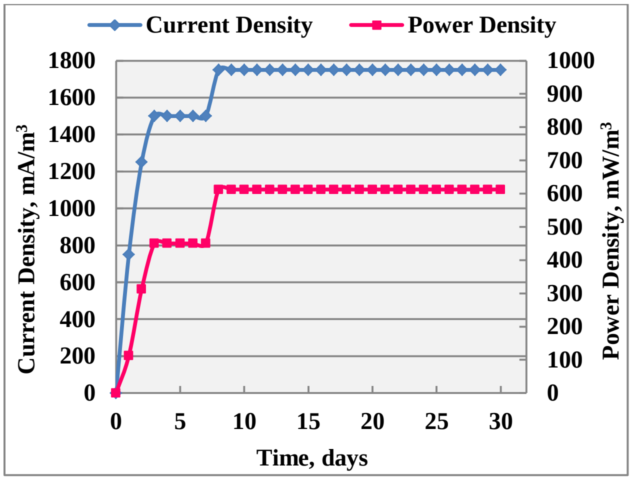


**Fig. 5** Profile of current and power generation for membrane less-MFC

**Polarization curves**

The performance of MFC can be investigated during a stable operation phase, under various external loads from 5 to 60000 Ω. Based on the procedure outlined by Zhou et al. [21], the output voltage values were measured and recorded, and converted to current values. In order to obtain the polarization curves, the current densities were plotted versus voltages and power densities.

Maximum current and power densities of 560.8 mA/m$^2$ and 181.1 mW/m$^2$, respectively were obtained at external resistance of 45 Ω for the polarization curve in membrane less-MFC as shown in Fig. 6. These results were favorable compared with the findings reported by Rodrigo et al. [13], Han et al.14, and Ismail & Jaeel [16].

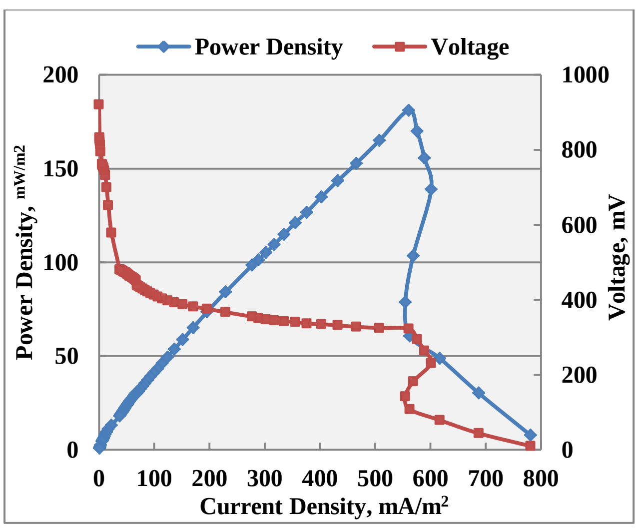


**Fig. 6** Polarization curve for membrane-less MFC

**Performance of PVC separator towards CEM membrane**

Generally, in order to evaluate the performance and efficiency of the PVC waste material as a compartments separator between the anode and cathode, the pH behavior in the anodic chamber was carefully monitored during the MFC operation. As shown in Figs.7 and 8 for membrane-MFC and membrane less-MFC, respectively operated for the same period. There was a notable increase in the pH of the effluent compared to influent pH for both MFCs. This observation indicated that both; the CEM membrane and PVC waste separator were successfully permeable of protons to transfer from the anolyte to the catholyte solution. These results are compatible with the common behavior of an efficient separator without fouling as cited by Sevda et al. [22]. These promising observations proved the eco-friendly and cost-effective approach of using the PVC waste material as a separator between the anodic and cathodic compartments.

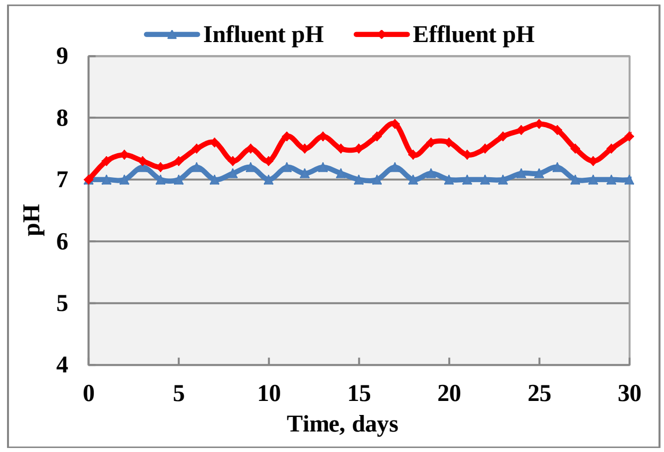


**Fig. 7** Profile of pH in membrane-MFC

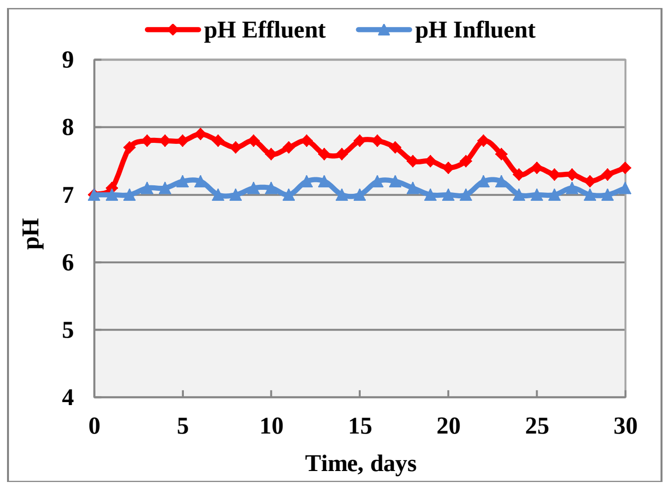


**Fig. 8** Profile of pH in membrane less-MFC

## 4. CONCLUSION

This study evaluated and demonstrated the efficiency of a complete system of membrane-less MFC preceded by primary treatment units consisted of holding-neutralization and sedimentation tanks. A piece of waste PVC sheets originally used for covering the walls and floors was used as a separator between anodic and cathodic compartments. The system was fueled for 30 days with actual potato chips processing wastewater for simultaneous wastewater treatment and electricity generation. The results revealed that the type of substrate was favorable to the biomass. Significant COD removal efficiencies > 99% was observed in membrane less-MFC. The results also demonstrated for a closed system of 100Ω: maximum power generation and current generation of 612.5 mW/$m^3$ and 1750 mA/$m^3$ were obtained in the membrane less-MFC. Polarization curve showed the efficiency of PVC material as an alternative choice for cation exchange membrane with an internal resistance value of 45 Ω. These promising observations proved the eco-friendly and cost-effective approach of using the PVC waste material as a separator between anodic and cathodic compartments.

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