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Research Article

BULGUR INDUSTRY WASTEWATER TREATMENT BY MICROBIAL FUEL CELL – EXPLORATORY STUDY

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ABSTRACT
The bulgur industry has importance in the food sector in Turkey. The wastewater generated from this industry can be considered bio waste. The microbial fuel cells (MFC) are a relatively new technique aiming to treat the wastewater and producing direct energy. This study aims to explore the degradation efficiency of the organic matters expressed as chemical oxygen demand (COD) founded in bulgur industry wastewater by microbial fuel cell techniques. Furthermore, it aims to study the potential formation of electricity from this type of wastewater. In this study, the MFC – double chamber system was performed. 1.5 L bulgur industry wastewater containing 3% of biomass was used. The COD and the voltage were measured. The COD generated from the bulgur industry wastewater was 28800 mg/L. After using the MFC system, the COD was decreased to reach 2560 mg/L with a removal efficiency of 91%. 1st order kinetic model had the best fit for COD removal with a correlation coefficient (R^2) of 0.95. The maximum and average voltages were 0.448 V~~olt~~ and 0.180 V~~olt~~, respectively. The average voltage for every 1 m^2 was 45 volt. As a result of the exploratory study, the MFC can be used to treat the bulgur industry wastewater and generating energy. But it should be combined with other treatment methods to meet the COD standard limits.

Keywords: *Microbial Fuel Cell; Bulgur Industry Wastewater, Energy Generation; Food Wastewater.*

1. INTRODUCTION

The demand for energy has been increased sharply since the industrial revolution. The energy uses were not limited to industrial activities. It enters the whole civilized activities. One of these activities is the Treatment of wastewater.

Wastewater treatment aims to safely dispose of wastewater without producing any harm for humans or the environment (Templeton and Butler, 2011).The treatment process is an energy-intensive process (Gikas and Tsoutsos, 2015). Tchobanoglous *et al*. (2003) had estimated the energy required for the wastewater treatment by conventional methods to be 1.1-2.4 MJ/1m^3. Gikas and Tsoutsos (2015) stated the needed energy for the small wastewater treatment plants could be higher.

The depletion of nonrenewable energy and the environmental problem related to greenhouse emissions forced towards more sustainable energy (Li *et al*., 2014). Many researchers considered wastewater as an energy source that might be used to partially cover the energy needed to treat it (Gude, 2015, Burkitt *et al*., 2016).

Microbial Fuel Cell (MFC) is a technique with the capability of treating wastewater and generating energy at the same time (Cheng *et al*., 2017). The principle of this technique is using the microorganism as catalysts with an objective of oxidizing organic and inorganic matter and generating electric current (Lee *et al*., 2012). MFC typically consists of aerobic (cathodic) and anaerobic (anodic) chambers. Those chambers separated by a proton exchange membrane. The digestion of organic matters occurs in the anaerobic chambers. The substrate oxidation half-reaction produces electrons and protons. The electron transfer by external resistance while the proton moves through the proton exchange membrane (Habermann, Pommer, 1991; Due *et al*., 2007; Huggins *et al*., 2013). The MFC schematic is shown in Fig. 1.

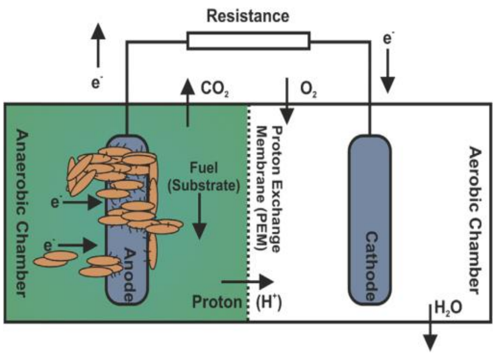

Fig. 1. Schematic plan for two-chamber microbial fuel cell (Du *et al.*, 2007)

The half-reactions for Acetate degradation by the MFC techniques are shown in Equations 1 and 2 (Mohan *et al*., 2007).

Anode reaction:

$$CH_3COO^- + 2H_2O \xrightarrow{(Anaerobic\ Microorganism)} CO_2 + 7H^+ + 8e^- \quad (1)$$

Cathode reaction:

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O \quad (2)$$

Microbial fuel cells were employed previously to treat various types of wastewater. Domestic wastewater, Sulfide, palm oil mill effluent, textile wastewater, food waste leachate, and Starch are some of those wastewaters (Köroğlu *et al*., 2014; Lee *et al*., 2012; Hisham *et al*., 2013; Mise and Saware, 2016)

The wastes from the food industry are mostly bio wastes. Starch-containing wastewater always consists of high concentrations of starch and protein, which is an energy source for MFC applications (He *et al*., 2017). The bulgur industry has importance in the food sector in Turkey. The Bulgur production reached 1.25 million/ year, and the annual consumption is about 13 kg/capita (Dünya Gıda Dergisi, 2018).

This study aims to investigate the degradation efficiency of the organic matters expressed as chemical oxygen demand (COD) from bulgur industry wastewater by microbial fuel cell techniques. Also, it aims to study the potential formation of electricity from this type of wastewater.

2. MATERIAL AND METHOD

2.1. Material

The bulgur wastewater was collected from a bulgur factory near Mersin city. The biomass was agglomerated from the outlet of the digester tank in the Karaduvar treatment plant. All of the chemicals used in the study were bought from Sigma-Aldrich. The agitation process was provided by LH-Fermentation equipment. The needed air was provided by the SOBO-SB222 air pump.

2.2. Biomass Percentage Optimization

Different percentages (2, 3, 4, 5 and 10%) of biomass and wastewater were filled into a 15 ml tubes. The tubes were closed with stoppers and placed into the water jar upside down. The jars were inserted into an incubator at 35^{o}C for several days. The volume of the generated methane gas was calculated for each tube by finding the differences between the first and the final level of the liquid. Fig. 2 shows the Biomass optimization process.

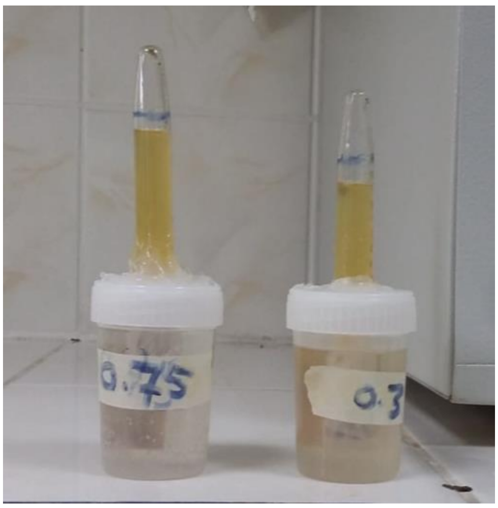

Fig. 2. Biomass optimization process

2.3. MFC Setup

In this study, a double-chambered microbial fuel cell was setup. The anaerobic and aerobic chambers were connected by a salt bridge. The preparation method is shown in the following steps:

2.3.1. Chambers Preparation

In the aerobic chamber, a plastic jar was filled by 5 liters distilled water. Air was injected into the jar to maintain enough aeration. For the anaerobic chamber, 1.5 liters of biomass and bulgur industry wastewater injected into a 2-liter cam jar. The mixture exposed to agitation by a mechanical mixer. Aluminum electrodes with dimensions of (8x5) cm were inserted into the cambers. The electrodes were suspended in the system by alligator clips. The electric wires were connected with external variable resistance.

2.3.2. Salt Bridge Preparation

Due to the high cost of the proton exchange membrane, a salt bridge was used and prepared as follows.

1M of potassium chloride (KCl) was prepared, mixed and heated to the boiling point. At the boiling point, agar (30g) was added gradually to the solution. The mixing process was continued until dissolving all the quantity of the agar. The agar was poured into 2 cm glass tubes with a length of 22cm. The glass tubes were stored in a refrigerator for further use. The system is shown in Fig. 3.

Fig. 3. MFC double system and output voltage measurement

2.4. Chemical Oxygen Demand Measurements and Kinetics Modeling

The chemical oxygen demand for the bulgur industry wastewater was determined by closed reflux method (5220 C) (AWWA, WEF, APHA, 1998). The change in the COD was calculated by Equation 3.

$$COD\ remocal\ \% = \frac{COD\ i - COD\ f}{COD\ i} \times 100\% \quad (3)$$

The COD data versus time were fitted to the zero order, first order, second order and third order kinetic reaction using the equations 4, 5, 6, and 7 respectively.

$$C_A = C_O - K_O t \quad (4)$$

$$C_A = C_O e^{-k_1 t} \quad (5)$$

$$\frac{1}{C_A} = \frac{1}{C_O} + K_2 t \quad (6)$$

Where, C_A and C_O are the COD at the time t and the initial COD (mg.L^{-1}), t is the time, K is the reaction rate coefficient (day^{-1}).

The voltage was measured and recorded at least 2 times per day by GESI voltmeter as shown in Fig. 3.

3. RESULT AND DISCUSSION

3.1. Biomass Optimization

The biomass / wastewater percentage was optimized by comparing the generated biogas from the different percentages. The maximum volume of the biogas was generated when the biomass/wastewater was 3%. This results is within the range of (2-6%) which is proposed by with the range proposed by Tchobanoglous *et al*. (2003). Judeh (2017) obtained an optimum result at biomass/wastewater of 2.5%. Other studies found the optimum yield for the glucose-fed MFCs at range of (7 - 22%) (Rabaey *et al*., 2003). Erenler & Ülke (2018) used a biomass/wastewater percentage of 23. Table 1 shows the methane results.

Table 1. The generated biogas at different biomass percentages

Biomass Percentage (%)	biogas volume (mL)
2	2.5
3	2.6
4	1.7
5	1.3
10	1.7

3.2. COD Removal Efficiency

Many researchers had studied various types of food processing wastewater. In this study, the bulgur industry wastewater was treated by MFC method. Firstly, the chemical oxygen demand for the wastewater generated from the Bulgur industry was measured. It found to be 28800 mg/L. At the end of the experiment, the COD decreased to 2560 mg/L. Liu *et al*. (2014) used the MFC system to reduce the COD concentration of the starch processing wastewater from 1700 mg/L to 50 mg/L after a duration of 30 days. The efficiency of this technique reached 91%. The startup period extended to 15 days. At the 15th day the efficiency reached 40.5%. For the 10 days later the efficiency increased sharply to reach 83.3 %. After that, the maximum efficiency was reached and stilled constant. The measured COD and the removal efficiency curves are shown in Fig. 4.

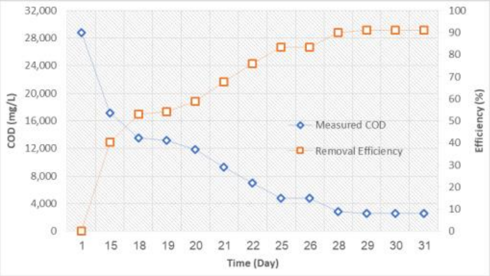

Fig. 4. The measured COD and the removal efficiency curves

The achieved COD removal efficiency in this study can be compared with other researches. Rodrigo *et al*. (2007) obtained A COD removal efficiency of 92% for urban wastewater. The COD removal of the Beet-sugar wastewater was in the range of (50%-70%) (Zhao et. al, 2013). MFC was successfully utilized to remove COD from dairy industry wastewater with %90 removal efficiency (Wang et. al, 2013).

3.3. COD Removal Kinetics

The equations from 4-7 were linearized. The K values were calculated and plotted versus the time. The correlation coefficients (R^2) for each model were noticed. Based on the coefficients for each model, the first order model is the most suitable one for the constructed MFC. Judeh (2017) investigate the degradation of the COD from municipal wastewater by MFC system and founded to be adequate to the first order. According to Ghaniyari-benis *et al*. (2010), the first order was good enough to describe the degradation of the organic matter using chambered hybrid anaerobic reactor. The zero, first, and second order models are shown in Figs. 5-7.

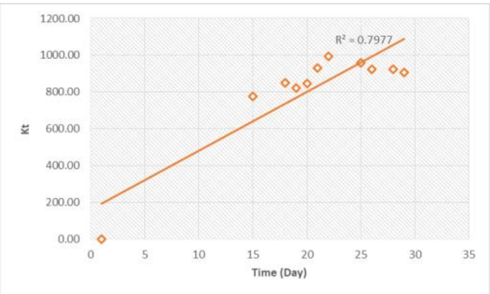

Fig. 5. Linearized Kt for zero order model vs time

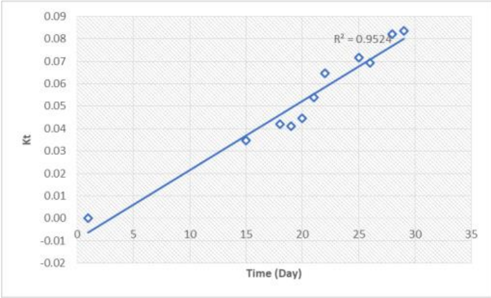

Fig. 6. Linearized Kt for first order model vs time

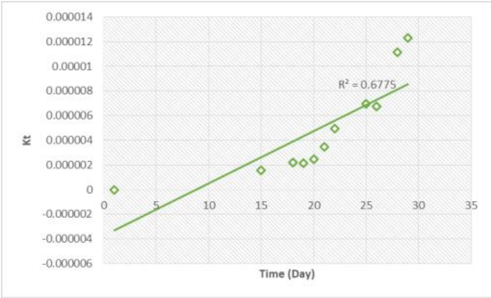

Fig. 7. Linearized Kt for second order model vs time

3.4. The Generated Voltage

The generated voltages were measured and the results are shown in Fig. 8.

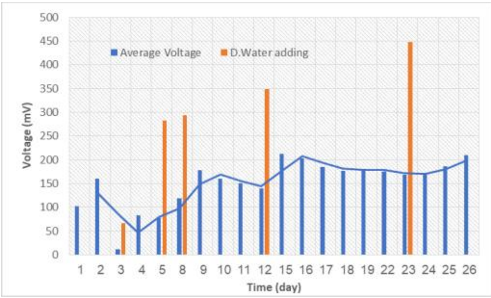

Fig. 8. The generated voltage over times

The maximum obtained voltage was 0.448 volt. The effect of changing of adding distilled water for the aerobic chamber. The voltage increased sharply when the new water added. The mean voltage was 0.180 volt. The average voltage per square meter was calculated by dividing the average voltage by the anode surface area. It reached 45 Volt/m^2. By comparing the voltage by other food wastewaters, the voltage generated in this study is larger than obtained from olive milling (0.38Volt) wastewater and the whey wastewater (0.41Volt) but not than molasses (0.54Volt) (Erenler &Ülke, 2018). The obtained voltage was affected by many variables. To acquire the optimum yield, so the system should be well optimized to have better results. After the optimization process, the obtained voltage can be used to partially cover the treatment energy.

4. CONCLUSION

In this study, the performance of treating bulgur industry wastewater by the MFC technique was assessed. The biomass / wastewater percentage was optimized by comparing the generated biogas from the different percentages. The maximum volume of the biogas was generated when the biomass/wastewater was 3%. The COD concentration was decreased from 28800 mg/L to 2560 mg/L with a removal efficiency of 91%. 1st order kinetic model had the best fit for COD removal with a correlation coefficient (R^2) of 0.95. The maximum and average voltages were 0.448 Volt and 0.180 Volt, respectively. The average voltage for every 1 m^2 was 45 volt. Even though the removal efficiency is high (91%), the MFC had not decreased the COD to the limits of the standard. The wastewater should be extra treated to reduce COD concentration. As a result of the exploratory study, the MFC can be used to treat the bulgur industry wastewater and generating energy. But it should be combined with other treatment methods to meet the standards.

Another note should be considered; this study is an exploratory study, so the system should be well optimized to have better results.

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