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Evaluating the Performance of Three Chambers Microbial Salinity Cell (MSC) Subjected to Different Substrate Concentrations to Accomplish Simultaneous Organic and Salt Removal in The Wastewater

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ABSTRACT

This study aimed to identify the effect of substrate concentration on the performance of a three chambers Microbial Salinity Cell (a three chambers MSC). In this study, a three chambers MSC were made from plexiglass with total volume of 200 ml. An aluminium wrapped with platinum on vulcan carbon cloth was used as electrodes, with each working area of 63 cm^2. The result showed that a three chambers MSC was able to generate electricity and at the same time removed the salinity. The degree of electricity generation and salinity removal was influenced by initial substrate concentration in the anode chamber. The higher substrate concentration, the better performance of the MSC. The best performance of the MSC was achieved when the initial substrate was 2034 mg/L as COD, lead to a maximum voltage of 0.44 V, and maximum current density of 0.29 mA/m^2. With %CE was 5.4%. The maximum conductivity upsurge in salinity chamber was from 11.2 µS/cm to 1027 µS/cm (corresponding to salinity of 0.57% ppt).

1. INTRODUCTION

The fish processing industry generates liquid wastewater contains high organic matter and salinity (Lefebvre & Moletta, 2006). The conventional biological treatment is used to treat this type of wastewater (Aloui, Khoufi, Loukil, & Sayadi, 2009). However, some issues, such as high salinity, hindered the performance of the conventional technology. In order to treat and at the same time to utilized this wastewater into more sustainable way, the microbial salinity cell was introduced. The objective of this technology was to simultaneously remove organic material and to convert it into electricity and to remove salt in the wastewater. The similar mechanisms, Microbial Desalination Cell (MDC), also can harvest electricity and perform desalination at the same time (Gude, 2016; Kim & Logan, 2013; Lefebvre, Tan, Kharkwal, & Ng, 2012; Mehanna, Kiely, Call, & Logan, 2010). However, MDC can only be used for drinking water desalination, not for real high salinity wastewater. Therefore, for more applicable technology to treat high salinity wastewater, microbial salinity cell (MSC) system concept was introduced.

A Microbial Salinity Cell (MSC) system consists of three chambers, which are anode, salinity and cathode chamber. Between anode and salinity chamber, cation exchange membrane (CEM) is installed, and between salinity and cathode chamber, anion exchange membrane is installed. Anode chamber is filled with a high salinity

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substrate. When biofilm oxidize the substrate, the proton will drift to the salinity chamber, and the electron will transfer to the external circuit (producing currents). While in the cathode, negative ions will drift into the salinity chamber. The flow of ions will increase the conductivity in the salinity chamber.

This study aimed to identify the effect of substrate concentration on the performance of a Three chambers Microbial Salinity Cell (a three chambers MSC), using synthetic wastewater containing glucose.

2. METHODS

2.1 Reactor Configuration

A three chambers MFC system was built, consisting of anode, salinity chamber and cathode chamber (as shown in Figure 1). Each chamber was made of plexy glass bottle filled with solution of 200 ml. Both anode and cathode were made of aluminum wrapped with platinum on vulcan carbon cloth (fuellcellstore.com, USA). The anode had a working area of 63 cm^2. A Cation Exchange Membrane (CEM) (Nafion 117, Chemours, USA) was attached to separate anode and salinity chamber. An Anion Exchange Membrane (AEM) (Fumasep FAS-30, Fuma-tech, USA) was installed to separate salinity and cathode chamber. Platinum wires were mounted in the electrodes, used as current collectors. Temperature in the anode chamber was maintained at 37^0C using hot plate. The cathode chamber was continuously sparged with oxygen.

2.2 Inoculum and substrate

Inoculums were a mix cultures, generated from inactive Aerobic Granular Sludge (AGS) (Figure 2). Selective Pressure mechanism was done to ensure that mixed culture was dominated by *Geobacter sulfurreducens* species by doing inoculation in a sealed bottle with growth medium for specific *Geobacter sulfurreducens* (DSMZ medium No. 826, Germany) for 73 hours. The growth of the inoculum was monitored using Optical Density (OD 600) methods (Figure 2).

Anolyte was made of a mixture of substrate (glucose), 40 ml seed mix microorganisms, 140 ml *Geobacter sulfurreducens* (DSMZ medium No. 826, Germany), 10 ml trace element and 10 ml vitamin (which both referred to DSMZ medium 141, Germany). The addition of glucose was varied, the first phase was 201 mg/L (as COD) and the second phase was 2034 mg/L (as COD). Salinity (middle) chamber was filled with 200 ml demineralized water. Catholyte was consisted of 200 ml of phosphate buffer (50 mM).

2.3 Operational Condition

The Microbial Salinity Cell (MSC) was operated using glucose as substrate, with two different concentrations: 201.2 mg/L (known as 1^{st} stage) and 2034 mg/L (known as 2^{nd} stage), analysed as COD. In the first stage, 201.2 mg/L glucose was used as substrate. Initial conductivity in the anode chamber was 15.09 mS/cm and the experiment was run for 6 days. In the second stage, after the MSC solution from the first stage was emptied, anode chamber was filled with new glucose-medium with a concentration of 2034 mg/L, salinity was 11 mS/cm and the experiment was run for 7 days. The MSC experiment was run as batch mode. During the experiment, the salinity increase was monitored in the salinity chamber along with the current and voltage.

2.4 Analysis and Calculation

The current dan voltage was observed using a potentiostat (Digi-IVY, Model DY 2023) or sometimes using a voltmeter (Hantek, 365), and recorded for every 100 s. The COD was measured using standard methods and the conductivity was measured using a conductivity meter (TES-1381). The optical density $(OD)_{600}$ was measured by scanning absorbance using a spectrophotometer at 600 nm.

Coulombic Efficiency (%CE) is defined as the fraction of electrons transferred to the anode among the total electron, released by substrate oxidation. %CE was calculated as in (Min & Logan, 2004). Salinity has derived by converting the conductivity value into salinity (ppt).

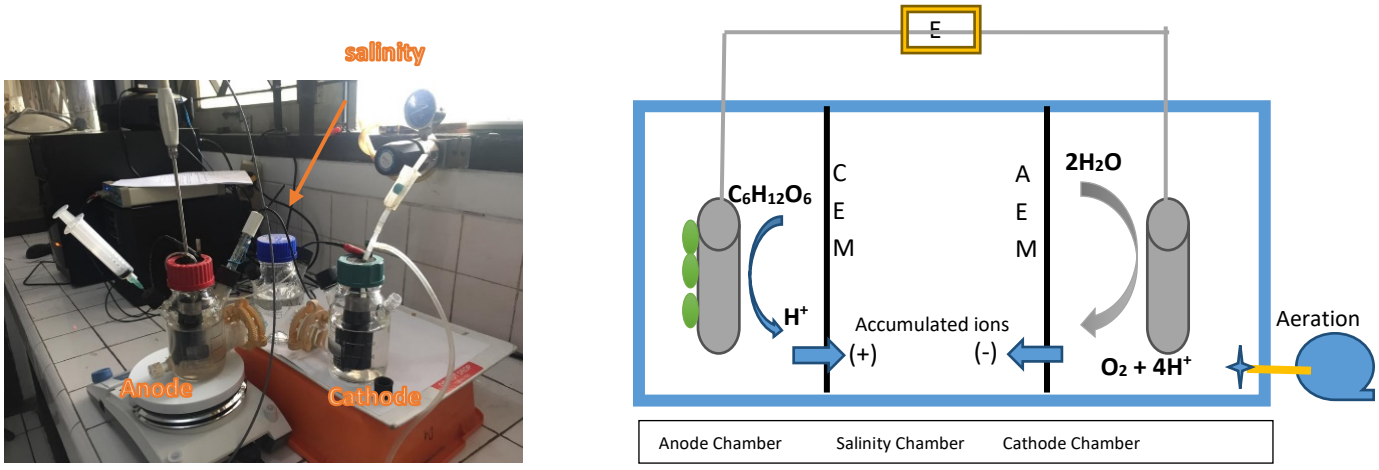

Figure 1. A reactor three chambers MSC (left) MSC scheme (right)

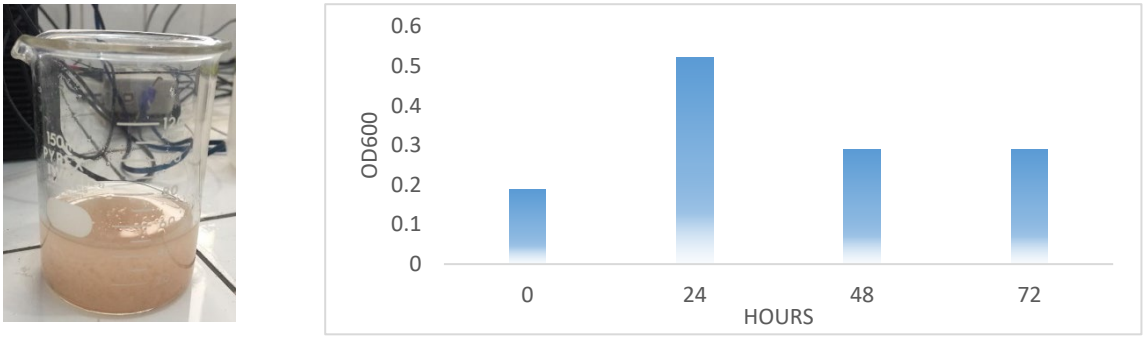

Figure 2. Inactive Aerobic Granular Sludge seed (left). Optical density of inoculum (at 72 h) before added to the MSC system (right).

3. RESULT AND DISCUSSION

3.1 MSC performance as a function of electricity generation: voltage and current response

In the first stage period, 201.2 mg/L glucose (concentration analysed as COD) was used as substrate. Initial conductivity in the anode chamber was 15.09 mS/cm and the experiment lasted for 5 days. The currents were recorded for every 100 s continuously for 6 days using a potentiometer (data were not shown), while voltage could only be recorded for 1 hour maximum because of technical limitation. The voltage profile only be recorded on day 1 and could not be recorded at day 6 because of the technical error from voltmeter, but judging from the currents data which did not show variation significantly, it also can be concluded that voltage will also do not variate significantly because normally currents were responded accordingly to voltage.

However, the Coulombic Efficiency (%CE) still can be calculated in this stage. Figure 3 shows the profile of voltage versus current density. Figure 3 shows that at the beginning, the voltage was 0.283 V and then dropped to 0.135 V while the currents could drop until 1.56×10^{-4} mA/m^2 but increase again for maximum 4.5×10^{-4} mA/m^2. The graph pattern (only for currents) keep repeated during 6 days observation using a potentiostat (data are not shown). And the maximum current density achieved during stage 1 was 4.5×10^{-4} mA/m^2, while the maximum voltage was 0.283 V. According to theoretical calculation using glucose as substrate, the maximum voltage reached in the system was 1.14V, thus in order to achieve the desirable voltage or current for practical purposes, the MSC should be stacked

(Aelterman, Rabaey, The Pham, Boon, & Verstraete, 2006). Compared to the theoretical calculation, the voltage and current produced in this study were still low, because of the wide distance between anode and cathode creates high over-potential of the system which inhibits the flows of the electron from anode to cathode (Fan, Hu, & Liu, 2007). Moreover, the low generation of both voltage and current (from Figure 3,4, and 5) can be also because of the energy that comes from the oxidation of glucose is used to drive the ions into salinity chamber rather than to produce electricity, the similar mechanism that also occurs in MDC system (Chen, Liang, Wei, Zhang, & Huang, 2012). To boost the capability of the anode to capture the electron from the system, polarization should be done. Unfortunately, because of the limitation of potentiostat model device, polarization was not possible to be done.

In the second stage, after the MSC solution from the first stage emptied, anode chamber was filled with new glucose-medium with concentration 2034 mg/L as COD, salinity was 11 mS/cm and experiment was run for 7 days. Because of the limitation ability of potentiometer to simultaneously measure current and voltage, for measuring voltage, another portable voltmeter was used (Hantex). Currents were continuously recorded for every 100 seconds, from day 1 to day 7 using a potentiometer (data are not all shown here). However, because the voltmeter could not observe currents for 24 hours continuously, the voltage was measured only for 1 hour at the beginning (day 1) and the ending of the cycle (day 7). Therefore, the data presented in Figure 4 and Figure 5 were data from day 1 and day 7 and only were measured for 1 hour, so that we could get a correlation between current and voltage.

Stage 2, with substrate concentration 2034 mg/L, at day 1 observation, the initial voltage was higher than at first stage. The maximum voltage was 0.44 V, with corresponding current density was 3.9 x 10^{-4} mA/m^2. However, the voltage then dropped at day 7 to a minimum of 0.15 but then raised again to 0.23 V, with corresponding current density was 0.29 mA/m^2. The average voltage during stage 2 was about 0.2 to 0.44 V, and the maximum current density was 0.29 mA/m^2 (in which 1000x higher than first stage). The rise of the current density and voltage was explainable, due to higher substrate concentration.

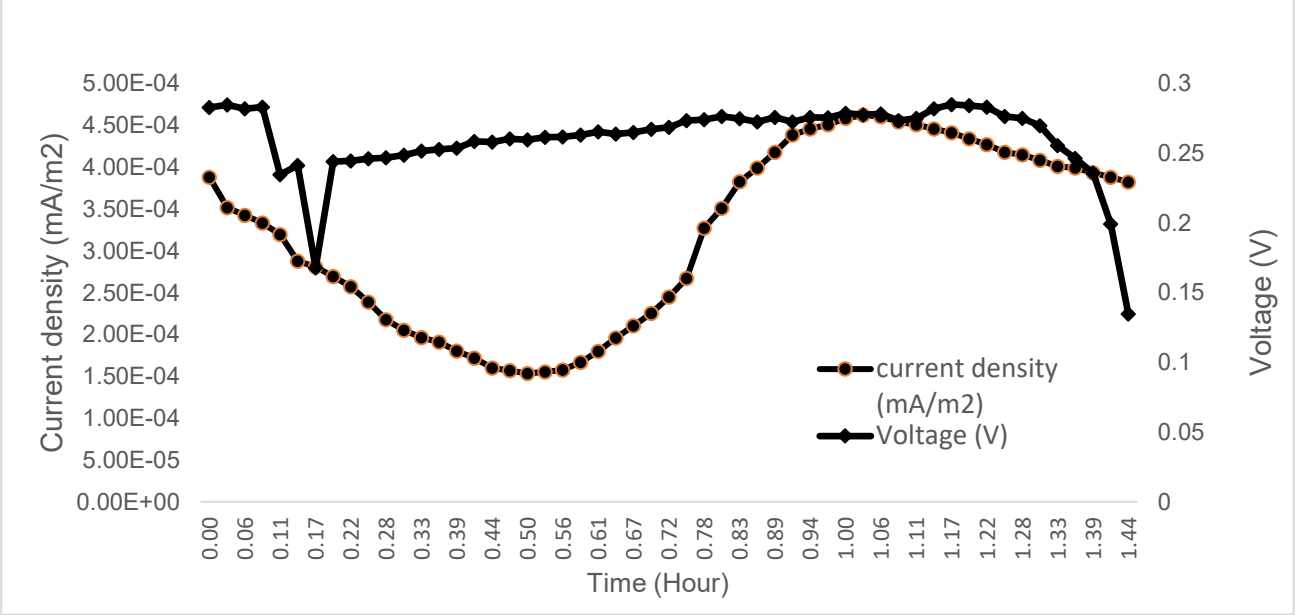

Figure 3. The voltage versus current density profile when the initial substrate concentration was 201.2 mg/L for day 1

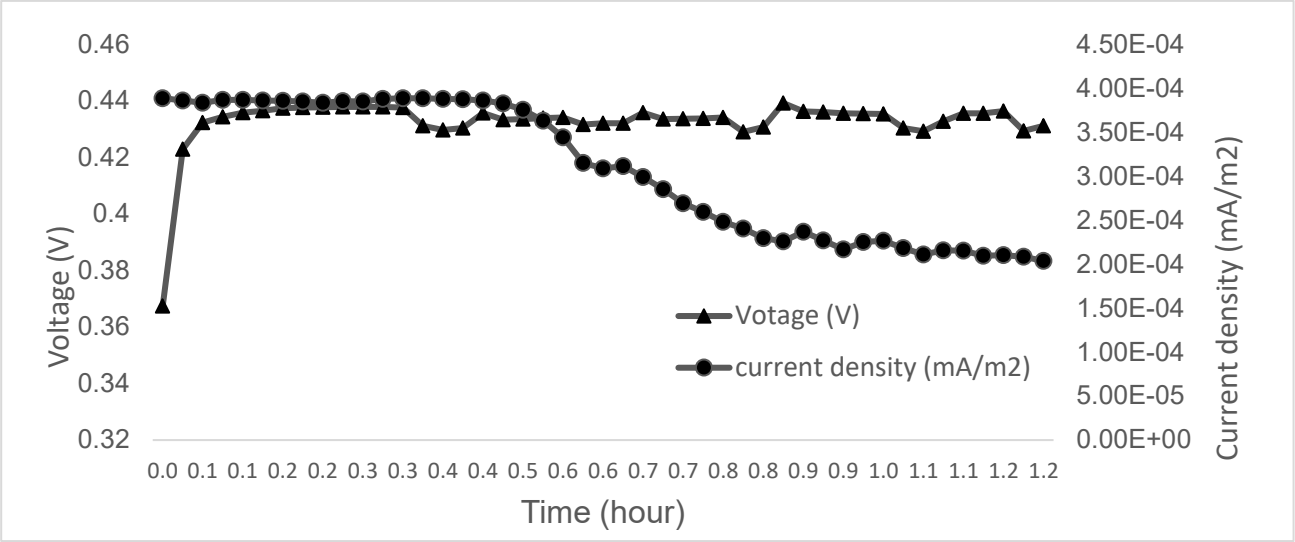

Figure 4. The voltage versus current density after MSC run for 1 day, when the initial substrate concentration 2034 mg/L (measured current and voltage continuously observed for 1 hour)

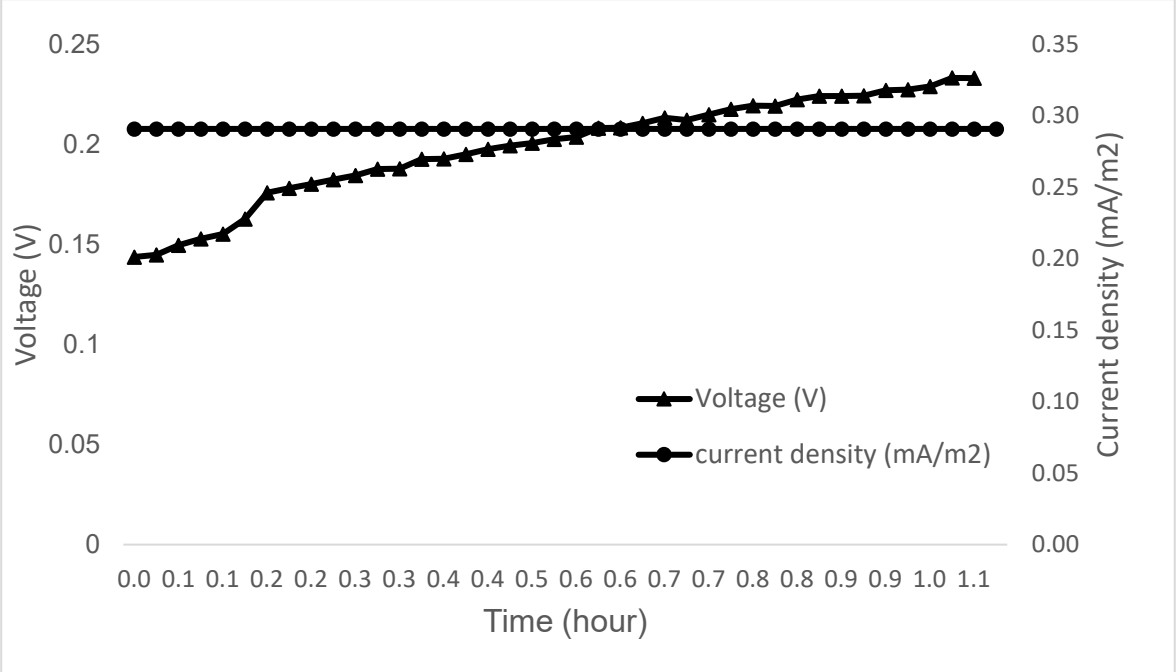

Figure 5. The voltage versus current density after MSC run for 7 day, with the initial substrate concentration 2034 mg/L (measured current and voltage continuously observed for 1 hour)

To measure the MSC performance, Coulombic Efficiency (written as %CE), was calculated as in Min & Logan, 2004. %CE was described as the ratio between electricity produced (as currents) versus substrate utilization (as COD). In stage 1, %CE was only 0.59% while in stage 2 %CE increased to 5.4%. These results showed that higher substrate concentration resulted in higher electricity produced per COD consumed. At low COD, the biofilm that consisted of different types of organisms compete for substrate (Jadhav & Ghangrekar, 2009). The heterotrophic

microorganisms that have faster growth will outcompete slow growth microorganisms (such as G. *sulfurreducence* or any electroactive microorganism) (Logan & Regan, 2006). The limited electron donor also affected the type of microorganism that growing in the anode chamber (Santoro, Arbizzani, Erable, & Ieropoulos, 2017).

3.2 MSC performance in terms of substrate utilization and increasing conductivity in salinity chamber

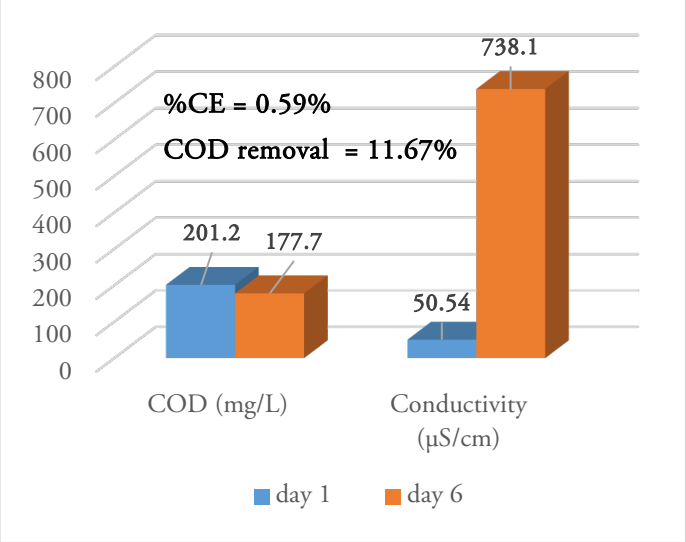

Figure 6. Substrate utilization versus conductivity increase in the first stage (when the initial substrate 201.2 mg/L)

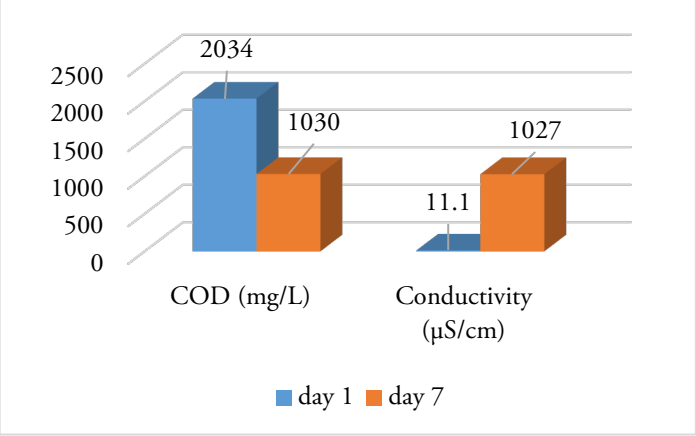

Figure 7. Substrate utilization versus conductivity increase in the second stage (when the initial substrate 2034 mg/L)

In this section, the effect of substrate utilization versus the amount of conductivity increase in the middle chamber was discussed. In stage 1, COD removal was 11.67% with corresponding conductivity increase in the salinity chamber was from 50.54 µS/cm to 738.1 µS/cm (equal to salinity = 0.36 ppt), and %CE was 0.59%. That means that the amount of substrate which can be converted into electricity was only 0.59%, the rest energy derived from the oxidation of organic substrate went for driving the ions from anode to salinity chamber, resulting in the increase of conductivity. In stage 2, COD removal was 49.36% with corresponding conductivity rise in the salinity chamber was from 11.2 µS/cm to 1027 µS/cm (salinity 0.57% ppt), and %CE was 5.4%. %CE gathered in this study was lower than (Zhang, Min, Huang, & Angelidaki, 2011), because of the relatively higher initial conductivity in the anode chamber that might be hindered microorganisms metabolism (Grattieri & Minteer, 2018). It can be concluded that the higher initial substrate concentration could lead to higher conductivity rise in the salinity chamber and the higher electricity generation. Higher COD means higher electron donor and energy, and could drive more salt ions from anode chamber into salinity chamber, and at the same time produce currents (Pant, Van Bogaert, Diels, & Vanbroekhoven, 2010).

4. CONCLUSION

This study showed that the performance of a three chambers Microbial Salinity Cell (MSC) was influenced by initial substrate concentration in the anode chamber. The best performance of MSC achieved when COD was 2034 mg/L, which simultaneously produced voltage of 0.44 V, current density of 0.29 mA/m^2 and %CE of 5.4%. Furthermore, conductivity concentration in the salinity chamber increased from 11.2 µS/cm to 1027 µS/cm (salinity 0.57% ppt). To improve the performance of MSC, anode polarization and shortened distance between anode and cathode should be done. For a more practical purpose of further full-scale application in order to achieve the desirable voltage or current, the MSC should be stacked.

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