International Journal of Technology (2015) 7: 1094-1100
ISSN 2086-9614

SEA WATER DESALINATION USING DEBARYOMYCES HANSENII WITH MICROBIAL DESALINATION CELL TECHNOLOGY

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(Received: June 2015 / Revised: September 2015 / Accepted: September 2015)

ABSTRACT

Desalination is a way to process sea water with a high salinity level, which makes water non-consumable. Various desalination technologies, such as distillation, vapor compression, and reverse osmosis, have been developed but require energy and large financial investments. Microbial desalination cell (MDC) is a modified desalination technology of a microbial fuel cell that can remove salt content in water with the help of microorganisms through organic matter degradation. This research used *Debaryomyces hansenii* to degrade organic material in the anode chamber. The ratio of the volume chamber, the volume ratio of culture:substrate, and the volume progression of the culture and substrate were evaluated in terms of salt removal and electricity generation. This research shows that MDC using a 9:1:9 ratio of the volume chamber, a culture:substrate ratio of 2:3 (v/v), and a volume progression of the culture and substrate of 1.5 times gave the best desalination performance: a salt removal level of 55.03%.

Keywords: *Debaryomyces hansenii*; Desalination; Microbial Desalination Cell; Salt removal; Single culture

1. INTRODUCTION

Water is a basic requirement for all living things. The water crisis is a global problem and frequently occurs in Indonesia. The demand for water in Indonesia is currently met using many resources, such as surface water and groundwater. Population growth and economic growth, however, will lead to an increase in the demand for water. In addition, the excessive use of groundwater can negatively impact resources and the environment.

The ocean that Indonesian owned has reached 5.8 million km^2 in volume and has the potential to be used as fresh water so as to fulfill the water demand in Indonesia. Desalination is a process where sea water with a high salinity level becomes fresh water that can be consumed. The process of desalination has been performed using reverse osmosis technology, multistage flash distillation, and vapor compression; energy is required to carry out the process using these technologies (Kim & Logan, 2013).

Microbial desalination cell (MDC) is an alternative process for completing desalination effectively. The MDC process can reduce the salt content in water with the help of microorganisms; this process takes place without the need for energy input. The MDC device consists of three rooms separated by an anion-exchange membrane on the anode side, a cation exchange membrane on the cathode side, and a chamber for the saline solution between the

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Permalink/DOI: http://dx.doi.org/10.14716/ijtech.v6i7.1368

membranes (Cao et al., 2009).

In this study, the osmotolerant yeast *Debaryomycess hansenii* was used as a microorganism to degrade organic material in the anode chamber. The ratio of the volume chamber, the volume ratio of culture:substrate, and the volume progression of the culture and substrate were used as a parameter to be examined.

2. METHODOLOGY

2.1. MDC Design

The MDC reactor consists of three chambers that are arranged in the following order: the anode chamber, salt chamber, and cathode chamber, respectively. The membrane AEM (AMI-7001, Membrane International, Inc.) was inserted between the anode chamber and salt chamber, and CEM (CMI-7000, Membrane International, Inc.) was inserted between the salt chamber and cathode chamber. Three pairs of graphite rod electrodes that came from the battery were arranged with 10 Ω cable barriers. Preparation of the membranes and electrode was conducted through soaking the membrane in a solution of NaCl at a temperature of 40^{o}C for 24 hours and soaking the electrode in a solution of HCl, NaOH, and aquadest. The anode chamber was filled with *Debaryomyces hansenii*, a glucose substrate, and a phosphate buffer. The desalination chamber was filled with NaCl 30 g/L or sea water, and the cathode chamber was filled with an electrolyte and phosphate buffer.

Reactor A (Figure 1) has a volume ratio of 500 mL: 250 mL: 500 mL, and reactor B has a volume ratio of 1800 mL: 200 mL: 1800 mL. The anode chamber was filled with a culture of *Debaryomyces hansenii*, a glucose substrate, and a phosphate buffer; the desalination chamber was filled with NaCl 30 g/L or sea water; and the cathode chamber was filled with an electrolyte $KMnO_4$ and phosphate buffer. A single cycle of the reactor lasted for 25 hours and reactor B for 40 hours. The initial pH in the anode chamber was 6.5 and the cathode chamber pH 7.

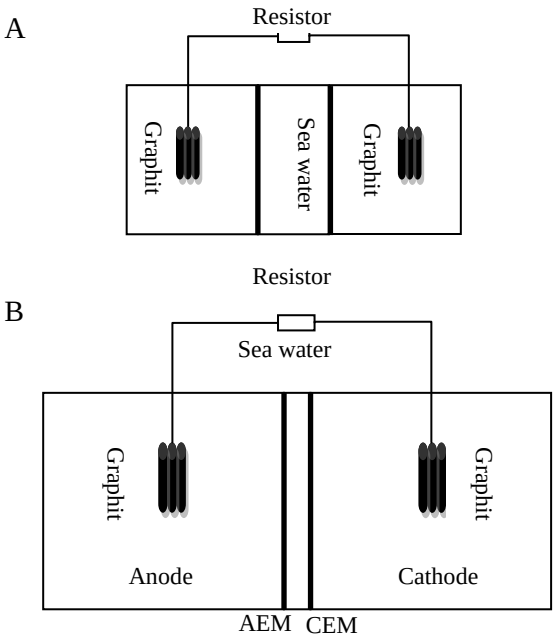

Figure 1 Design of MDC

2.2. Analysis

Electricity generation was measured using a wireless multimeter. The pH in the anode and cathode chambers was measured using a pH meter at the beginning and at the end of each cycle.

The reduction of salt / salt removal was tested using a conductivity meter every hour. Salt removal (SR) expressed as a percentage of the number of moles of salt that were removed compared to the initial moles of salt is indicated in Equation 1 (Jacobson et al., 2011).

$$SR = \frac{(n_o - n_i)}{n_o} \times 100\% \quad (1)$$

where *SR* is the salt removal (% mol), n_o is the initial moles of salt (g/L), n_i is the moles of salt after desalination (g/L).

Power density expressed as the amount of electricity generation per unit volume of substrate is shown in Equation 2.

$$Power\ Density = \frac{i^2.R}{V} \quad (2)$$

where *Power Density* is in unit of W/m^3, *i* is the electrical currents (A), *R* is the electrical resistant (Ohm), and *V* is the anode chamber volume (m^3).

3. RESULTS AND DISCUSSION

3.1. Desalination Performance in 2:1:2 Ratio of Volume Chamber with Variation of Volume Ratio of Culture:Substrate

The volume ratio of culture:substrate in this study varied among 2:1, 1:1, and 2:3 on the basis of a 100 mL culture volume. The data obtained is shown in Figure 2. From Figure 2, it can be seen that *Debaryomyces hansenii* had the ability to reduce the salinity. At hours 0 to 5, the salt removal profiles of the three variations coincided. In the following hours, the salt removal level continued to increase but in a different order, namely 2:1, 1:1, and 2:3. It can be concluded that the culture:substrate ratio of 2:3 was the variation that achieved the highest level of salt removal, reaching 29.17% at the 25th hour. The desalination rate in this experiment depended on the activities that microorganisms performed in the anode chamber. After the 15th hour, the salt removal level significantly increased due to the microorganism's reaching its acclimation period.

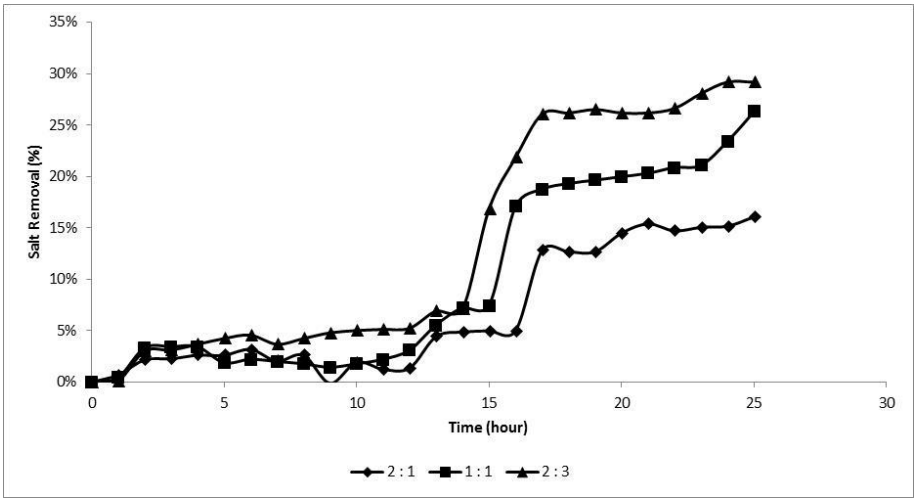

Figure 2 Salt removal for MDC with 2:1:2 ratio of volume chamber with variation of volume ratio of culture:substrate

In previous studies, including Kartiko (2013), the performance of the desalination process using *Saccharomyces cereviseae* led to 30.47% salt removal at the 120th hour. If salt removal by both microorganisms is compared, *Debaryomyces hansenii* has an advantage, with salt removal reaching 29.17%, while Saccharomyces cereviseae generated about 14% salt removal at the 25th hour. This may be the result of the characteristics differing between the two yeasts; *Debaryomycess hansenii* has a higher level of resistance to high salinity compared to *Saccharomyces cereviseae* (Breuer & Harms, 2006).

In the process of desalination, organic matter in the anode chamber was degraded by microorganisms, and in line with this, electrons were generated from the anode chamber and flowed into the cathode chamber. Cations and anions in the salt chamber migrated into the anode and cathode chambers due to a difference in potential between the anode and cathode chambers (Betts, 2009). Electricity was generated during the 25-hour desalination process in a 2:1:2 MDC chamber and 2:3 volume ratio of culture:substrate, with an average power density 7.4 mW/m^3.

3.2. Desalination Performance in 9:1:9 Ratio of Volume Chamber with Variation of Volume Ratio of Culture:Substrate

Figure 3 showed an increase in salt removal by all variations. The results show that the variations of the culture:substrate volume ratio of 2:1, 1:1, and 2:3, respectively, reached salt removal levels of 31.8%, 33.5%, and 50% at the 40th hour. The patterns are similar for all of the culture : substrate volume ratios of 2:1, 1:1, 2:3. This happened because of the availability of substrate for the microorganisms. At the ratio of 2:3, the salt removal level was seen increasing due to the amount of available substrate that still met the microorganisms' needs.

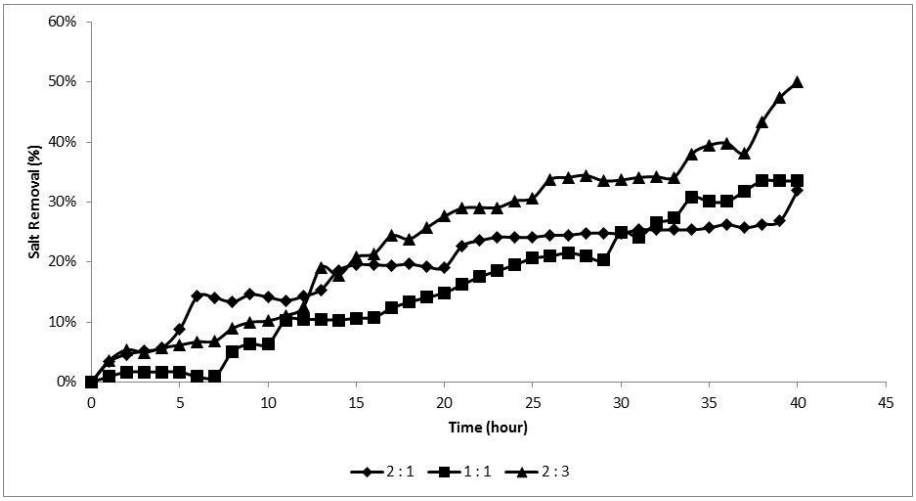

Figure 3 Salt removal for MDC with 9:1:9 ratio of volume chamber with variation of volume ratio of culture:substrate

In comparing the performance between the volume chamber ratios of 2:1:2 and 9:1:9 at the 25th hour, it can be seen that the volume chamber ratio of 2:1:2, along with the culture:substrate ratio of 2:3, reached 29.17%, while in the other chamber ratio reached 30.64%. The increased performance was due to the increased desalination volume of the anode and cathode to nine times the salt chamber volume. This can occur because a greater number of microorganisms and substrates results in greater energy and therefore will also affect the desalination process.

Kim and Logan (2013) said that the high salt removal level requires a large volume of solution in the anode and cathode chambers. In addition, the improved performance of the chamber with

the volume chamber ratio of 9:1:9 is caused by the expansion of the membrane surface area. A large membrane surface area will increase the transport of ions and also salt removal (Cao, 2009). The average electricity generation in the 9:1:9 MDC chamber during 40 hours of operation reached 4.6 mW/m^3.

3.3. Desalination Performance in 9:1:9 Ratio of Volume Chamber with Variation of Volume Progression of Culture and Substrate

In this experiment, each culture and substrate volume increase was accompanied by a decrease in the volume of the buffer used. This experiment aimed to determine the optimal buffer volumes to be used. From Figure 4 below, it can be seen that at the beginning of the desalination process with a two times volume progression of the culture and substrate, a reduction of the salt levels occurred very quickly at about -0 hours up to -5 hours. However, in the next few hours, a decrease in the salinity of this variation tended to take place slowly.

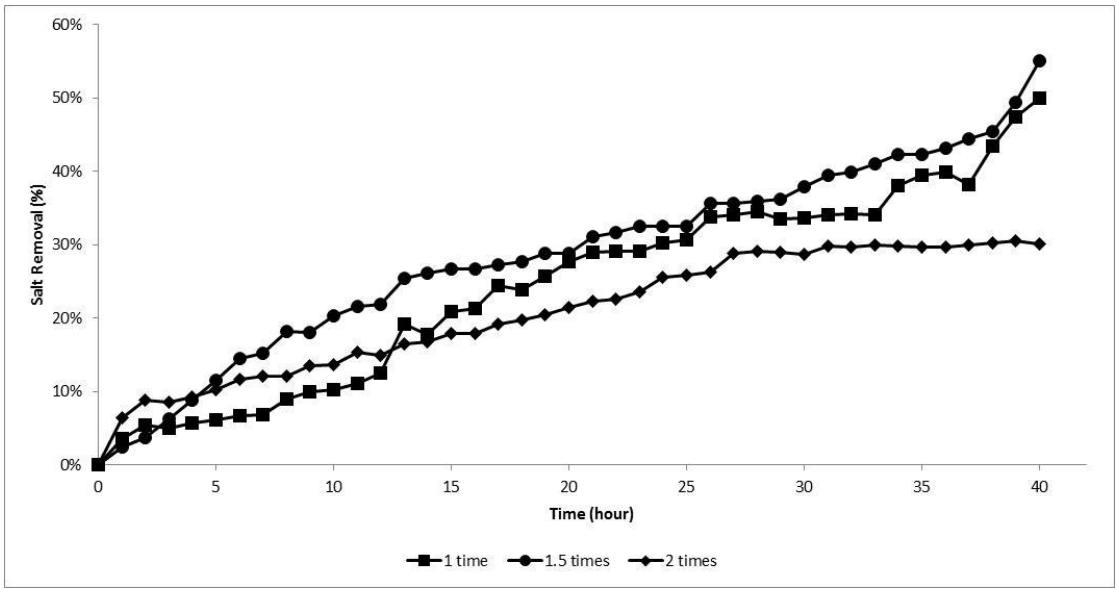

Figure 4 Salt removal for MDC with 9:1:9 ratio of volume chamber with variation of volume progression of culture and substrate

By contrast, with a 1.5 times volume progression, there was no significant decrease in the salt levels at the beginning, but the decrease in salinity lasted until the 40th hour. The variation of the 1.5 times volume progression of the culture and substrate had the highest salt removal level, which reached 55.03%, even when the volume of the culture and substrate was used more than the volume of the buffer solution was, but the pH could still be maintained at the required level. Electricity generation in this experiment had a higher voltage than the previous one did. This was due to the increase in the volume of the culture and substrate in the anode chamber, which caused the electrical energy produced to be greater, as the organic matter degradation conducted by the microorganisms was greater, reaching 70.9 mW/m^3.

3.4. Desalination Performance in 9:1:9 Ratio of Volume Chamber using Sea Water as Desalinated Water

This experiment was carried out using sea water as the solution to be desalinated. In previous experiments involving the variation of the volume ratio of culture:substrate and the volume progression of the culture and substrate, it was concluded that the best performance of desalination occurred with the volume ratio of culture : substrate of 2:3 along with a two times

volume progression of the culture and substrate. Both conditions were used to desalinate sea water and obtained the results shown in Figure 5.

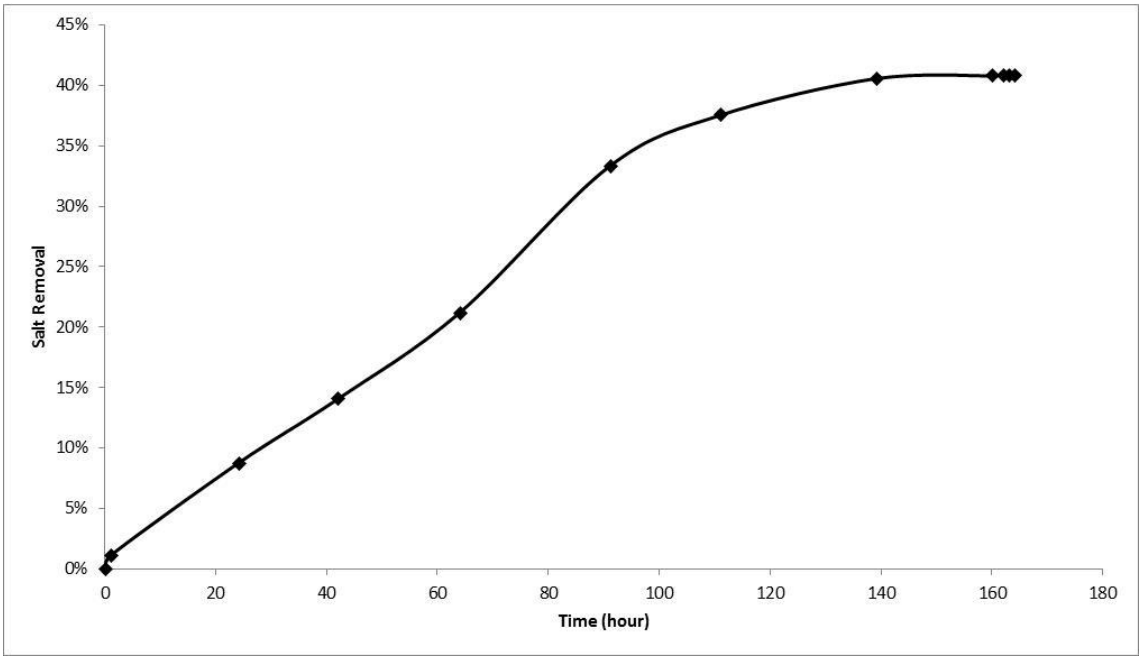

Figure 5 Salt removal of sea water in 9:1:9 MDC with ratio of culture:substrate 2:3 (v/v) and two times Volume Progression of Culture and Substrate

The experiment was conducted for 164 hours; the salt removal level achieved was 40.79%, with a salinity of 16.3 g/L, and average electricity generation went up to 488mW/m^3. The difference between the desalination performance associated with the NaCl solution as the seawater model and the original seawater was very influential on the outcome of desalination. This difference may have occurred because seawater contains many impurities and ions, not only Na^+ and Cl^- but also SO_4^{2-}, Ca^{2+}, Mg^{2+}, and F^-. According to WHO (World Health Organization), the maximum concentration of Na^+ ions in drinking water is 200 mg/L, and the maximum concentration of Cl- ions is 250 mg/L. Desalinated sea water cannot yet be equated to fresh water; in other words, further stages are required to reduce salinity.

3.5. pH Changes

In all variations in the experiment, a decrease in pH in the anode chamber was found, while the pH in the cathode chamber was relatively constant. This phenomenon is related to the changes in the pH buffer limits in maintaining the pH. During the desalination process, the change in pH in the anode chamber tended to decrease in association with the accumulation of protons during the production of electricity (Ren, 2006; Widdel, 2011). Cl^- migrated into the anode chamber so as to form hydrochloric acid (HCl), so the pH declined. In the cathode chamber, the hydroxyl ions formed as a result of the cathode reaction, such as oxygen reduction or hydrogen evolution (Kim & Logan, 2013).

4. CONCLUSION

MDC using a single culture of *Debaryomyces hansenii* proved to have better performance compared with desalination using *Saccharomyces cereviseae*. The highest salt removal level of 55.03% was achieved with the volume chamber ratio of 9:1:9, the volume ratio of culture:substrate of 2:3, and 1.5 times volume progression of the culture and substrate. The

MDC system using seawater as the desalination solution resulted in 40.79% salt removal in 164 hours.

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