Yeast fuel cell: Application for desalination

Ummy Mardiana¹²³*, Christophe Innocent¹, Marc Cretin¹, Buchari Buchari² and Suryo Gandasasmita²

¹Institut Européen des Membranes, ENSCM-UM2-CNRS, (UMR 5635), Université de Montpellier 2, CC047, place E. Bataillon, 34293 Montpellier Cedex 5, France
²Institut Teknologi Bandung, Jalan Ganesha 10 Bandung, West of Java Indonesia 40132
³STIKes Bakti Tunas Husada Tasikmalaya, Jalan Cilolohan 36 Tasikmalaya, West of Java Indonesia 46115

*E-mail: mardiana.ramdan@gmail.com

Abstract. Yeasts have been implicated in microbial fuel cells as biocatalysts because they are non-pathogenic organisms, easily handled and robust with a good tolerance in different environmental conditions. Here we investigated baker’s yeast Saccharomyces cerevisiae through the oxidation of glucose. Yeast was used in the anolyte, to transfer electrons to the anode in the presence of methylene blue as mediator whereas K₃Fe(CN)₆ was used as an electron acceptor for the reduction reaction in the catholyte. Power production with biofuel cell was coupled with a desalination process. The maximum current density produced by the cell was 88 mA.m⁻². In those conditions, it was found that concentration of salt was removed 64% from initial 0.6 M after 1-month operation. This result proves that yeast fuel cells can be used to remove salt through electrically driven membrane processes and demonstrated that could be applied for energy production and desalination. Further developments are in progress to improve power output to make yeast fuel cells applicable for water treatment.

1. Introduction

Current research on energy production has been intensively developed. Microbial fuel cells (MFCs) are a new opportunity for the sustainable production of energy by converting chemical energy to electrical energy by biodegradation using microorganisms as biocatalysts [1–3]. MFCs have advantages as easy to operate without needing a complicated instrument, efficient at ambient or even at low temperature [4] without requiring energy input. In MFCs, microorganisms oxidize organic compounds and produce electrons at the anode, passing through the external circuit to the cathode where the final electron acceptor is reduced. Power density can be produced with various organic compounds such as acetate [3], glucose, sucrose and fructose [5]. Electron mediators such as methylene blue, neutral red are sometimes needed to transfer electrons from microorganism to anode[6–8] although applying mediator-less MFC The have also been studied [9–13]. Modified electrodes have been also carried out [10,14–16]. Some microorganisms have been implied in MFC. The use of Saccharomyces cerevisiae [9,17,18], Candida melibiose [5] and Arxula adeninivorans [19] as microorganisms have been also investigated.

Biocatalyst in the anodic chamber has an important role in cell performance. The mechanisms of electron transfer can take place directly, mediated or endogenous (i.e. mediator produced by bacteria
themselves). It is known that many prokaryotic microorganisms could utilize oxygen environment for their growth through respiratory pathways in aerobic conditions and fermentation pathways in anaerobic conditions. Yeast can grow in both environments, is easily activated by hydrating or temperature, inexpensive, does not need sterile conditions because good tolerances in different environmental conditions and hence could be stored in the dry state [14].

In our configuration work, a two compartments MFC was constructed with graphite electrode as an anode, and nickel as a cathode. Anode compartment contained the yeast *Saccharomyces cerevisiae*, methylene blue as a mediator as previously designed [7,8] and glucose in phosphate buffer pH 7 as an oxidizer. Methylene blue is first reduced in the outer cell membrane of yeast. The reduced form of mediator captured electrons to the anode, producing electricity and re-oxidizing the mediator. The other half-cell (i.e. cathodic compartment) contained potassium ferricyanide, which receives the electrons from the external circuit and becomes reduced. The presence of oxygen in catholyte will oxidize Fe$^{2+}$ to Fe$^{3+}$ which causes a cyclic reaction. It is to notice that ferricyanide more favorable as electron acceptor than oxygen because this latter will diffuse through the membrane to the anode compartment to oxidize methylene blue before process transport to the anode [14]. Nafion® was used as proton exchange membrane, because of its high ionic conductivity [7].

Recently microbial fuel cell was implicated to be one of promising biotechnology for desalination and wastewater treatment [20–27]. The electrical potential gradient is produced by exoelectrogenic bacteria by driving force of ion transport through an ion exchange membrane.

In the first part, we developed here a microbial fuel cell (MFC) to produce electricity from baker’s yeast, *Saccharomyces cerevisiae*. The construction of biofuel cell is simple and is available quickly, without conditioning time, unlike microbial biofuel cell based on electroactive biofilm. In a second part, the concept was applied to desalination in an electrodialysis based cell. Simultaneously, we demonstrated that yeast fuel cell can serve as a viable option for integrated energy production and removed salt ion through desalination.

Yeast-based fuel cells have attracted the attention and interest of researchers although they deliver a lower power output than bacterial fuel cell but several studies have reported that by electrodes modification [28,29] or optimization of mediator i.e. methylene blue [7], methyl orange and methyl red [30,31], the performances of the biocatalytic systems could improve. As described previously, referring to the nature of yeast as a simple biocatalyst and does not require specific condition then we utilize their activities for energy production and followed for application in desalination.

Nowadays some research based on desalination have been developed [32–34]. The use of microbial desalination cell (MDC) represents a new approach for desalination. Some operational condition and the reactor design have varied widely, but the use of yeast as a biocatalyst is a new application. Yeast fuel cell has a great potential for desalination as a low-cost desalination process with significant environmental benefits. Therefore, it is evidence that some studies should be studied intensively to investigate this novel process and to enhance the performance of yeast fuel cell and desalination process.

MDC have recently drawn attention as a low-energy method of water desalination. The simplest MDC is a microbial fuel cell (MFC) that is modified to contain a middle chamber for desalination, by using two ion exchange membranes between the anode and cathode chamber [35]. In the anode chamber, organic matter is oxidized by a microorganism, with the electrons released by the circuit and protons into solution. Electrons from the anode flow to the cathode where they combine with protons and oxygen to form water [36, 37]. The production of protons at the anode and consumption of protons at the cathode drives desalination of saltwater in the dilute chamber, as salt ions in the saline water in the middle chamber (i.e. dilute chamber) migrate through the cation and anion exchange membranes to balance charge [38]. As a result, the desalination process in an MDC does not require external energy input for driving in separation like that in conventional electrodialysis, thereby exhibiting significant energy benefits.

We propose here a new method of desalination process through microbial fuel cell with baker’s yeast as a biocatalyst. For that, four-compartment desalination cell has been compiled consist anode
chamber, concentrate, dilute and cathode chamber as illustrated in figure 2. The current is generated at the anode by baker’s yeast, and protons are migration through CEM. Therefore, the negatively charged species move from the dilute compartment into concentrate compartment. Positively charged species moved from the dilute compartment through CEM and will react with ferricyanide ion in the cathode compartment. This loss of ionic species from the dilute compartment through concentrate and cathode results in water desalination without external electrical energy supply.

We have been tested several conditions to optimize current and power density of the MFC. The experiments have been focused on the effect of yeast preparation, the behavior of mediator, temperature, and yeast stability. We can achieve two goals as simultaneously; the energy production and the desalination. In our present work, we demonstrated the challenges of yeast as a biocatalyst for practical application of MDC as a sustainable method for water desalination.

2. Material and methods

2.1. Preparation of yeast

A protocol of preparation for *Saccharomyces cerevisiae* has been used as previously designed [39]. It consists of preparing a slurry of 2 g. dried yeast, 1.8 g. peptone (Sigma-Aldrich, France), 1.5 g. dextrose (Sigma-Aldrich, France) and 1 g. malt extract (Sigma-Aldrich, France). The mixture is cultivated for 24h at 30°C in 50 mL phosphate buffer pH 7. Cells were harvested by centrifugation at 5000 rpm for 5 min., washed twice in phosphate buffer pH 7 and then re-suspended in phosphate buffer, and then kept at 4°C as stored cell, and activated at 40°C, 30 min. prior to use in MFC.

2.2. MFC architecture and experimental procedure

The fuel cells were constituted of anode and cathode compartments separated by Nafion® 117 (Dupont, USA) as proton exchange membrane. The Nafion® membrane was pretreated by boiling the film in H₂O₂ (30%), then washing in deionized water and 0.5 M H₂SO₄, each 1h and stored in deionized water until use. A schematic of the MFC system is shown in figure 1.

---

**Figure 1.** Scheme of yeast fuel cell system.
A two compartment fuel cell similar to one design by Walker [14] was constructed with graphite electrodes separated by a proton conducting membrane. One-half of the cell contained yeast, *Saccharomyces cerevisiae*, glucose and an electron mediator. The oxidation-reduction mediator enters the outer cell membrane and becomes reduced, then leaves in the reduced state. The reduced mediator transfers the captured electrons to an electrode, producing an electric current and re-oxidizing the mediator. The other half of the cell contained an electron acceptor, potassium ferricyanide as observed in a previous study [8, 40] which accepts the electrons from the circuit and becomes reduced. Oxygen in catholyte will oxidize Fe$^{2+}$ back to Fe$^{3+}$. Ferricyanide was preferred as the electron acceptor over an oxygen-saturated solution because we did not want significant oxygen diffusion through the membrane into the anode compartment where it would oxidize the methylene blue before the methylene blue could transfer electrons to the electrode.

The observations have been made using Chronoamperometry and MFC. Chronoamperometry was carried out for 24 hours using graphite as the working electrode, platinum as a counter electrode and saturated calomel electrode (SCE) as a reference electrode. While, the MFC has run for several days and current generated were recorded using a multimeter Voltcraft model VC 850.

The desalination systems displayed in figure 2 was designed a cubic-shaped MFC and similar construction in previous study [41]. The device consists of a four compartments system, with a cation exchange membrane (CEM) next to the anode, an anion exchange membrane (AEM) separating concentrate and dilute compartments and a CEM next to the cathode. The addition of glucose was monitored to prevent the declining value of current. The inside volumes of each compartment were 80 mL. In anode compartment consist of yeast, mediator and glucose 0.1M. meanwhile, the concentrate and dilute compartment contain KNO$_3$ 0.5 M and sea water, respectively. K$_3$Fe(CN)$_6$ 0.02 M in cathode compartment as electron acceptor.

![Figure 2. Scheme of yeast fuel cell system for desalination. (CEM: cation exchange membrane, AEM: anion exchange membrane, Mediator used was methylene blue).](image)

The external resistance of the device (figure 2) was fixed at 1kΩ [7]. All desalination process was operated at ambient temperature (25±1°C). The voltage (E) in desalination process was recorded using...
a digital multimeter Voltcraft model VC 850 and the current (I) generated was determined from the equation $I = E/R$. 2 mL of dilute and concentrate solution have been taken for the measurement of salt concentration by ionic chromatography (DIONEX ICS 900 for cation and DIONEX ICS 1000 for anion).

2.2.1. Electrodes and membrane preparation. Carbon graphite (7x1.5x 0.5cm) and nickel (7x1.5x 0.2cm) were used as anode and cathode material respectively. Previously washed in 1M HCl for 48h then rinsed with ultrapure water to clean from trash material. Nafion® membrane was cleaned in 0.5 M HNO$_3$ for 24h and kept in ultrapure water prior used.

2.2.2. Anodic and cathodic solutions. The MFC anode chamber was fed with glucose monohydrate (Sigma-Aldrich, France) 0.1 M, yeast 2 g/100 mL, methylene blue (Sigma-Aldrich, France) 0.1mM in phosphate buffer pH 7. The phosphate buffer (PB) was obtained from 4.08 g Na$_2$HPO$_4$ (Sigma-Aldrich, France) and 3.28 g NaH$_2$PO$_4$ (Sigma-Aldrich, France) dissolved in 1L ultrapure water. The cathode compartment contained potassium ferricyanide (PF) (Sigma-Aldrich, France) 0.02 M in phosphate buffer pH 7. Dilute and concentrate compartments consist of sea water from Palavas beach Montpellier, France and KNO$_3$ (Sigma-Aldrich, France) 1M.

2.3. Desalination process
The kinetics of transport through the membrane was described as a first-order reaction in saltness concentration as described in equation (1)[42]:

$$\ln(C/C_0) = -kt$$

(1)

where $C$ is the salt ion concentration at some given time in the concentrate compartment, $C_0$ the initial concentration of a salt ion in the dilute compartment, $k$ is the rate constant (s$^{-1}$), and $t$ is the time of transport (s). values were calculated from the plot of $\ln(C/C_0)$ vs time. The relation of $(C/C_0)$ vs time was linear. The permeability coefficient ($P$) was measured as equation (2).

$$P = \frac{V}{A}k$$

(2)

Where $V$ (L) is the volume of the solution in the compartment and $A$ (m$^2$) is an area of the effective membrane. The initial flux ($J_i$) were defined as equation (3).

$$J_i = PC_o$$

(3)

The percentage of salt ion transported was determined according to equation (4).

$$\% \text{ Transport} = \frac{[C(t)]}{[C_0]} \times 100\%$$

(4)

3. Result and discussion

3.1. Preparation of yeast
The aim of the yeast preparation is its activation. The effect of yeast preparation on current response after one day of running is shown in figure 3. The current density generated after yeast preparation is higher than without preparation because of yeast growth. Yeast growth leads then to higher output current because of the increase in the quantity of glucose molecules oxidized. The Observations have also been conducted in MFC after performed during 6 days.
In the case of yeast preparation, malt extract and peptone influence the activation of the yeast. The metabolism is also more efficient, and oxidation of glucose starts quickly.

3.2. Determination amount of yeast.

The plate count is one of the most accurate means of enumeration of viable microbes because we get a visual indicator for every cell in the specimen. The technique stems from Robert Koch's insight gained from viewing colonies growing on the surface of a spoiling slice of potato. In practice, a small aliquot of a liquid suspension of microbes is spread on the surface of solidified nutrient medium, which when incubated, leads to each cell 'developing' into a visible colony through repeated fission. By counting the number of colonies that grow on a sterile agar plate, one can determine the number of yeast cells in a packet of yeast. However, there are too many yeast cells to count them so they must first be diluted. In a serial dilution, aliquots of some solution are diluted stepwise such that the first dilution serves as the source from which an aliquot is taken for the second dilution, etc. In this experimental part, the total plate count (TPC) of yeast has been calculated, and it was \(3.10^7\) /gr-cc. Meanwhile, the number of colonies on the control plate is used to reduce the amount of the dilution plate is a force multiplied by the dilution to obtain the amount of yeast per gram/cc. The number of colonies control plate must not be more than 5. This method is used only to calculate the amount of live yeast.

3.3. The behavior and toxicity of mediator

In Baker’s yeast-based fuel cells, exogenous mediators are a necessity since \(S.\ cerevisiae\) is not known to produce such mediators indigenously. To improve the efficiency of the mediated electron transport from the microorganism to the anode and thus to enhance the generated power, methylene blue and neutral red have been selected as an artificial mediator as described in the previous study[6,43]. In this section, the mediator has been made in suspension solution of PB p\(H\) 7 with a concentration of 10mM, respectively. It has been reported that power delivered as a function of mediator applied 29.8 mW from methylene blue and 30.4 mW from neutral red respectively. Results show that both methylene blue and neutral red did not have significant differences. They can be accepted and applied in MFC based \(Saccharomyces\ cerevisiae\). Both methylene blue and neutral red could soluble and chemically stable in the anolyte and have all these requirements and also applicable for yeast species. As studied previously by Babanova [6], methylene blue and neutral red
have resulted in a good performed when applied in MFC based yeast *Candida melibiosica*. It is suggested that the redox potential of methylene blue and neutral red has than closer to NADH/NAD$^+$ (-0.320 V vs.NHE) while another artificial mediator such as methylene green, methyl orange, and methyl red is not so. Taking this, we presumed that the compounds with a potential redox closer to the NADH/NAD$^+$ potential could take an electron from NADH.

As a good mediator, the artificial mediator must be electrochemically active, must easily penetrate the cell membrane and the kinetic of the oxidation process at the electrode and non-toxic to the microorganisms. For that purpose, we analyzed cytotoxicity for methylene blue and neutral red as mediators. Sterile filter paper disks were soaked with 1 mM and 10 mM solutions of mediators. Then, they were placed in contact with a constant amount of *Saccharomyces cerevisiae* in a monolayer on agar medium and incubated at 28°C for 24 hours (Kirby-Bauer’ disc agar diffusion test)[44]. Results show that the absence of zones of inhibition around the samples suggested biocompatibility of the compound studied (*i.e.* methylene blue and neutral red), and they can be applied in yeast-based fuel cell.

### 3.4. The influence of temperature

The influence of temperature on MFC is presented in figure 4. The observation has been done after operating during 7 days. The optimal temperature was 40°C. Average power density increased from 1.20 mW.m$^{-2}$ at ambient temperature to about 2.44 mW.m$^{-2}$ at 30°C and reached 4.75 mW.m$^{-2}$ at 40°C. At 50°C, the average power density is only 2.32 mW.m$^{-2}$

![Figure 4. Power density mW.m$^{-2}$ generated by the MFC as a function of temperature.](image)

Yeast is a microorganism which their activity could affect, one of them is by temperature. Results confirm that one of the factors of the microorganism growth is temperature. The optimal value has been achieved at 40°C. If the system applied at the higher temperature, it could cause the damage of microorganism viability and as a consequently the MFC process will be disrupted. This has been evidenced by operating MFC at 50°C; power density has been reduced by 51%.

### 3.5. Power stability

The stability of the power delivered by the MFC was determined by chronoamperometry at 0.3 V vs. SCE over three weeks and displayed in figure 5.
This experiment has been carried out in the batch model, without refreshment of *Saccharomyces cerevisiae*. The addition of glucose was done at the beginning of each week as a source of fuel. The maximum power density has been achieved in the second week. After the addition of glucose at the beginning of the third week, the results were not an increase in power density. It is assumed that this corresponds to a lifetime of yeast. The coulomb efficiency (CE) defined as the fraction of electrons extracted for conversion into electricity versus that in the starting organic material, calculated by equation (5)[45].

\[
CE = \frac{\int i \, dt}{b F c v}
\]  

(5)

Where \(I\) was current over time, \(b\) is the number of mol of electrons produced per mole of glucose (\(b = 24\) for glucose), \(F\) was faraday 96500 mol\(^{-1}\) of the electron, \(c\) was consumed substrate concentration (\(c = 0.1\) M), \(v\) was the analyte volume (\(v = 100\) mL). The column efficiency for each cycle was shown in Table 1.

| Time     | Coulomb efficiency (CE) |
|----------|-------------------------|
| 1st week | 43.5                    |
| 2nd week | 61.7                    |
| 3rd week | 23.4                    |

From table 1 shows that the second week it has been a maximum of the CE value, but not so with that seen from 3rd week. It was the lowest point. We assumed that there has been a decrease of yeast activities in oxidize substrates.

### 3.6. Electricity generation from MFC based yeast as biocatalyst

The MFC has been performed for 8 days, and the observation of the current have been recorded every day. During the process, there was no supplemented of substrate and replacement of PF. The result was presented in this figure 6.
The composition anode chamber consisted of 2% of yeast suspension solution in 100 mL BP pH 7, methylene blue 10 mM and glucose 0.1 M, respectively. Cathode chamber was consist of PF 0.02 M. The MFC was monitored using a Volt multi meter craft (model VC 850). Voltage was recorded, different resistors were applied, and current have been measured at 1 kΩ as previously studied [7]. The observation of value was recorded for 5-10 min until the voltage stabilized. Electricity was generated with maximum value 2.3 A.m⁻². The decrease value was assumed the viability of yeast or reducing the concentration of glucose during MFC performed. To further understand the effect of the anolyte recirculation and energy consumption is needed to investigate more.

Figure 6 shows at the beginning, the increase of the current signal in the presence of glucose is due to the activities of *Saccharomyces cerevisiae* allowing the catalytic oxidation of glucose and electron transfer occurs through the facilitation of the artificial redox mediator (*i.e.*, methylene blue) to the surface of the anode. The reactions at the anode and the cathode compartments are depicted in this equation (6).

**anode:**
\[
\begin{align*}
\text{MB}^{\text{oxidized}} + \text{NADH}^{\text{yeast}} & \rightarrow \text{NAD}^+ + \text{MB}^{\text{reduced}} \\
\text{MB}^{\text{oxidized}} + \text{NADH}^{\text{yeast}} & \rightarrow \text{NAD}^+ + \text{MB}^{\text{reduced}} \\
\text{MB}^{\text{reduced}} & \rightarrow \text{MB}^{\text{oxidized}} + 2e^- + H^+
\end{align*}
\]

**Cathode:**
\[
\begin{align*}
4\text{PF}^{\text{oxidized}} + 4e^- & \rightarrow 4\text{PF}^{\text{reduced}} \\
4\text{PF}^{\text{reduced}} + O_2 + 4H^+ & \rightarrow 2H_2O + 4\text{PF}^{\text{oxidized}}
\end{align*}
\]

3.7. Desalination

In our present work, the energy produced from MFC will be applied in desalination process. We have been constructed a desalination cell as displayed in Figure 2, using K₃Fe(CN)₆ as an electron acceptor in the cathodic chamber and glucose as an electron donor, methylene blue as mediator and baker’s yeast as biocatalyst in the anodic chamber. The electrochemical chain is constituted by the following arrangement: anodic chamber, concentrate compartment, dilute compartment, and cathodic
chamber. CEM was placed close to the anodic chamber and AEM among CEM sequentially. Graphite and nickel were used as anode and cathode respectively. Migration of each ion was determined by measuring the concentration of salt by ionic chromatography during the process.

Figure 7. NaCl transport (%) and current density generated from desalination process during 30 days of run.

Results confirm that 64% of NaCl initially continued in the dilute compartment moved to the concentrate compartment after 1 month under a maximum current density of 88 mA.m\(^{-2}\). There was twice times replacement of PF and the addition of glucose for maintenance performance during desalination. Meanwhile, the batch operation has been applied in anolyte chamber, its mean during the process there is no replacement of yeast. The current generated was recorded every 30 min. The efficiency of the desalination is demonstrated by the flux of salt in the case of seawater demineralization. The flux value was 25 ± 1. A small flux increase is even recorded with sea water probably due to the higher conductivity of sea water. The desalination rate is one of the important parameters of MDC performance, which greatly dependent on the salt ion sea water. Ideally, the salt concentration in dilute compartment should be higher than the electrolyte concentration (i.e., KNO\(_3\)) since a low concentration could deliver in lowering the desalination rate.

The desalination performance can also be increased using multiple ion exchange membrane (IEM) pair which inserted between anode and cathode compartment. The increase in the number of cell pairs reduces the voltage required for each cell allowing a greater net energy obtained. Moreover, the use of thin IEM and desalination compartment, the internal resistance diminishes and the efficient of ion separation and water desalination can be achieved [41].

There are some challenges that must be addressed in the future development of the yeast fuel cell and the application of desalination. First, the improvement of power delivery from this system needs to be further improved; because the efficiency process is necessary to increase. One possible approach to improving performance by modification of anode or cathode. Besides that, a strategy for a system scale up especially in desalination based yeast as biocatalyst should be developed to transform laboratory results into a practical technology.
4. Conclusion

This study has demonstrated a biological fuel cell operating with glucose oxidation by baker’s yeast, *Saccharomyces cerevisiae* was performed. The effect of yeast preparation, mediator, temperature and stability of yeast were evaluated. Application yeast to water desalination was also studied. The ability of yeast to produce electricity was examined. The optimum conditions were obtained at 40°C. Methylene blue was accepted and nontoxic for living cell and the lifetime is around 2 weeks and the effect of yeast preparation resulted in improving MFC performance.

Application of yeast fuel cell for desalination was tested to recover NaCl from sea water. After 1 month operation, 64 % of ions moved from the dilute compartment to the concentrate compartment. The maximum current density during the process was 88mAm⁻².

We have presented a simple method of construction of microbial fuel cell based on baker’s yeast and the application for desalination process. This autonomous device able to produce power and remove salt simultaneously from real sea water has been studied. The improvement of this process with immobilization of yeast on the electrode is in progress.

Acknowledgements

This work was supported by grant Doctor Scholarships Indonesian Directorate General of Higher Education (DIKTI) in the framework Double Degree Indonesia-France and partially supported by Membranes European Institute (IEM) Montpellier France.

References

[1] Potter AM C, Character B and Sep N 2010 Electrical Effects Accompanying the Decomposition of Organic Compounds Published by The Royal Society Electrical Effects accompanying the Decomposition of Organic 84 260–76

[2] Rabaey K and Verstraete W 2005 Microbial fuel cells: novel biotechnology for energy generation. Trends Biotechnol. 23 291–8

[3] Logan B E and Regan J M 2006 Electricity-producing bacterial communities in microbial fuel cells. Trends Microbiol. 14 512–8

[4] Cheng S, Xing D and Logan B E 2011 Electricity generation of single-chamber microbial fuel cells at low temperatures. Biosens. Bioelectron. 26 1913–7

[5] Hubenova Y and Mitov M 2010 Bioelectrochemistry Potential application of Candida melibiosica in biofuel cells Bioelectrochemistry 78 57–61

[6] Babanova S, Hubenova Y and Mitov M 2011 Influence of artificial mediators on yeast-based fuel cell performance J. Biosci. Bioeng. 112 379–87

[7] Rahimnejad M, Najafpour G D, Ghoreyshi A, Shakeri M and Zare H 2011 Methylene blue as electron promoters in microbial fuel cell Int. J. Hydrogen Energy 36 13335–41

[8] Gunawardena A, Fernando S and To F 2008 Performance of a Yeast-mediated Biological Fuel Cell 1893–907

[9] Sayed E T, Tsujiguchi T and Nakagawa N 2012 Catalytic activity of baker’s yeast in a mediatorless microbial fuel cell Bioelectrochemistry 86 97–101

[10] Prasad D, Arun S, Murugesan M, Padmanaban S, Satyanarayanan R S, Berchmans S and Yegnaraman V 2007 Direct electron transfer with yeast cells and construction of a mediatorless microbial fuel cell. Biosens. Bioelectron. 22 2604–10

[11] Zou Y, Xiang C, Yang L, Sun L, Xu F and Cao Z 2008 A mediatorless microbial fuel cell using polypyrrole coated carbon nanotubes composite as anode material 33 4856–62

[12] Liu Z and Li H 2007 Effects of bio- and abio-factors on electricity production in a mediatorless microbial fuel cell 36 209–14

[13] Liu J, Qiao Y, Xian C, Lim S, Song H and Ming C 2012 Bioresource Technology Graphene / carbon cloth anode for high-performance mediatorless microbial fuel cells Bioresour. Technol. 114 275–80
[14] Walker A L and Walker C W 2006 Biological fuel cell and application as a reserve power source J. Power Sources160 123–9
[15] Cheng S and Liu H 2006 Power Densities Using Different Cathode Catalysts (Pt and CoTMPP) and Polymer Binders (Nafion and PTFE) in Single Chamber Microbial Fuel Cells 40 364–9
[16] Cheng S, Liu H and Logan B E 2006 Increased performance of single-chamber microbial fuel cells using an improved cathode structure Electrochem. commun. 8 489–94
[17] Raghavulu S V, Goud R K, Sarma P N and Mohan S V 2011 Bioresource Technology Saccharomyces cerevisiae as anodic biocatalyst for power generation in biofuel cell: Influence of redox condition and substrate load Bioresour. Technol.102 2751–7
[18] Nielsen J, Larsson C, Maris A Van and Pronk J 2013 Metabolic engineering of yeast for production of fuels and chemicals Curr. Opin. Biotechnol.24 398–404
[19] Haslett N D, Rawson F J, Barrière F, Kunze G, Pasco N, Gooneratne R and Baronian K H R 2011 Biosensors and Bioelectronics Characterisation of yeast microbial fuel cell with the yeast Arxula adeninivorans as the biocatalyst Biosens. Bioelectron.26 3742–7
[20] Zhang F, Chen M, Zhang Y and Zeng R J 2012 Microbial desalination cells with ion exchange resin packed to enhance desalination at low salt concentration 418 28–33
[21] Luo H, Xu P and Ren Z 2012 Bioresource Technology Long-term performance and characterization of microbial desalination cells in treating domestic wastewater Bioresour. Technol.120 187–93
[22] Kim Y and Logan B E 2013 Simultaneous removal of organic matter and salt ions from saline wastewater in bioelectrochemical systems Desalination308 115–21
[23] Kim Y and Logan B E 2013 Microbial desalination cells for energy production and desalination Desalination308 122–30
[24] Du Z, Li H and Gu T 2007 A state of the art review on microbial fuel cells: A promising technology for wastewater treatment and bioenergy. Biotechnol. Adv.25 464–82
[25] Qu Y, Feng Y, Liu J, He W, Shi X, Yang Q, Lv J and Logan B E 2013 Salt removal using multiple microbial desalination cells under continuous flow conditions Desalination317 17–22
[26] Brastad K S and He Z 2013 Water softening using microbial desalination cell technology DES309 32–7
[27] Mehanna M, Saito T, Yan J, Hickner M, Cao X, Huang X and Logan B E 2010 Using microbial desalination cells to reduce water salinity prior to reverse osmosis Energy Environ. Sci.3 1114
[28] Wang K, Liu Y and Chen S 2011 Improved microbial electrocatalysis with neutral red immobilized electrode J. Power Sources196 164–8
[29] Wei J, Liang P, and Huang X 2011 Recent progress in electrodes for microbial fuel cells. Bioresour. Technol.102 9335–44
[30] Hosseini M G and Ahadzadeh I 2013 Electrochemical impedance study on methyl orange and methyl red as power enhancing electron mediators in glucose-fed microbial fuel cell J. Taiwan Inst. Chem. Eng.44 617–21
[31] Park D H and Zeikus J G 2000 Electricity Generation in Microbial Fuel Cells Using Neutral Red as an Electrophore Electricity Generation in Microbial Fuel Cells Using Neutral Red as an Electrophore66
[32] Jacobson K S, Drew D M, and He Z 2011 Efficient salt removal in a continuously operated upflow microbial desalination cell with an air cathode. Bioresour. Technol.102 376–80
[33] Luo H, Xu P, Roane T M, Jenkins P E and Ren Z 2012 Microbial desalination cells for improved performance in wastewater treatment, electricity production, and desalination Bioresour. Technol.105 60–6
[34] Qu Y, Feng Y, Wang X, Liu J, Lv J, He W and Logan B E 2012 Simultaneous water desalination and electricity generation in a microbial desalination cell with electrolyte recirculation for pH control. Bioresour. Technol.106 89–94
[35] Miller S, Shemer H and Semiat R 2015 Energy and environmental issues in desalination
Desalination 366 2–8
[36] Mehanna M, Kiely P D, Call D F and Logan B E 2010 Microbial Electrodialysis Cell for
Simultaneous Water Desalination and Hydrogen Gas Production 44 9578–83
[37] Liang P, Xiao K, Zhou Y, Zhang X and Logan B E 2009 A New Method for Water Desalination
Using Microbial Desalination Cells 43 7148–52
[38] Zhang F, Chen M, Zhang Y and Zeng R J 2012 Microbial desalination cells with ion exchange
resin packed to enhance desalination at low salt concentration J. Memb. Sci. 417-418 28–33
[39] Sayed E T, Tsujiguchi T and Nakagawa N 2012 Catalytic activity of baker’s yeast in a
mediatorless microbial fuel cell. Bioelectrochemistry 86 97–101
[40] Kong X, Sun Y, Yuan Z, Li D, Li L and Li Y 2010 Effect of cathode electron-receiver on the
performance of microbial fuel cells Int. J. Hydrogen Energy 35 7224–7
[41] Kim Y and Logan B E 2011 Series Assembly of Microbial Desalination Cells Containing
Stacked Electrodialysis Cells for Partial or Complete Seawater Desalination 5840–5
[42] Kozlowski C a., Walkowiak W and Girek T 2008 Modified cyclodextrin polymers as selective
ion carriers for Pb(II) separation across plasticized membranes J. Memb. Sci. 310 312–20
[43] Wilkinson S, Klar J and Applegarth S 2006 Optimizing Biofuel Cell Performance Using a
Targeted Mixed Mediator Combination Electroanalysis 18 2001–7
[44] Alagumarthanayagam A, Pavankumar A R, Vasanthamallika T K and Sankaran K 2009
Evaluation of solid (disc diffusion)- and liquid (turbidity)-phase antibiogram methods for
clinical isolates of diarrheagenic E. coli and correlation with efflux. J. Antibiot. (Tokyo). 62
377–84
[45] Yong Y-C, Liao Z-H, Sun J-Z, Zheng T, Jiang R-R and Song H 2013 Enhancement of
coulombic efficiency and salt tolerance in microbial fuel cells by graphite/alginate granules
immobilization of Shewanella oneidensis MR-1 Process Biochem. 48 1947–51