MODESTUM
OPEN ACCESS

Eurasian Journal of Analytical Chemistry, 2018, 13(5), em49
ISSN:1306-3057
Research Paper https://doi.org/10.29333/ejac/94974

Utilization of Distillery Effluent as Substrate for Power Generation with Optimized Parametric Conditions using Microbial Fuel Cell

Abdul Sattar Jatoi [1], M. M. Tunio [2], Sajid Riaz [1], Rashid Abro [1*], Muhammad Hassam Wajahat [1], Khadija Qureshi [3], Asif Shah [4], Sabzoi Nizamuddin [5], N. M. Mubarak [6*]

[1] Department of Chemical Engineering, Dawood University of Engineering and Technology Karachi, Sindh, PAKISTAN
[2] Department of Energy & Environment, Quaid-e-Awam University of Engineering, Science, and Technology, Nawabshah, Sindh, PAKISTAN
[3] Department of Chemical Engineering, Mehran University of Engineering and Technology, Jamshoro, Sindh, PAKISTAN
[4] Department of Metallurgy and Materials Engineering, Dawood University of Engineering and Technology, Karachi, Sindh, PAKISTAN
[5] School of Engineering, RMIT University, Melbourne, AUSTRALIA
[6] Department of Chemical Engineering, Faculty of Engineering and Science, Curtin University, 98009 Sarawak, MALAYSIA

Received 18 April 2018 ▪ Revised 1 July 2018 ▪ Accepted 14 August 2018

ABSTRACT
Distillery effluents create many environmental problems via their direct disposal in open ponds. There is a need to explore the technology for treating such wastes and making useful energy from it. In the modern era, Microbial Fuel Cell (MFC) are gaining popularity regarding working mechanism for treating wastewater as well as electricity generation. Current study primarily focuses to utilize distillery effluent as valuable substrate in microbial fuel cell coupled with a parametric effect. *Saccharomyces cerevisiae* were utilized as biocatalyst in MFC with different organic loads in the form of substrate concentration followed by various aeration rate, and pH for power generation. With numerous changes in aeration rate, substrate concentration, and pH values automatically effect on power generation. The maximum power generation was observed at 175 mg/l about power density 69 mW/m^2, current density 82.48 mA/m^2, voltage 770 mv, power 0.6391 mW and current 0.83 mA. It is concluded that by utilizing microbial fuel cell we can handle the problem associated with distillery wastewater. A further study could be done on the modification of the process based on commercial and different operational aspects.

Keywords: distillery effluent, *Saccharomyces cerevisiae***,** dual chamber, microbial fuel cell, aeration rate, pH, substrate concentration

INTRODUCTION

The growing concerns of renewable energy requirement increases with respect to depletion of fossil fuels [1-3]. Apart from this environmental risks are also drawing attention of the researchers to develop new alternatives [4,5]. Wastewater from the brewery leading to extensive soil and water pollution. From environmental and aesthetic perspectives, it is becoming increasingly important to remove pollutants and colors from distillery wastewater. Fermenters and Condensers Cooling water and fermenter wastewater are the major contaminants of typical breweries. It is quite challenging to treat the stream by conventional methods due to the presence of large amounts of effluent and certain stubborn compounds. Therefore, to supplement the existing treatments, several studies

✉ sattar.ch76@gmail.com ✉ mureed.tunio@gmail.com ✉ engr_sajid@outlook.com
✉ rashid50@hotmail.com **(*Correspondence)** ✉ hassam.wajahat@gmail.com
✉ khadija.qureshi@faculty.muet.edu.pk ✉ asif.shah@duet.edu.pk ✉ nizamuddin248@gmail.com
✉ mubarak.yaseen@gmail.com mubarak.mujawar@curtin.edu.my **(*Correspondence)**

Table 1. Characteristic of distillery effluent

Characteristic	pH	BOD (mg/l)	COD (mg/l)	Colour	TS (mg/l)	Conductivity (ms/cm)	DS (mg/l)	Chlorides (mg/l)
Average value	4	3661	89810	brown	7400	20	59600	6910

encompassing physico-chemical and biological treatments have been conducted [6]. Improving wastewater services by adopting sustainable technologies is an imperative need of the time for achieving sustainability in wastewater treatment sector. The inherent characteristics of bioconversion processes such as the ability to operate at mild temperatures and pressures, high -conversion efficiencies result in more streamlined and less technologically complex processes. These characteristics enable flexible, smaller-scale, and capital expenditure–efficient operation [7]. MFCs technology is becoming attractive to researchers for combined renewable energy production and wastewater treatment [8]. MFCs generates electricity by capturing electrons from the anaerobic respiratory processes of microorganisms [9,10]. Microorganisms degrades the organic matter contained in a substrate and, at the same time produces electricity [11,12]. In MFCs the electrons travel through the anode and an external resistor, which generates a current, to the cathode where the circuit is completed by pairing with protons. Three special features including energy saving, less sludge production and less energy production make MFCs outstanding compared with the existing technologies [13].

MFCs have been widely used to produce electricity as well as wastewater treatment from different compounds, including acetate, lactate, and glucose [14-16] azo dyes [17], domestic wastewater or wastewater [18], swine wastewater [19], food processing wastewater [20], starch processing wastewater [21], chocolate industry wastewater [22]. He el al. [13] has discussed the general features of the MFC in greater details and a long with the application of different type of MFCs in municipal, agricultural wastewater and industrial wastewater including wastewater from food processing, dye manufacturing and textile industry. Gude [23] has recently listed the advantages of MFCs over other available options. Several MFC studies have tested a range of operation temperatures and demonstrated consistently higher power densities with higher temperatures, within the limits of the microbial populations [24-27].

Distillery effluents accompanied major sources of organic matter for electricity production in MFCs [28]. Depletion of fossil fuels made people consider alternate sources [6], and bio-ethanol has become popular in one of them. Also, alcohol distillery units increased rapidly due to industrial applications such as pharmaceutical, foods, perfume, etc [29]. The distilleries use the residue of sugar crystallization i.e. molasses for bio-ethanol production and it is estimated that up to 88% of the molasses constituents end up as waste [30-32]. The main problem for the production of bio-ethanol is that it produces large amounts of wastewater on average, 8−15L of distillery wastewater are generated per liter of ethanol produced. This study focuses on extracting the energy from distillery effluent couple with parametric effects using *saccharomyces cerevisiae* as biocatalyst.

Materials and Experimental Approach

Inoculum for anode chamber

Yeast *Saccharomyces cerevisiae* [14] or baker yeast (sigma Aldrich) was purchased from local market Karachi from which desired inoculum were prepared with composition in g/l glucose, 8; $(NH_4)_2$ HPO_4, 0.62, and yeast extract 2.4; at pH 5 and incubated for 16 h on an orbital shaker at 140 rpm at 32°C. The distillery effluent was collected from Al Abbas distillery plant and analyzed. **Table 1** shows composition of distillery wastewater, which is utilized as substrate with different concentration in Microbial fuel cell.

Experimental condition

The sample of distillery effluent was used in anodic compartment as substrate and within the cathode normal tap water was placed. The aquarium pump tube was inserted through the cathode container's lid to provide oxygen. Flow of aeration rate was controlled though use of Flowmeter. Both the anodic and cathodic containers sides and lids were sealed and made air tight and fastened with epoxy as shown in **Figure 1**. A dual chamber microbial fuel cell was used to treat the distillery effluent as well as producing energy. Different conditions were maintained in anode and cathode chambers. The cathodic compartment was kept in aerobic conditions while aneaerobic in anodic chamber. In order to maintain the aerobic conditions in the cathodic compartment air fish pump was used for oxidation of proton which came from the anode to the cathode chamber for water formation. Under different pH, the anode chamber was maintained for power generation to make the optimum condition for microbial growth in MFC. The electrodes were inserted into respective chambers while circuit connections were set with the copper wires fixed into the drilled holes of the electrodes and sealed with epoxy resin to avoid corrosion of copper wire [33,34]. The fabricated MFCs were sterilized with Ethanol (70 %) and irradiated with UV for 15 min.

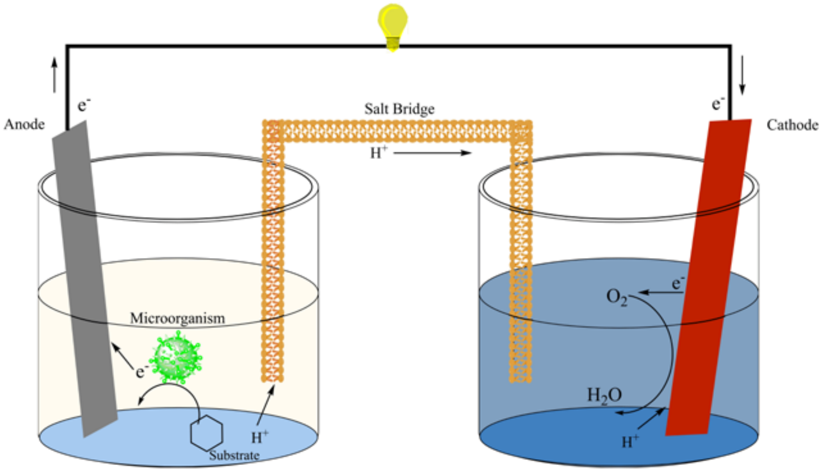

Figure 1. Schematic diagram of Microbial Fuel Cell

Electrical and other parametric measurements

The readings were measured for electrical current symbolized as (I) and voltage as (V), obtained during the experiments with a digital multimeter attached to an external circuit of 200 Ω. The resulting voltages and currents across the electrical device terminals were recorded at various external resistances (R) (200 to 20 Ω) and the electrical outputs were noted after stabilization. The readings were taken after 10-minute intervals for an overall timespan of 300 minutes.

Power density and current

The power generated is calculated using the electrical current and potential measured by a multimeter and calculated using equation (1), the power density is calculated using equation (2) [35]

$$P = V \times I \quad (1)$$

$$Pd = P/A \quad (2)$$

$$E = P \times t \quad (3)$$

With: P = power (W); V = potential (V); I = current (A); Pd = power density (W/m^2); E = energy (J)

t = fermentation time (seconds) A = surface area of the anode (m^2). Area of anode is $0.012m^2$ was used throughout all experiments.

RESULTS

All experiments related with dual chamber microbial fuel cell conducted and observed within 3 days. The performance of MFCs mainly depends on the nature and the composition of wastewater, which is characterized and tabulated in **Table 1**. **Table 2** shows effect of various parameter on performance of MFCs, which includes aeration rate, pH and substrate concentration. In the present investigation, the performance of the suggested MFCs was evaluated in terms of energy generation from wastewater. All electrical parameters were measured through use of a multimeter. Results demonstrate that performance of microbial fuel cell could affect by varying different operational and nutritional parameter. In **Table 2** current, voltage was measured using digital meter and power, power density and current density calculated through equations 1, 2, 3, which describe the performance of MFC inform of various parameters. Such parameters include aeration rate from 120-220 ml/min, pH 5-8, and substrate concentration 175-225 mg/l. These results also suggested that the selected strain of microorganism was able to readily convert the organics present in the distillery effluent at their optimum efficiency resulting in the transfer of maximum no. of electrons leading to concomitant voltage generation.

Table 2. Current. Voltage, Power, Power Density and Current Density at various parameter

	Oxygen flow rate (ml/min)				pH value				Substrate mg/lit			
	120	150	180	210	5	6	7	8	75	125	175	225
Current (mA)	0.80	0.88	0.94	0.98	0.79	0.83	0.86	0.89	0.75	0.79	0.83	0.81
Voltage (volts)	0.77	0.86	0.95	0.97	0.75	0.79	0.82	0.85	0.72	0.74	0.77	0.75
Power (mW)	0.623	0.76	0.89	0.91	0.59	0.655	0.705	0.7565	0.54	0.58	0.6391	0.5431
Power density (mW/m2)	50.43	61.5	71.9	78.4	49.4	54.64	58.76	63.042	45	48.7	53.258	51.21
Current density (mA/m2)	67.29	73.9	78.9	82.4	65.8	69.16	71.67	74.167	62.5	65.8	69.166	64.1

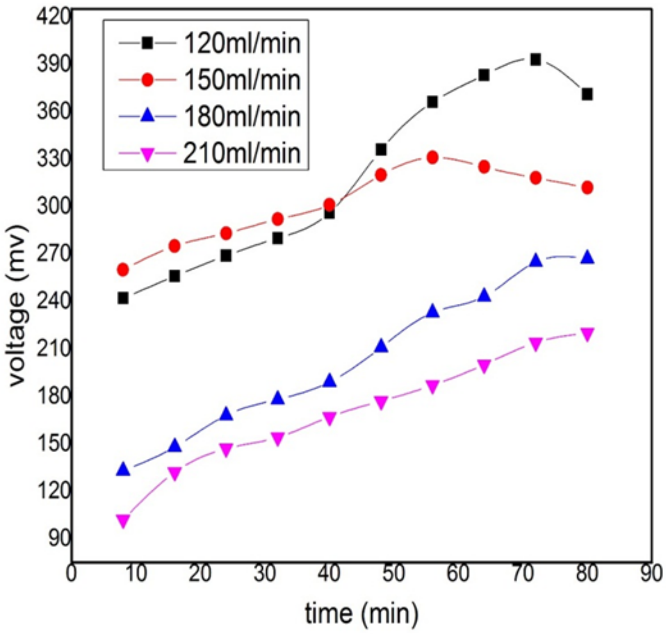

Figure 2. Effect of aeration rate on performance of microbial fuel cell

DISCUSSION

The empirical work was performed in a double sided MFC. The results obtained from microbial fuel cell was maintained with optimized parametric conditions, which expressed the substrate and its concentration predicted the amount of electricity produced from it. These results additionally prompt that the chosen mediator less media was able to readily convert the organic matter within the sludge at their optimum potential leading to the transfer of most number of electrons resulting in concomitant voltage generation.

Aeration Rate Effect on Power Generation

Microbial fuel cell operation was successfully handled through the addition of proper air into the cathodic chamber for oxidation of proton coming from the anodic chamber. For proper operation of the microbial fuel cell different aeration rates were analyzed to investigate the optimized value for maximum current generation. In this regard various ranges for aeration rates were utilized, which were 120-210 ml/min with step size 50 ml/min. **Figure 2** highlights the current generation with respect to time at different aeration rates. The maximum voltage generation was observed about at 120 ml/min, but sustainable electricity production observed at 180 ml/min. It highlights that after 56 hours the line is decreasing due to the change in dissolved oxygen. This occurs because during the running of MFC different parameters effect the dissolved oxygen because at that time temperature of cathode chamber increases while it deceases the voltage generation.

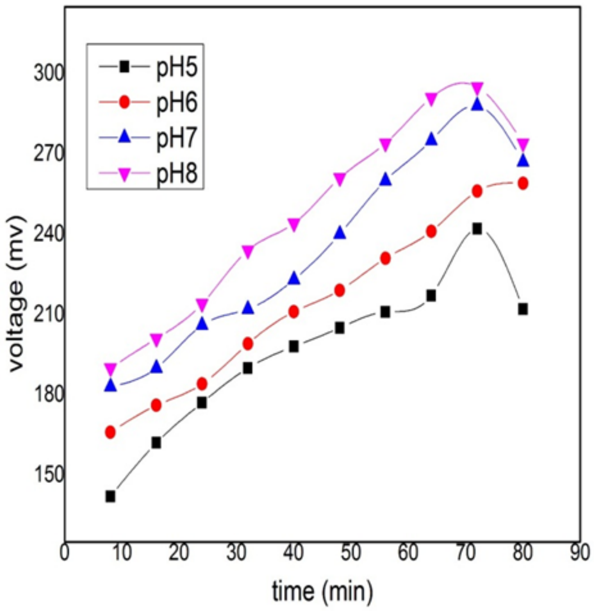

Figure 3. Effect of pH on performance of microbial fuel cell

Effect of pH on Power Generation

Distillery wastewater (DW) generated from the ethanol producing process is a low-pH wastewater (<4) with high temperature (70–80◦C), high organic load (>100 g COD/L), high sulfate concentrations (>1.3 g/L) and dark brown color [6]. The performance of the microbial fuel cell can be influenced by different pH ranges during microbial growth. This occurs because acidic and basic nature has significant effects reported from pervious [36,37] and current works. **Figure 3** clearly shows the importance of pH in power generation from distillery effluent. From 5-8 pH ranges were under investigation for growth of microbes in anode chamber to maximize electron production from substrate containing high organic load presented in **Table 1**. The experiments were conducted for different pH ranges, which show activates of microbe's minimum at lower pH when compared with higher pH ranges. This is by the neutralization of proteins or active sites under acidity. These results demonstrated the impact of pH on voltage Generation. The maximum voltage generation observed at pH 8 about 280 mv, while minimum at pH 5 about 240 mv as shown in **Figure 3**.

Effect of Substrate Concentration

The substrate was added into anode chamber of MFC with different concentrations, which measured through Chemical Oxygen Demand (COD) content in substrate. Concentration of substrate operated with the use of water addition. From 75-225 mg/l of substrate concentration were utilized to investigate the optimal concentration at which maximum voltage was generated. **Figure 4** highlights the impact of different substrate concentrations on power generation with respect to time spends. It can clearly be observed in **Figure 4** which suggests that when substrate concentration increases up to 175 mg/l the power generation is its greatest value. This could be due to the decreasing organic compound present in the distillery effluent and microbial activity could inhibit by changing the concentration of substrate and maximum power generation observed when substrate concentration 175 mg/l about 1400 mv while minimum at 125mg/l about 1200 mv.

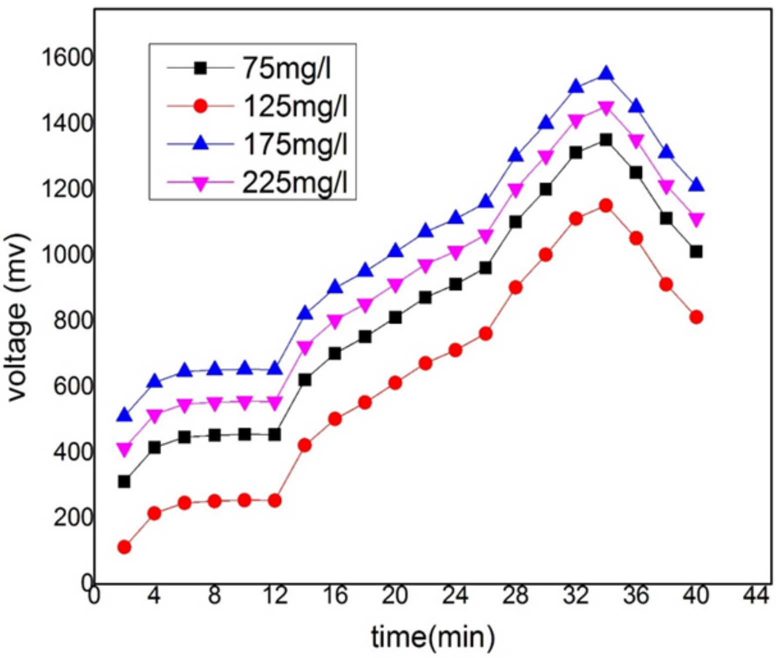

Figure 4. Effect of substrate concertation on performance of microbial fuel cell

CHALLENGES AND PERSPECTIVES

Microbial fuel cell is one of the tremendous technologies which utilize microbes as biocatalysts for treatment of wastewater as well as for energy production. Microbes are utilized to speed up the anaerobic treatment process, remove the organic matter and chemical oxygen demand. This could lead to an increase in the energy production as well as treatment of waste. Like other waste, distillery effluent had significant effect on the environment after they are disposed of in open ponds. These types of waste could be treated to mitigate environmental problems. The current study was conducted to integrate the use of distillery wastewater for energy production with the cheap available resources for microbial fuel cell. Further work could be done on development of continues operation of microbial fuel cell for treating such waste with optimize parameters.

CONCLUSION

The dual chamber microbial fuel cell was used for energy production from distillery effluent. Different parameters were studied in order to investigate the optimal conditions for maximum energy production. The maximum voltage generated was obtained to be about 280 mv at 120 ml/min of aeration rate, pH 8 and substrate concentration 175 mg/l. Stable voltage generated by distillery effluent though microbial fuel cell with the use of 180 ml/min of aeration rate. Microbial fuel cell technology proven that no one alternative technology could handle these types of waste. In near future this technology could be one of most interesting fields for research.

ACKNOWLEDGEMENT

Authors thanked to Department of Chemical Engineering, Dawood University of Engineering and Technology, Karachi, Sindh, Pakistan for providing research facility and financial support to complete this project.

REFERENCES

1. Baloch HA, Yang T, Li R, Nizamuddin S, Kai X, Bhutto AW. Parametric study of co-gasification of ternary blends of rice straw, polyethylene and polyvinylchloride. Clean Technologies and Environmental Policy. 2016;18(4):1031-1042. https://doi.org/10.1007/s10098-016-1092-4
2. Nizamuddin S, Baloch HA, Mubarak NM, Riaz S, Siddiqui M, Takkalkar P, Tunio M, Mazari S, Bhutto AW. Solvothermal Liquefaction of Corn Stalk: Physico-Chemical Properties of Bio-oil and Biochar. Waste and Biomass Valorization. 2018:1-12.

3. Mubarak N, Fo Y, Al-Salim HS, Sahu J, Abdullah E, Nizamuddin S, Jayakumar N, Ganesan P. Removal of methylene blue and Orange-G from waste water using magnetic biochar. International Journal of Nanoscience. 2015;14(04):1550009. https://doi.org/10.1142/S0219581X1550009X
4. Khanam AJ. DEVELOPMENTS IN THE AREA OF ENZYMATIC BIOFUEL CELLS. Smart Nanocomposites. 2015;6(1):15.
5. Singh HM, Pathak AK, Chopra K, Tyagi V, Anand S, Kothari R. Microbial fuel cells: a sustainable solution for bioelectricity generation and wastewater treatment. Biofuels. 2018:1-21. https://doi.org/10.1080/17597269.2018.1426162
6. Pant D, Adholeya A. Biological approaches for treatment of distillery wastewater: a review. Bioresource technology. 2007;98(12):2321-2334. https://doi.org/10.1016/j.biortech.2006.09.027
7. Clomburg JM, Crumbley AM, Gonzalez R. Industrial biomanufacturing: The future of chemical production. Science. 2017;355(6320). https://doi.org/10.1126/science.aag0804
8. Rodrigo MA, Cañizares P, Lobato J, Paz R, Sáez C, Linares JJ. Production of electricity from the treatment of urban waste water using a microbial fuel cell. Journal of Power Sources. 2007;169(1):198-204. https://doi.org/10.1016/j.jpowsour.2007.01.054
9. Carver SM, Vuoriranta P, Tuovinen OH. A thermophilic microbial fuel cell design. Journal of Power Sources. 2011;196(8):3757-3760. https://doi.org/10.1016/j.jpowsour.2010.12.088
10. Tursun H, Liu R, Li J, Abro R, Wang X, Gao Y, Li Y. Carbon material optimized biocathode for improving microbial fuel cell performance. Frontiers in microbiology. 2016;7:6. https://doi.org/10.3389/fmicb.2016.00006
11. Trapero JR, Horcajada L, Linares JJ, Lobato J. Is microbial fuel cell technology ready? An economic answer towards industrial commercialization. Applied Energy 185, Part 1. 2017:698-707. https://doi.org/10.1016/j.apenergy.2016.10.109
12. Naushad M. Fabrication of bioanode by using electrically conducting polythiophene via entrapment technique. Korean Journal of Chemical Engineering. 2016;33(1):120-125. https://doi.org/10.1007/s11814-015-0116-9
13. He L, Du P, Chen Y, Lu H, Cheng X, Chang B, Wang Z. Advances in microbial fuel cells for wastewater treatment. Renewable and Sustainable Energy Reviews. 2017;71:388-403. https://doi.org/10.1016/j.rser.2016.12.069
14. Liu H, Logan BE. Electricity generation using an air-cathode single chamber microbial fuel cell in the presence and absence of a proton exchange membrane. Environmental science & technology. 2004;38(14):4040-4046. https://doi.org/10.1021/es0499344
15. ul Haque S, inamuddin Nasar A, Rajender B, Khan A, Asiri AM, Ashraf GM. Optimization of Glucose Powered Biofuel Cell Anode Developed by Polyaniline-Silver as Electron Transfer Enhancer and Ferritin as Biocompatible Redox Mediator. Scientific reports. 2017;7(1):12703. https://doi.org/10.1038/s41598-017-12708-6
16. ul Haque S, inamuddin Nasar A, Asiri AM. Fabrication and characterization of electrochemically prepared bioanode (polyaniline/ferritin/glucose oxidase) for biofuel cell application. Chemical Physics Letters. 2018;692:277-284. https://doi.org/10.1016/j.cplett.2017.12.035
17. Huang W, Chen J, Hu Y, Chen J, Sun J, Zhang L. Enhanced simultaneous decolorization of azo dye and electricity generation in microbial fuel cell (MFC) with redox mediator modified anode. International Journal of Hydrogen Energy. 2016; 42(4):2349-2359. https://doi.org/10.1016/j.ijhydene.2016.09.216
18. Min B, Logan BE. Continuous electricity generation from domestic wastewater and organic substrates in a flat plate microbial fuel cell. Environmental science & technology. 2004;38(21):5809-5814. https://doi.org/10.1021/es0491026
19. Min B, Kim J, Oh S, Regan JM, Logan BE. Electricity generation from swine wastewater using microbial fuel cells. Water research. 2005;39(20):4961-4968. https://doi.org/10.1016/j.watres.2005.09.039
20. Oh S, Logan BE. Hydrogen and electricity production from a food processing wastewater using fermentation and microbial fuel cell technologies. Water research. 2005;39(19):4673-4682. https://doi.org/10.1016/j.watres.2005.09.019
21. Lu N, Zhou S-g, Zhuang L, Zhang J-t, Ni J-r. Electricity generation from starch processing wastewater using microbial fuel cell technology. Biochemical engineering journal. 2009;43(3):246-251. https://doi.org/10.1016/j.bej.2008.10.005
22. Patil SA, Surakasi VP, Koul S, Ijmulwar S, Vivek A, Shouche Y, Kapadnis B. Electricity generation using chocolate industry wastewater and its treatment in activated sludge based microbial fuel cell and analysis of developed microbial community in the anode chamber. Bioresource technology. 2009;100(21):5132-5139. https://doi.org/10.1016/j.biortech.2009.05.041
23. Gude VG. Wastewater treatment in microbial fuel cells – an overview. Journal of Cleaner Production. 2016;122:287-307. https://doi.org/10.1016/j.jclepro.2016.02.022

24. Choi Y, Jung E, Park H, Paik SR, Jung S, Kim S. Construction of microbial fuel cells using thermophilic microorganisms, Bacillus licheniformis and Bacillus thermoglucosidasius. Bulletin of the Korean Chemical Society. 2004;25(6):813-818.
25. Moon H, Chang IS, Kim BH. Continuous electricity production from artificial wastewater using a mediator-less microbial fuel cell. Bioresource Technology. 2006;97(4):621-627. https://doi.org/10.1016/j.biortech.2005.03.027
26. Perveen R, Inamuddin ul Haque S, Nasar A, Asiri AM, Ashraf GM. Electrocatalytic Performance of Chemically Synthesized PIn-Au-SGO Composite toward Mediated Biofuel Cell Anode. Scientific reports. 2017;7(1):13353. https://doi.org/10.1038/s41598-017-13539-1
27. Perveen R, Inamuddin, Nasar A, Beenish, Asiri AM. Synthesis and characterization of a novel electron conducting biocomposite as biofuel cell anode. International Journal of Biological Macromolecules. 2018;106:755-762. https://doi.org/10.1016/j.ijbiomac.2017.08.074
28. Sevda S, Dominguez-Benetton X, Vanbroekhoven K, De Wever H, Sreekrishnan T, Pant D. High strength wastewater treatment accompanied by power generation using air cathode microbial fuel cell. Applied energy. 2013;105:194-206. https://doi.org/10.1016/j.apenergy.2012.12.037
29. Mohana S, Acharya BK, Madamwar D. Distillery spent wash: Treatment technologies and potential applications. Journal of Hazardous Materials. 2009;163(1):12-25. https://doi.org/10.1016/j.jhazmat.2008.06.079
30. Jain N, Minocha A, Verma C. Degradation of predigested distillery effluent by isolated bacterial strains. 2002.
31. Jatoi AS, Mahar H, Aziz S, Siddique M, Memon F, Malik AA, Hussain S, Kakar E. To Investigate the Optimized Conditions of Salt Bridge for Bio-Electricity Generation from Distillery Waste Water Using Microbial Fuel Cell. NUST Journal of Engineering Sciences. 2016;9(2):29-34.
32. Jatoi AS, Siddique M, Mengal AN, Soomro SA, Aziz S. Comparative Study of Different Biomass on Bio-electricity Generation Using Microbial Fuel Cell. Journal of Applied and Emerging Sciences. 2016;6(2):74-78.
33. Kim HJ, Park HS, Hyun MS, Chang IS, Kim M, Kim BH. A mediator-less microbial fuel cell using a metal reducing bacterium, Shewanella putrefaciens. Enzyme and Microbial technology. 2002;30(2):145-152. https://doi.org/10.1016/S0141-0229(01)00478-1
34. Yong-Jin Z, Li-Xian S, Fen X, Li-Ni Y. E-coli microbial fuel cell using new methylene blue as electron mediator. 2007.
35. Permana D, Rosdianti D, Ishmayana S, Rachman SD, Putra HE, Rahayuningwulan D, Hariyadi HR. Preliminary Investigation of Electricity Production Using Dual Chamber Microbial Fuel Cell (DCMFC) with Saccharomyces Cerevisiae as Biocatalyst and Methylene Blue as an Electron Mediator. Procedia Chemistry. 2015;17:36-43. https://doi.org/10.1016/j.proche.2015.12.123
36. Rozendal RA, Hamelers HVM, Buisman CJN. Effects of Membrane Cation Transport on pH and Microbial Fuel Cell Performance. Environmental Science & Technology. 2006;40(17):5206-5211. https://doi.org/10.1021/es060387r
37. Jadhav GS, Ghangrekar MM. Performance of microbial fuel cell subjected to variation in pH, temperature, external load and substrate concentration. Bioresource Technology. 2009;100(2):717-723. https://doi.org/10.1016/j.biortech.2008.07.041

http://www.eurasianjournals.com