Peer-Reviewed /ISSN: 2616-9754 A J Life Sci. 2018, 1 (2): 42-53 Original Research Article

Abasyn Journal of Life Sciences

Open Access

Journal home: www.ajlifesciences.com

Microbial Fuel Cell for bio-electricity generation via Bio-Electrochemical conversion of Fermentation Industry Sludge

Abdul Sattar Jatoi [1,2]*, Imran Nazir Unar[2], Manzoor-ul-haq Rajput[2], Shaheen Aziz[2], Suhail Ahmed Soomro[2], Masroor Abro[2,3], Jawad Ahmed Khoso[4], Mohammad Siddique[5]

[1] *Department of Chemical Engineering Dawood University of Engineering & Technology, 74800, Karachi Sindh Pakistan*
[2] *Department of Chemical Engineering Mehran University of Engineering & Technology, Jamshoro, Sindh Pakistan*
[3]*College of Chemical Engineering, Beijing University of Chemical Technology, Beijing 100029, P. R. China.*
[4]*School of Chemistry and Chemical Engineering, State Key Laboratory of Metal Matrix Composites, Shanghai Jiao Tong University, Shanghai, 200240, China*
[5]*Department of Chemical Engineering Department BUITEMS, Quetta, Pakistan*

Abstract

Microbial fuel cell (MFC) is one of the promising fuel cell technologies. MFCs offer a breakthrough for the treatment of wastewater coupled with energy generation. However, their applications are mostly limited to laboratories. Present research is focused on conducting the biological treatment of wastewater originated from fermentation industry using microbial fuel cell (MFC) through the microbes to achieve the wastewater treatment as well as renewable energy generation. The efficiency of MFC was studied at different operating and nutritional conditions, including pH, temperature, aeration rate and substrate concentration with biocatalyst *Saccharomyces servisa.* The open-circuit maximum voltage generated 2100 mv and using 50 Ω resister given 1800 mv. Numerous parametric effect was measured by altering the value of aeration rate from 20-35 mL/min with 5 mL/min step size; pH from 6-9 with step size pH 1, and substrate from 25-100% with step size 25%. From above discussed parameter power and current density were maximum at pH 8 about 725 mv/l and 350 mA. Results suggested that utilization of fermented sludge in MFC could give direction to handle the problem of fermentation industries and also to overcome a small fraction of energy crisis.

Keywords: Electricity generation, Primary fermented sludge, Microbial fuel cell

Article Info:
Received:
June 28, 2018
Received Revised:
July 10, 2018
Accepted:
July 10, 2018
Available online:
September 25, 2018

Corresponding author:
abdul.sattar@duet.edu.pk

How to cite:
Jatoi AS,Unar IN, Rajput M, Aziz S, Soomro SA, Abro M, Khoso JA, Siddique M. Microbial fuel cell for bio-electricity generation via bio-electrochemical conversion of fermentation industry sludge. *Abasyn Journal of Life Sciences 2018; 1(2): 42-53.*

1. INTRODUCTION

In the past 10-15 years, the microbial fuel cell (MFC) technology has captured the attention of the scientific community for the possibility of transforming organic waste directly into electricity through microbially catalyzed anodic, and microbial/enzymatic/abiotic cathodic electrochemical reactions[1]. It also treats waste water streams that cause environmental problem[2]. In Microbial Fuel Cells (MFCs) electroactive bacteria were utilized to convert organic matter into electron and proton. Traveling of electron from the anode chamber to the cathode chamber via external circuit, whereas protons are concerned, which diffuse into the cathode compartment through membrane. MFCs are bio-electrochemical devices that lead to bacteria for harvesting electron and proton from organic matter oxidation. The mechanism of water production in the cathode chamber due to the transfer of electron via external circuit and proton transfer through cation exchange membrane, oxidation occurs in the cathode chamber due to addition of oxygen from atmosphere [3].

MFCs has been stated in the literature as a new and fast method for the generation of electricity [4] and can be helpful for supply of power to small devices [5]. MFCs having the ability for converting organic matter into electricity. In distinction to conventional fuel cells, MFCs put a positive response with respect to high energy-conversion production and minor reaction conditions (e.g., neutral pH, ambient temperature, and normal pressure). Additionally, MFCs can produce energy from organic matter after conversion of substrate. Among those feedstocks for MFC contain simple carbohydrates, like glucose[6], butyrate and acetate [7], domestic wastewater, swine wastewater containing complex organic compounds [8], and manure sludge waste[9, 10] created a maximum electrical current of approximately 60 l A and hundreds of millivolts when electrodes of graphite foil were connected in the zone of aerated aerobic as compare to anaerobic sludge zone [11]. Electrical energy production done by different biomass related with their nature in organic[12]. Preliminary testing using a dual-chamber MFC with a water-based cathode showed that electricity can be produced from pig waste water containing 8320±190 mg/L of soluble chemical oxygen demand (SCOD) (45 mW/m^2 maximum power density (MPD)). A wider range of tests using a single-chamber air cathode MFC resulted in 261 mW/m^2 MPD (resistor 200 Ω) equated to the same system consuming domestic wastewater (146 ± 1) 8 mW/m^2) having higher concentrations of organic substances. Saturation kinetics with MPD in the substrate concentrations were used to develop a model for power generation by fixing MPD (fixed 1000 Ω resistor) and half saturation concentration (total COD). Ammonia decreased from 198 ± 1 to 34 ± 1 mg/L (83% removal). Wastewater was autoclaved and sonicated after dilution and setting ratios (1:10) in order to improve the treatment efficiency and power output. This pretreatment (110 ± 4 mW/m^2) increased the power generated by 16% compared to wastewater without pretreatment (96 ± 4 mW/m^2). The SCOD removal rate was increased from 88% to 92% by agitating the diluted wastewater, although the power output was slightly lower.[9]. Bio-electrochemical employed in fuel cell for conversion of chemical energy into electrical energy by digesting the organic matter present in the anode chamber. Bio-electrochemical system plays an important role for electroactive bacteria for transferring electron from degradation of organic matter into the cathode chamber for energy and water generation. Bio-electrochemical exhibit advantages over use of organic substrate without use of expensive metals in the form of catalyst [13].

Current work is focused on bio-electrochemical conversion of fermentation waste into bioelectricity using MFC. The efficiency of MFC was studied at different operating and nutritional conditions, including pH, temperature, aeration rate and substrate concentration with biocatalyst *Saccharomyces servisa.*

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Biocatalyst

Saccharomyces cerevisiae was purchased from local market of analytical grade, which was used as a biocatalyst. *Saccharomyces cerevisiae* was grown on the medium with composition (g/L); glucose, 10; (NH4)2 HPO4, 0.64 , and yeast extract 2.5; at pH 6. About 100 ml of inoculum was utilized and incubated for 24 h on an orbital shaker at 100 rpm at 32°C [14]. *Saccharomyces cerevisiae* culture was added to anode chamber after substrate (waste) addition for digesting organic matter.

2.1.2 Primary fermented sludge

Fermentation of ethanol is one of the developed methods for conversion of sugar into industrial alcohol, apart from this sludge also draw off this sludge also contain the handsome amount of organic matter. Different samples of primary fermented sludge were collected from Al-Abbas distillery Plant. Waste water sample of 100 ml was taken into an anode chamber. Using salt bridge anode and cathode chamber was connected. Potassium Ferricyanide was used in the cathode chamber. Graphite electrode was inserted in both chambers, and the voltage was measured using multimeter (DT830D), and the output power was recorded on the daily basis.

2.2 Methodology

2.2.1 Configuration of Microbial Fuel Cell

MFC (Fig. 1) used in this study was consisted of two chambers connected with proton exchange membrane. In the anode chamber, about 1 L sample of fermented sludge was added, and *Saccharomyces servisae* were utilized as bio-catalysts in the anode chamber. Cathode chamber (Table 1) was aerated by air fish pump, which provided different aeration rates controlled by flow meter attached at the end of the pump. Different parameters were studied via altering their ranges. Such parameters are aeration rate, concentration substrate (fermented sludge) and pH. From 20-35 ml/min were utilized for aeration in cathode chamber with the difference of 5 ml/min, from 6-9 pH were maintained for microbial growth in the anode chamber though buffer solution with the difference of 1 pH, and for substrate concentration (fermented sludge) various ranges were utilized for optimization of power output, which including 25-75% with step size 25%.

Table 1. Typical dimension of Microbial Fuel Cell configuration

Items	Height (in)	Dia (in)	Length (in)
Cathodic chamber	13	8	-
Anodic chamber	13	8	-
Salt bridge	-	1	4

2.2.2 Preparation of anode and cathode chamber

A working MFC was constructed and run in continuous-flow mode with an acetate-based substrate feed. Power outputs were recorded and compared between different anode designs to determine that surface shear rate and not surface area is the determining factor in dictating power output in a MFC.[15].

Apart from above study, new design was made which is shown in Fig.1. Fig.1. highlight's the development of anode and cathode compartment with the approach of maximum electron transfer by considering the optimized condition for proton exchange membrane made up 10% agarose concentration.

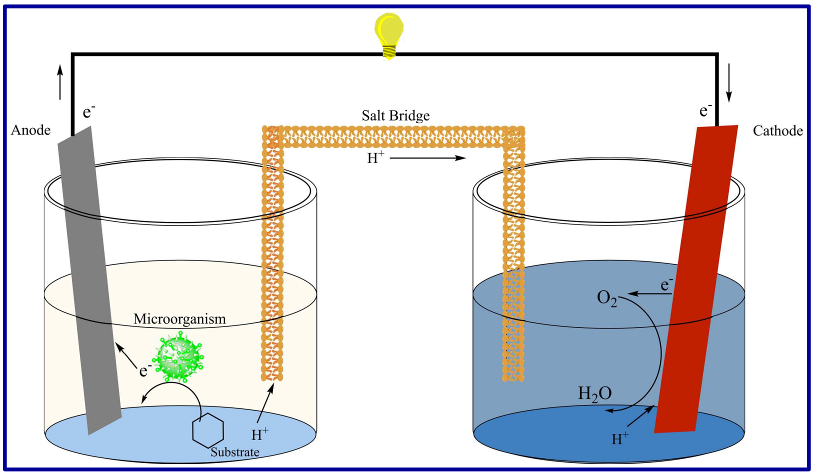

Fig.1. MFC for utilizing the substrate primary fermented sludge

2.2.3 Electrode preparation

The new electrodes were activated by soaking in HCl (1M) and 100% ethanol for 50 and 25 minutes respectively. Electrodes were washed after each interval of 50 minutes with 1 M solution of NaOH and HCl just for removal of inorganic contaminations and metals. Electrodes were kept in distilled water for further experiments.

1.2.4 Preparation of Salt bridge for proton transfer

Salt bridge was prepared from agar salt with concentration couple with different salt. The main purpose of salt bridge is to conduct proton from anode chamber to cathode chamber via electron transfer to external circuit producing water after oxidation of proton. In salt bridge, different agarose concentrations (7-10%) were employed. The maximum voltage generation was observed at 10% agarose with NaCl, and Kcl. The salt bridge is prepared by heating 10% agarose with different salts couple with 100 ml of solution. After heating at 50^{o}C the mixture of agarose with common salt stayed for 10 min for solidification of gel. The gel containing PVC pipe was fitted between two compartments.

2. RESULTS AND DISCUSSIONS

MFC performance can be judged through several factors that alter the current production from substrate digesting. MFC application is growing now days regarding energy generation couple with treatment of waste (liquid or solid). This study investigated the different factors influenced on MFC such as aeration rate, pH, and concentration of substrate processed (Table 2). Fermented sludge is also a waste from fermentation industry, with this regard; study was focused to investigate the potential effect of primary fermented sludge as a substrate in MFC. Bioconversion of primary fermented sludge was under study to investigate the effects of oxygen flow rate, pH and concentration of sludge on electricity generation using double chamber MFC.

Table 2. Analysis of Microbial Fuel Cell through different Parameters

Parameter	**Aeration rate (ml/min)**				**pH for anode compartment**				**concentration of primary fermented sludge**		
	20	**25**	**30**	**35**	**6**	**7**	**8**	**9**	**25**	**50**	**75**
Current generation (mA)	0.78	0.83	0.86	0.91	0.73	0.75	0.78	0.71	0.82	0.86	0.98
Voltage generation (volts)	0.72	0.83	0.91	1.1	0.69	0.72	0.74	0.70	0.80	0.84	0.87
Power production (mW)	0.56	0.69	0.78	1.0	0.5	0.54	0.58	0.49	0.60	0.72	0.85
Power density (mW/m2)	45.3	55.5	63.1	80.7	40.6	43.	46.5	40.0	52.9	58.2	68.7
Current density (mA/m2)	62.9	66.9	69.3	73.3	58.8	60.4	62.9	57.2	66.1	69.3	79.0

3.1 Effect of agarose concentration on performance of MFC.

Performance of MFC was checked in between proton exchange membrane of MFC[16] and salt bridge[17]. Salt bridge is the best replacement for cost reduction of expensive proton exchange membrane in MFC dual chamber. Fig.2 drawn regarding effect of agarose salt concentrations on performance of microbial fuel cell. Different agarose concentrations were analyzed for investigating the optimum condition for MFC. Fig. 2 shows the ultimate effect of agarose concentrations on voltage when changing the value of agarose from 1-10%. The MPD was observed by [18]sevda & sreekrishnan 2014. at a 5% salt concentration couple with 10% agar, using methylene blue as the electron acceptor, with voltage and current of 0.551V and 0.47 mA, respectively. Apart from this previous work related with different agarose concentrations regarding distillery waste water is about 10% couple with current and voltage generation 0.67 mv and 0.0642 mA[19] respectively. A maximum voltage generation was observed using 0.08 mM methylene blue as a mediator to obtain a power density coupling of 17.59 mW/m^2 and 89.22 mW . Another mediator neutral red were also used for identifying their applicability for transferring proton and electron from anode to cathode chamber. Mediators present positive impact on bio-film formation. These results suggests that with the use of methylene blue as mediator indorse proton transport through salt bridge, that cause increase performance of microbial fuel cell for energy generation [20]. On behalf that salt bridge were tested with different concentrations of agar salt for maximizing the power output from Primary Fermented Sludge. From 8-11% of agar concentrations tested in salt bridge on performance of microbial fuel cell for electricity generation. When microbial Fuel Cell was operated for 24 hrs, voltage generation was recorded after every 2 hrs via multimeter. In Fig. 2 it is clearly seen that at 16 hour after growth period, at 10% agar concentration in salt bridge got maximum value about 290 mv/l and then slowly decreased after 18 hrs due to variation in agar salt concentration.

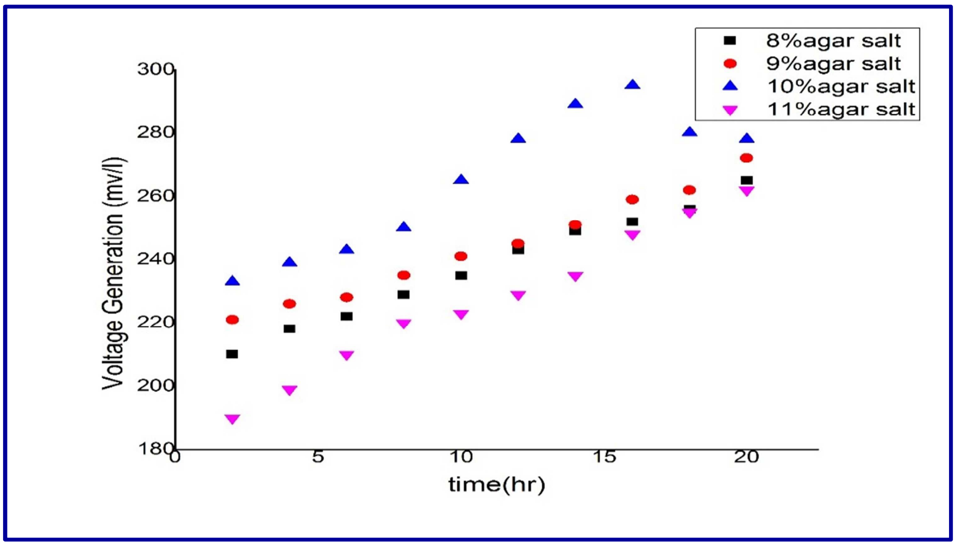

Fig.2. voltage generation at various agar salt concentrations in salt bridge

3.2 Effect of oxygen flow rate on bioelectricity generation

For effective treatment of sludge in anode chamber oxygen flow rate had the effect for oxidation of proton drawn in anode chamber. Different flow rate were tested by keeping time as independent variable and voltage generation as dependent variable The effect of the oxygen flow rate on power generation during MFC operation was studied using a different oxygen flow rate of 20 to 35 ml/min, generating electricity between 220 and 995 mV per liter of the original fermented sludge treatment (Fig. 3). These results show that as the air flow rate increases, the power generation increases and reaches a maximum of about 1 V at an oxygen flow rate of 150 ml/min, after which the power genenration decreases. This indicates that at higher air flow rates, the MFC power generation capacity is significantly reduced due to the higher oxygen rate in the air diffusing near the anode, which may be due to disturbing of the anaerobic microorganisms living on the anode surface

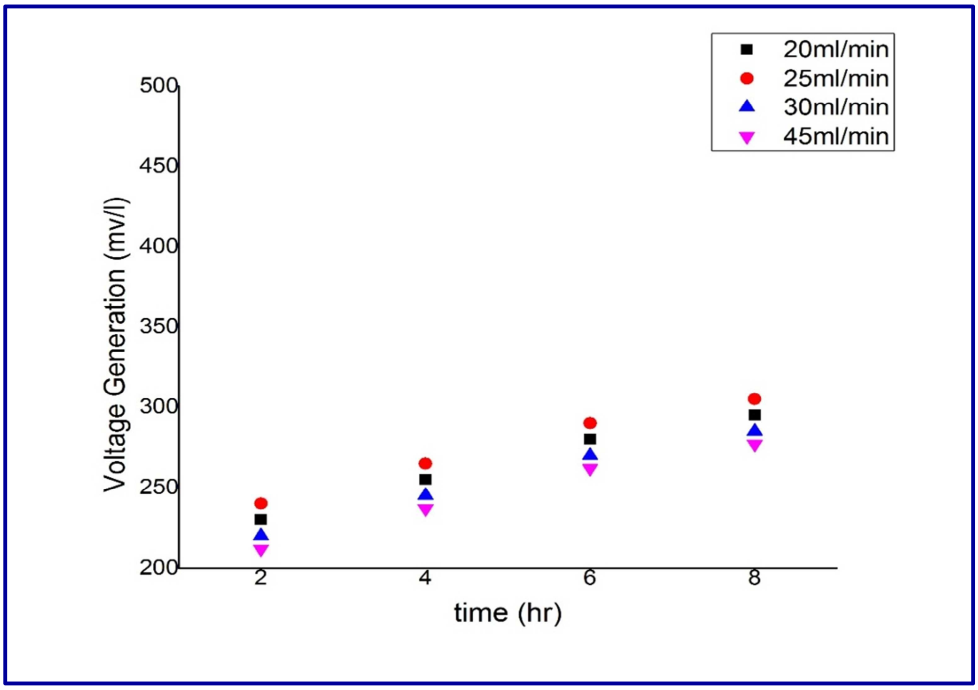

Fig.3. Effect of aeration rate on power production from primery fermented suldge

3.3 Effect of pH on power production

Microbial activity of microorganisms can be influenced by pH, which is considered as a major factor affecting the activity of microorganisms. pH of solution is one of the important factor for digestion of substrate couple with energy generation. In this regard, different ranges of pH were utilized to investigate the optimized condition regarding metabolic activity of microorganism. Fig. 4 highlight pH effect on power production using primary fermented sludge as a substrate. Maximum power production obtained at pH value of 8 and minimum at pH value of 6. It is due to the microbial activity that inhibit by acidic condition produced in anode chamber, the enzyme secreted by the microorganism may have an advantageous form of ionic groups at its active site to function properly. It is reported that changes in pH will result in changes in the ionic form of the active site which will further alter the enzymatic activity leading to a change in reaction rate [21]. Higher pH range gives maximum value regarding power density as compare to the lower ranges pH, actually this alternating in current production due to pH is nothing but the activity of electrochemical behavior of microorganism in anode chamber. lowers. This finding is consistent with that reported by [22]Z. He et al. They observed that neutral pH was suitable for cellulose degradation, because acidic conditions tend to inhibit the growth of most cellulose-degrading yeasts [23]. The maximum activity of microbial aggregates was found in their original pH values. Different parameters may effect on microorganism activity which can enhance power generation like virulence, amino acid degradation, proton translocation and adaptation to alkaline or acidic conditions [24]. Depending on the organism and growth conditions, changes in external pH can lead to several major physiological changes, including internal pH, ion concentration, membrane potential, and proton motility[25]. This is consistent with our results, indicating that the optimum current is produced at the original pH 8 of each sample.

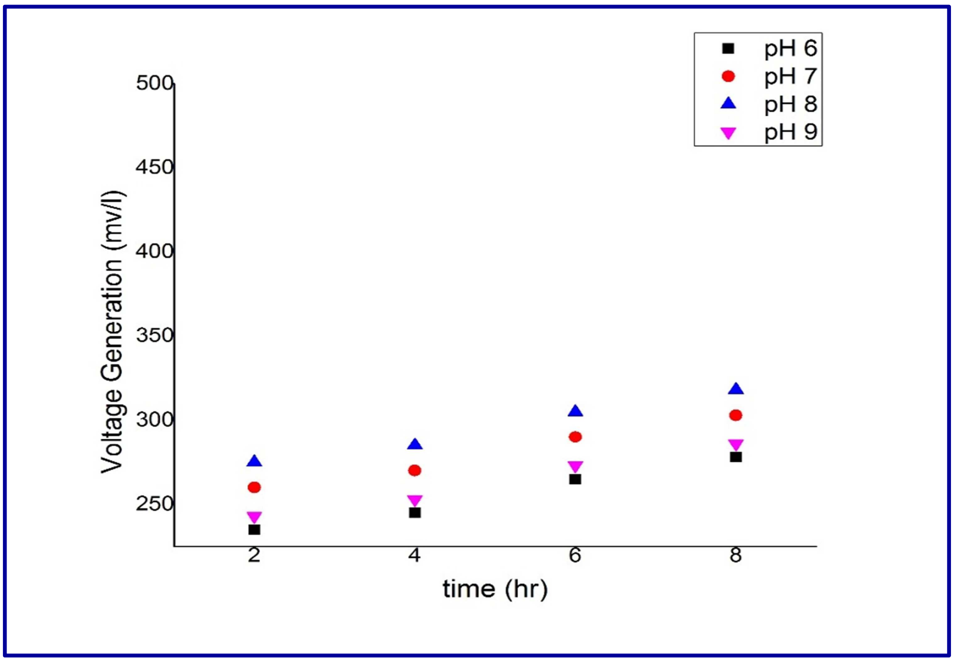

Fig.4. Effect of pH on power production

3.4 Effect of concentration of substrate on power production

Microbial production of electricity may become an important form of future bio-energy, because MFC have ability to utilize various substrate including complex organic waste and renewable biomass for energy generation.. Substantial amounts of substrate have been explored as feeds. The main substrates that have been tried include various types of artificial and actual wastewater and lignocellulosic biomass. Despite the relatively low current and power production, it is expected that the amount of current (and electrical power) that can be extracted from these systems will be greatly enhanced with improvements in the technology and knowledge of these unique systems. Various substrates have been explored in MFC to date, their resulting properties, limitations, and potential future substrates.[26]. Different concentrations of primary fermented sludge were used to measure the maximum energy production.. It is clearly shown in the Fig. 5 that 75% sludge concentration produces the maximum power generation compared to other concentrations.

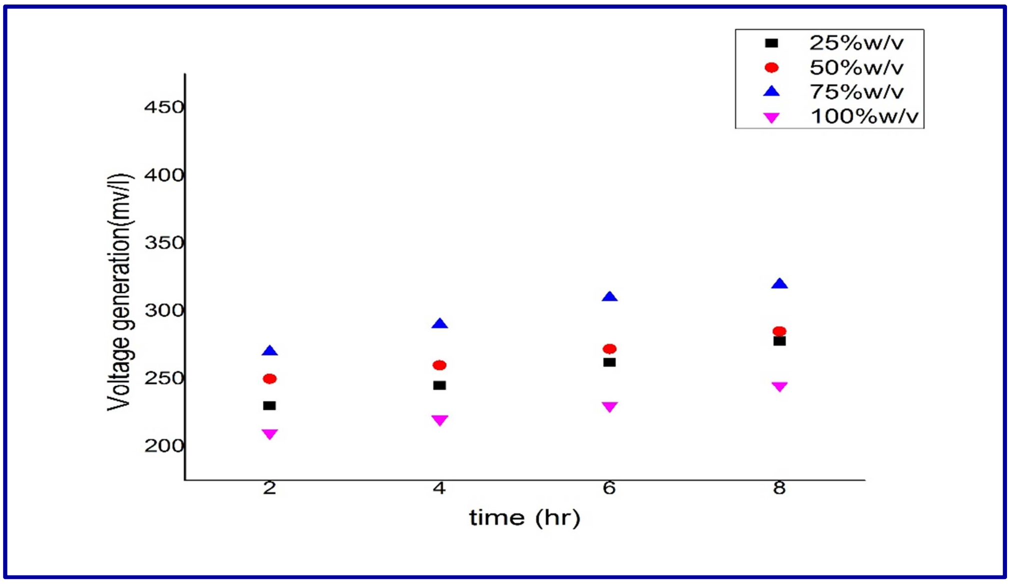

Fig.5. Effect of Substrate (fermented suldge) on power production

3.5 effect of Power and Current Density at Different aeration Rate, and pH

The power and current density generated in double chambered air cathode chamber MFC was recorded for a period of 480 hrs. From Fig. 6, it is clear that highest values were produced at 25 ml/min at the end of 480 hrs and after this the maximum value gradually decreased due to the decreasing levels of organic matter concentrations. There is an increase in values as concentration of agarose increased from 7% to 10%, this is due to the effective transfer of protons and as the gels is highly polymerized, thus maintaining anaerobic conditions and increasing the growth of microorganisms. But there is reduction in values for 11% and 12% concentrations of agarose as the highly-polymerized gel prevents the effective transfer of protons. The overall efficiency of the MFC was examined by considering various parameters like voltage, current, power, power density and current density.

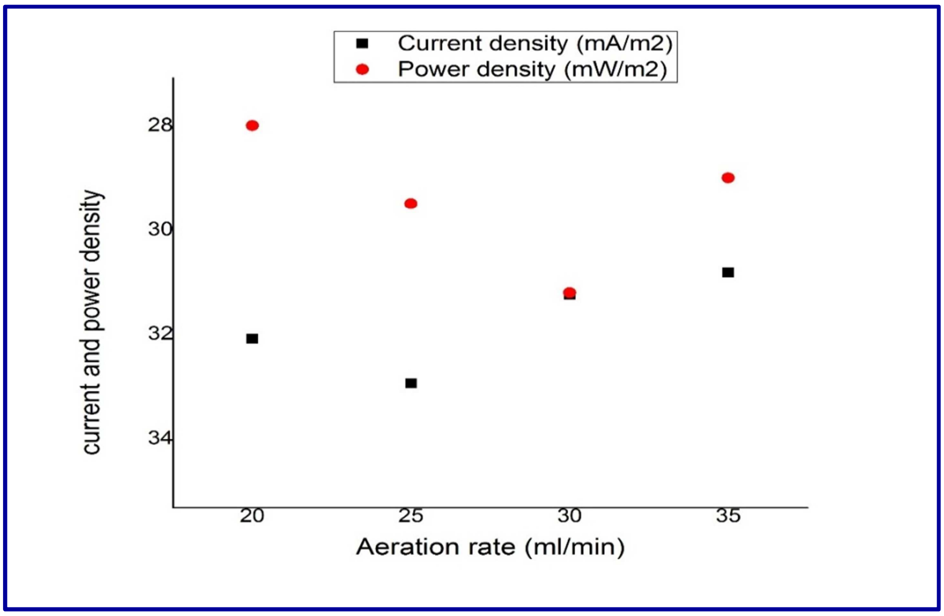

Fig.6. Effect of aeration rate on Current and power density from primery fermented suldge

pH has an important factor for energy generation about metabolic activity of microorganism. Related with power and current density, study focused that variation in pH had considerable effect over current and power density. pH 9 give 38.6% more power density then pH 7, This lead to Microbial activity of microbes used for digesting the substrate present in anode chamber for electron and proton generation. Performance of microbial fuel cell can be increased couple with bicarbonate buffer as pH buffer for waste water treatment.[27]. The air cathode MFC is used to treat municipal wastewater by adjusting the pH between 6 and 10. The short-term test showed the highest power yield (0.66 W m-3) at pH 9.5. The MFC operation in the continuous control mode at 30 days and at the optimum pH raised the performance of the cell relative to the power generation to 1.8 Wm^{-3}. Organic removal (77% influent COD) and physical ammonium losses are directly affected by pH and it follow the same behavior as power generation. At pH above the optimum pH, the anaerobic bacteria are affected and the power generation is stopped[28]. When the SLR was 0.75 kg COD kg VSS-1 d-1, the best performance of organic removal and power production was obtained. The maximum power densities of 158 mW/m^2 and 600 mW/m^2 were obtained in MFC-1 (feed pH 6.0) and MFC-2 (feed pH 8.0), respectively. The internal resistance of cells decreased with the increase of SLR. The maximum power density in MFC-1 was 109.5 mW/m^2 for MFC-1 and 459 mW/m^2 for MFC-2 and 30% smaller than MFC-I and 23.5 respectively when operated on biofilm on the anode. MFC-2 had an SLR of 0.75 kg COD kg VSS-1 d^{-1}. When the permanganate salt was added as the catholyte, the maximum bulk power of 15.51 W/m^3 and 36.72 W/m^3 was obtained in MFC-1 and MFC-2, respectively. Higher feed pH (8.0) favors higher power production[29] But in current research related modified up to 1750 W/m^3 at current density of 0.99.

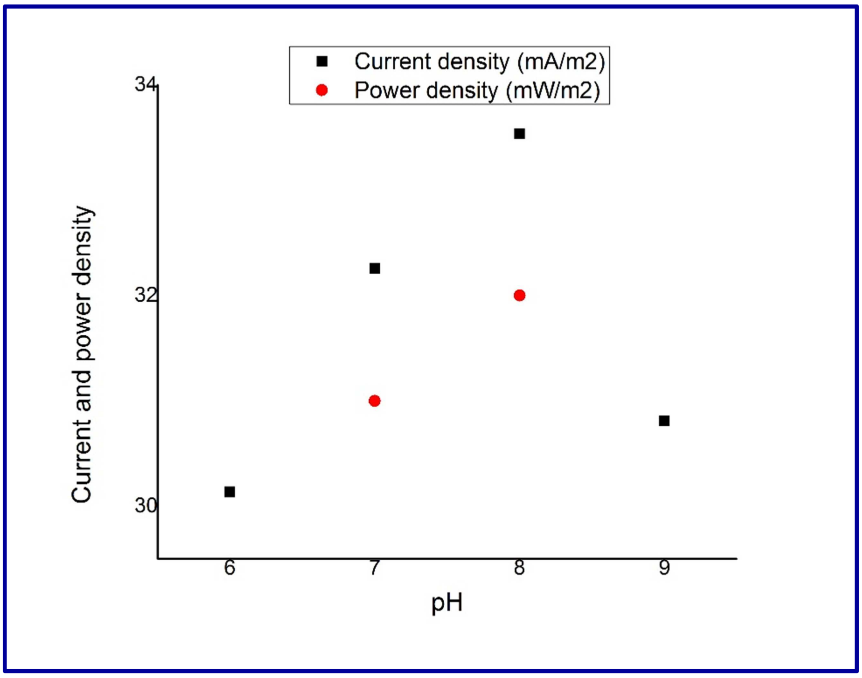

Fig.7. Effect of pH on power production from primery fermented suldge

4. CONCLUSIONS

Fermented sludge was utilized for power generation in microbial fuel cell with the effect of various parameters. Such parameters are aeration rate, concentration substrate (fermented sludge) and pH. *Saccharomyces servisae* were employed for getting optimal results with respect to utilization of fermented sludge. Numerous parametric effect were measured by altering the value of aeration rate from 20-35 ml/min with 5ml/min step size, pH from 6-9 with step size 1pH, and substrate from 25-100% with step size 25%. From above discussed parameters; power and current density were maximum at pH 8 about 725 mv/l and 350mA. It is exhibited that present study creates maximum power density up to 0.38±0.02 W/m^2 compare with 0.32 ± 0.01 W/m^2 [30].

ACKNOWLEDGEMENTS

Authors thanked to Chemical Engineering Department Dawood University of Engineering and Technology Karachi and Mehran University of Engineering and Technology Jamshoro for providing research support.

CONFLICT OF INTEREST

All authors declare no conflict of interest regarding this article.

REFERENCES

1. Santoro C, Arbizzani C, Erable B, Ieropoulos I. Microbial fuel cells: From fundamentals to applications. A review. *Journal of Power Sources.* 2017;356:225-244.
2. Papaharalabos G, Greenman J, Melhuish C, Ieropoulos I. A novel small scale Microbial Fuel Cell design for increased electricity generation and waste water treatment. *international journal of hydrogen energy.* 2015;40(11):4263-4268.
3. Gajda I, Greenman J, Melhuish C, et al. Water formation at the cathode and sodium recovery using microbial fuel cells (MFCs). *Sustainable Energy Technologies and Assessments.* 2014;7:187-194.
4. Ieropoulos I, Greenman J, Melhuish C. Improved energy output levels from small-scale microbial fuel cells. *Bioelectrochemistry.* 2010;78(1):44-50.
5. Papaharalabos G, Greenman J, Melhuish C, et al. Increased power output from micro porous layer (MPL) cathode microbial fuel cells (MFC). *International Journal of Hydrogen Energy.* 2013;38(26):11552-11558.
6. Chaudhuri SK, Lovley DR. Electricity generation by direct oxidation of glucose in mediatorless microbial fuel cells. *Nature biotechnology.* 2003;21(10):1229-1232.
7. Liu H, Cheng S, Logan BE. Production of electricity from acetate or butyrate using a single-chamber microbial fuel cell. *Environmental science & technology.* 2005;39(2):658-662.
8. Logan BE. Simultaneous wastewater treatment and biological electricity generation. *Water Science and Technology.* 2005;52(1-2):31-37.
9. 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.
10. Dentel S, Strogen B, Chiu P. Direct generation of electricity from sludges and other liquid wastes. *Water Science and Technology.* 2004;50(9):161-168.
11. Scott K, Murano C. A study of a microbial fuel cell battery using manure sludge waste. *Journal of Chemical Technology and Biotechnology.* 2007;82(9):809-817.
12. 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):pp74-78.
13. Pant D, Singh A, Van Bogaert G, et al. Bioelectrochemical systems (BES) for sustainable energy production and product recovery from organic wastes and industrial wastewaters. *Rsc Advances.* 2012;2(4):1248-1263.

14. Shah FA, Aziz S, Rajoka M. Ethanol production kinetics by a thermo-tolerant mutant of Saccharomyces cerevisiae from starch industry waste (Hydrol). *Pakistan Journal of Analytical & Environmental Chemistry.* 2010;11(1):6.
15. Gerber M. *The Effect of Anode Geometry on Power Output in Microbial Fuel Cells*, The Ohio State University; 2014.
16. Min B, Cheng S, Logan BE. Electricity generation using membrane and salt bridge microbial fuel cells. *Water research.* 2005;39(9):1675-1686.
17. Parkash A, Aziz S, Abro M, Kousar A, Soomro SA, Jatoi AS. IMPACT OF AGAROSE CONCENTRATIONS ON ELECTRICITY GENERATION USING HOSTEL SLUDGE BASED DUEL CHAMBERED MICROBIAL FUEL CELL. *Science International (Lahore).* 2015;27(2 Section A):1057-1061.
18. Sevda S, Sreekrishnan T. Removal of organic matters and nitrogenous pollutants simultaneously from two different wastewaters using biocathode microbial fuel cell. *Journal of Environmental Science and Health, Part A.* 2014;49(11):1265-1275.
19. Jatoi AS, Mahar H, Aziz S, et al. 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 (NJES).* 2016;9(2).
20. Sevda S, Sreekrishnan T. Effect of salt concentration and mediators in salt bridge microbial fuel cell for electricity generation from synthetic wastewater. *Journal of Environmental Science and Health, Part A.* 2012;47(6):878-886.
21. You S-J. Identification of denitrifying bacteria diversity in an activated sludge system by using nitrite reductase genes. *Biotechnology letters.* 2005;27(19):1477-1482.
22. He Z, Minteer SD, Angenent LT. Electricity generation from artificial wastewater using an upflow microbial fuel cell. *Environmental science & technology.* 2005;39(14):5262-5267.
23. Aelterman P, Rabaey K, Pham HT, Boon N, Verstraete W. Continuous electricity generation at high voltages and currents using stacked microbial fuel cells. *Environmental science & technology.* 2006;40(10):3388-3394.
24. Raghavulu SV, Mohan SV, Goud RK, Sarma P. Effect of anodic pH microenvironment on microbial fuel cell (MFC) performance in concurrence with aerated and ferricyanide catholytes. *Electrochemistry Communications.* 2009;11(2):371-375.
25. Rosenberg H. Phosphate transport in prokaryotes. *Ion transport in prokaryotes.* 1987:205-248.
26. Pant D, Van Bogaert G, Diels L, Vanbroekhoven K. A review of the substrates used in microbial fuel cells (MFCs) for sustainable energy production. *Bioresource technology.* 2010;101(6):1533-1543.
27. Fan Y, Hu H, Liu H. Sustainable power generation in microbial fuel cells using bicarbonate buffer and proton transfer mechanisms. *Environmental science & technology.* 2007;41(23):8154-8158.
28. Puig S, Serra M, Coma M, Cabré M, Balaguer MD, Colprim J. Effect of pH on nutrient dynamics and electricity production using microbial fuel cells. *Bioresource technology.* 2010;101(24):9594-9599.
29. Behera M, Ghangrekar M. Performance of microbial fuel cell in response to change in sludge loading rate at different anodic feed pH. *Bioresource technology.* 2009;100(21):5114-5121.
30. Yang F, Ren L, Pu Y, Logan BE. Electricity generation from fermented primary sludge using single-chamber air-cathode microbial fuel cells. *Bioresource technology.* 2013;128:784-787.